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Irrigation water salinity and silicon negatively interfere with the physiology and delay the flowering of ornamental sunflowers

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Abstract

Although silicon is considered a non-essential element for plants, its application can mitigate the harmful effects of salt stress. In this sense, the objective was to evaluate the physiological and flowering responses of ornamental sunflower depending on the application of silicon and irrigation with saline water. The experiment was carried out in a greenhouse in a completely randomized design with six replications, in a 4 x 5 factorial scheme, referring to four electrical conductivities of irrigation water (ECw): 0.5; 1.5; 2.5 and 3.5 dS m^{-1} and silicon doses: 0, 50, 100, 150 and 200 mg L^{-1}, with potassium silicate as the source. The following were evaluated: internal carbon concentration, transpiration, rate of liquid photosynthesis, instant efficiency of carboxylation, leaf indexes of chlorophyll a, b, chlorophyll a/b ratio, total chlorophyll, external and internal diameter of the chapter, number of petals, appearance of floral bud, beginning of flowering and full opening of the floral bud. Salinity negatively affects photosynthetic activity and flowering of ornamental sunflower plants, so that plants irrigated with saline water (3.5 dS m^{-1}) delayed the appearance of the flower bud, the flowering index and the total opening of the floral button. The application of silicon in ornamental sunflower plants is not effective to mitigate the deleterious effects of salinity on the plant's physiology. In addition, the addition of silicon is also not able to repair the losses in terms of flowering caused by salt stress in the species.

Keywords: *Helianthus annuus* L., photosynthesis, saline stress

Introduction

In recent years, flower cultivation has generated employment and income in Brazil (Nascimento et al., 2019), with ornamental sunflower production being a viable profitable activity, especially in small production areas. Sunflower producing regions, mainly in northeastern Brazil, have suffered from water scarcity and water quality when available, which are one of the great challenges for flower growers (Oliveira et al., 2017).

Irrigation is an alternative adopted in cultivated areas to guarantee the production of agricultural crops. However, saline waters in agricultural areas are common in Northeast Brazil (Medeiros et al., 2017). The use of these waters negatively affects seed germination, seedling emergence, growth and production (Parihar et al., 2015). Among the effects caused by the use of saline waters, the reduction of biomass, phytotoxicity and nutritional imbalance, decrease in photosynthetic activity due to the low level of photosynthetic pigments production and stimulation of the synthesis of chlorophyllase, an enzyme that inhibits the production of chlorophyll (Lucena et al., 2012).

One of the strategies to mitigate the deleterious effects of salinity on plants is the application of silicon (Si), which, although not considered an essential element for plants, can promote several benefits, such as reducing the negative impacts of stress. In plant species that have been subjected to biotic or abiotic stress, studies show beneficial effects of Si fertilization (Liu et al., 2019; Khorasaninejad & Hemmati, 2020).

Regarding saline stress in plants, Si proved to be effective in reducing it in different species. Si-mediated salt stress mitigation involves several regulatory mechanisms such as photosynthesis, osmotic adjustment, detoxification of harmful reactive oxygen species using antioxidants and non-antioxidants, and nutrient

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absorption efficiency (Zhang et al. 2017; Liu et al., 2019).).

In crops such as tomato (Lycopersicon lycopersicum (L.) H. Karst.) and rice (Oryza sativa) under saline stress conditions, the application of silicon promoted greater leaf area, chlorophyll content and improved the structure of chloroplasts, providing an increase in photosynthetic activity (Haghighi & Pessarakli, 2013; Lekklar et al. 2019). In addition, in oilseeds, the application of Si can promote greater growth under saline irrigation conditions (Ferraz et al., 2015; Hurtado et al., 2019).

In a study carried out with sunflower (Helianthus annuus L.), silicon contributes to the attenuation of saline stress by improving the ability of these plants to absorb nutrients. However, in the aforementioned study there is no demonstration of the effects of silicon on plant physiology, as well as on its flowering (Hurtado et al., 2019). Thus, the objective of this work was to evaluate the physiology and flowering of ornamental sunflower under silicon application and irrigation with saline water.

Material and Methods

Plant material and experiment site

The experiment was carried out in a greenhouse located in the Olericulture Sector of the Federal University of Paraíba (UFPB), Areia-PB, Brazil.

The plant material used came from commercial ornamental sunflower seeds (*Helianthus annuus* L., Sol nocturnal variety) for cultivation in pots. The Nocturnal Sun variety reaches 2 to 3 meters in height, its production is approximately 10 stems/plant and small flowers. Its leaves are hairy, which gives it a grayish color. In addition, it has capitulum-type inflorescences in assorted colors, with dark shades, ranging from dark orange, red and brown.

The 'Sol Noturno' ornamental sunflower seeds were purchased from Isla®. Germination occurred directly in the pots, with the ability to 5 dm³, filled with soil from the Chã-de-Jardim community, Areia, PB, classified as eutrophic Regolithic Neosol, with sandy loam-clay texture, non-saline and non-sodic, with chemical and physical analyzes evaluated (Table 1). After germination, the most vigorous seedling was selected.

The plants were irrigated daily, with a volume of water sufficient to raise the soil moisture to field capacity values, recording the entire gross volume applied. Field capacity was determined by the difference between the applied volume and the drained volume 48 hours after irrigation. These irrigations were carried out with non-saline waters. (CEa= 0.5 dS m^{-1}) and salt flats (ECw = 1.5; 2.5 e 3.5 dS m^{-1}). 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. Irrigation with the different electrical conductivities was started 10 days after emergence.

Table 1. Physical and chemical attributes of the soil used in the experiment.

Physics	Values	Fertility	Values
AG (g kg^{-1})	454	pH em água (1:2,5)	7.03
AF (g kg^{-1})	435	P (mg dm^{-3})	28.88
Silte (g kg^{-1})	192	K^+ (mg dm^{-3})	290.00
Argila (g kg^{-1})	219	Na^+ ($cmol_c$ dm^{-3})	0.31
Ada (g kg^{-1})	27	Ca^{+2} ($cmol_c$ dm^{-3})	4.50
GF (%)	87.7	Mg^{+2} ($cmol_c$ dm^{-3})	2.10
Ds (g cm^{-3})	1.00	Al^{+3} ($cmol_c$ dm^{-3})	0.00
Dp (g cm^{-3})	2.61	H^++Al^{+3} ($cmol_c$ dm^{-3})	1.73
Pt (m^3 m^{-3})	0.62	SB ($cmol_c$ dm^{-3})	7.65
Ucc (g kg^{-1})	169.3	CTC ($cmol_c$ dm^{-3})	9.38
Upmp (g kg^{-1})	117.91	V (%)	81.56
Ad (g kg^{-1})	51.40	m (%)	0.00
Class textural	Clay franc sandy	M.O (g kg^{-1})	21.83

AG = Coarse sand; AF = Fine sand; Ada = Clay available in water; GF = Flocculation degree (clay – Ada/clay)*100; Ds = soil density; Dp = Particle density; Pt = total porosity; (1-(Ds/Dp)*100) Ucc = Volumetric humidity at field capacity level – 0.033 Mpa; Upmp = Humidity at permanent wilting point level - 1.5 Mpa; Ad = available water, M.O = Organic matter; SB = Sum of bases ($Ca^{+2}+Mg^{+2}+K^++Na^+$); CTC = Cation exchange capacity = [SB+(H++Al+3)]; V = Saturation by base = (SB/CTC) x 100; m = (100 x Al^3) / t = (100 x Al^3) / Ca^{+2} + Mg^{+2} + K^+ + Na^+ + Al^{+3}).

The water used for irrigation was analyzed and presented the following characteristics: pH= 7.90; Electric conductivity = 0.50 dS m^{-1}; Ca^{2+} = 1.56 $mmol_c$ L^{-1}; Mg^{2+} = 0.32 $mmol_c$ L^{-1}; Na^+ = 3.81 $mmol_c$ L^{-1}; K^+ = 0.28 $mmol_c$ L^{-1}; SO_4^{2-} = 0.50 $mmol_c$ L^{-1}; CO_3^{2-} = 0.40 $mmol_c$ L^{-1}; HCO_3^- = 7.50 $mmol_c$ L^{-1}; Cl^- = 1.00; RAS = 3.93 $mmol_c$ L^{-1}; PST = 4.33% and Water classification = C_1S_1.

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 of the treatments were applied through a manual sprayer. Each treatment was diluted in 100 mL of water and this volume was applied to the plants, which were divided into 4 applications, at 15, 30, 45 and 60 days after emergence. As the source of silicon (potassium silicate) contains 15% of K_2O, compensation was carried out via fertigation for each treatment, subtracting the amount of K applied via foliar in the topdressing fertilization, thus maintaining the homogenization of this element, independent of treatment.

In the experimental units, a plastic film similar to mulching was placed, in order to prevent the solution containing Si from coming into contact with the soil, preventing its absorption. After application, the excess solution that remained on the mulching was removed with the aid of a syringe, preventing the solution from entering the bag.

A completely randomized experimental design, presenting a factorial scheme of 4 x 5, with 6 repetitions, referring to four electrical conductivities of the irrigation water (ECw): 0.5; 1.5; 2.5 e 3.5 dS m^{-1} and five doses of silicon: 0, 50, 100, 150 and 200 mg L^{-1}. The experimental units consisted of five plants, grown in polyethylene bags.

Physiological and flowering analyzes

The effect of different treatments on ornamental sunflower was evaluated at 45 days after sowing, by determining the internal carbon concentration (Ci - μmol CO_2 mol ar^{-1}), transpiration (E - mmol H_2O m^{-2} s^{-1}), net photosynthesis rate (A - μmol CO_2 m^{-2} s^{-1}) and the intrinsic efficiency of carboxylation (EiC - A/Ci - μmol m^{-2} s^{-1})/(μmol mol ar^{-1})]. An infrared gas analyzer (IRGA) model LCpro+Sistem was used for the gas exchange analysis. With the aid of a Clorofilog® chlorophyll meter (Falker) measurements of leaf chlorophyll a, b, chlorophyll a/b and total chlorophyll indices were also performed.

At the end of the experiment, 60 days after irrigation with saline water, when the sunflower plants presented the flower in the R9 stage (physiological maturation phase), that is, capitulum dorsum and yellow bracts (Castro & Farias, 2005) evaluated -se: The external diameter (DE) and internal diameter of the head (DI), number of petals (NP), in the flowers when harvested, as well as the appearance of floral bud (APBOT, days after emergence), beginning of flowering (IF, days after emergence) and total opening of the flower bud (ABTOT, days after emergence).

DE was obtained by averaging horizontal and vertical measurements of petal boundaries; the DI was obtained from the arithmetic mean of the vertical and horizontal limits obtained in the disc flowers and the NP was counted all the petals without any discrimination criterion; the APBOT was obtained by counting the days from sowing until the moment when a sphere was seen in the center of the apical meristem; for the IF, the moment in which the color of the flower is already noticed was considered, in the ABTOT, the counting of the days from sowing until the day when all the petals (flowers of the ray) were fully opened.

Statistical analysis

Data were submitted to analysis of variance using the F Test ($P \leq 0.05$). For variables with a significant interaction effect, the response surface was adjusted, and if not, the polynomial regression analysis was performed. Analyzes were performed using SAS® statistical software (Cody, 2015).

Results and Discussion

No significant effect was observed for the interaction between the levels of electrical conductivity in the irrigation water and the doses of silicon on the variables analyzed. The electrical conductivities significantly influenced most of the analyzed variables, except for the transpiration rate, chlorophyll b index, internal flower diameter and number of petals, which showed no difference. For the silicon doses, it was found that only the photosynthesis rate and the internal concentration of CO_2 were statistically influenced.

The net photosynthetic rate (A) of ornamental sunflower plants decreased as the electrical conductivities in the irrigation water increased, with the highest rate (21.60 μmol of CO_2 m^{-2} s^{-1}) when the plants were irrigated with water from 0.5 dS m^{-1} and the smallest(18,42 μmol of CO_2 m^{-2} s^{-1}) with irrigation with water from 3.5 dS m^{-1}. As the EWc increased, there was a reduction in 1.08 μmol of CO_2 m^{-2} s^{-1} (14.72%) on the net photosynthesis rate per unit increase in ECw, in plants irrigated with water frome 3.5 dS m^{-1} compared to those irrigated with water of 0.5 dS m^{-1} (Figure 1A).

The decrease in the net photosynthesis rate may have been influenced by irrigation with saline water, since under stress conditions the stomata of sunflower plants may have closed, reducing the entry of carbon. Thus, with the reduction of CO_2 input in the intercellular spaces or in the substomatic chamber, it may have affected the photosynthetic activity of sunflower plants (Flexas et al., 2008; Kusvuran, 2012).

The doses of Si provided an increase in the net photosynthesis rate of ornamental sunflower plants, obtaining a maximum point of 21.55 μmol of CO_2 m^{-2} s^{-1} in plants that received 50 mg L^{-1} of silicon. However, from this dose there was a reduction in the net photosynthetic rate until the dose of 200 mg L^{-1}, being observed in this the lowest net photosynthetic rate (15.98 μmol CO_2 m^{-2} s^{-1}) (Figure 1B).

The ECw of irrigation water increased the internal concentration of CO_2 (Ci) of ornamental sunflower plants, observing an increase of 28.65% in plants irrigated with water from 3,5 dS m^{-1} compared to those irrigated with water from 0.5 dS m^{-1}. The highest internal concentration of CO_2 (265.84 μmol m^{-2} s^{-1}) occurred in plants irrigated with water from 3.5 dS m^{-1} (Figure 1C). According to the adjustment of the equation, the dose of 80 mg L^{-1} of silicon promoted the lowest internal concentration of CO_2 (254.9 μmol m^{-2} s^{-1}), while the dose of 200 mg L^{-1} promoted the highest Ci (256.18 μmol m^{-2} s^{-1}) (Figure 1D).

These results corroborate those observed by Sousa Junior et al. (2017) when they found that the saline increment reduced gas exchange in sunflower irrigated with saline water. The same was observed by Lima et al. (2017) in castor bean culture, where they found that the increase in the electrical conductivity of water promoted deleterious effects on gas exchange and chloroplast pigments. The increase in CO_2 concentration and the reduction in photosynthetic activity may have been caused by the reduction in rubisco activity, as this response occurs due to the damage to the photosynthetic apparatus in the carboxylation step and to the increase in photorespiration, since Ribulose 1-5 biphosphate carboxylase oxygenase (Rubisco) catalyzes the first step of this route (Pereira et al., 2004).

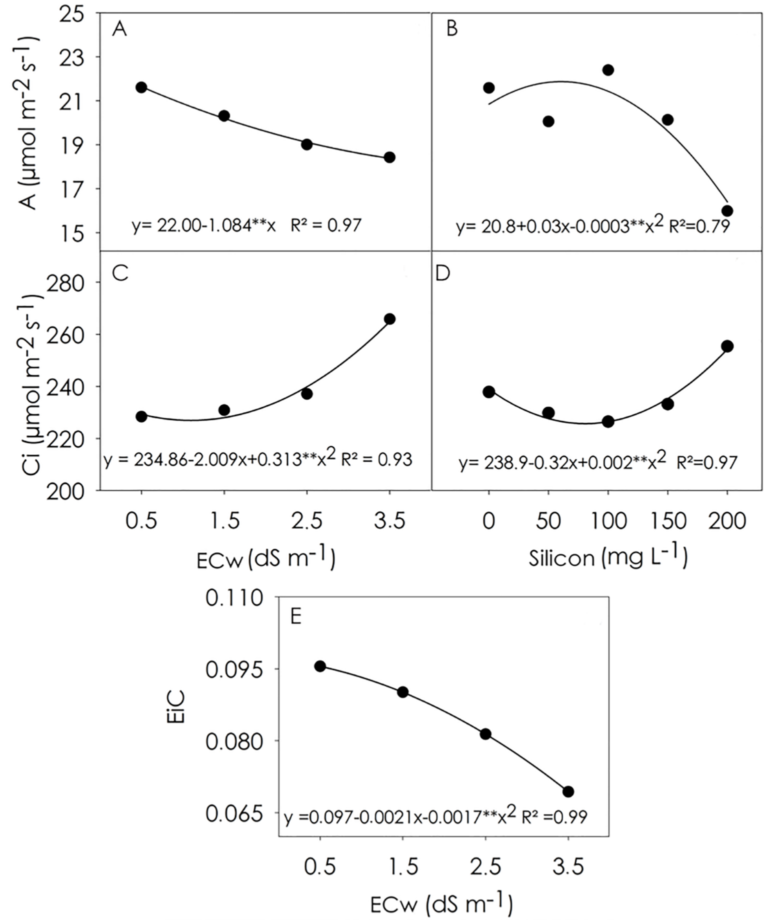

Figure 1. Net photosynthesis rate "A" (A and B), internal carbon concentration "Ci" (C and D) and instantaneous efficiency of carboxylation "EiC" (E) of ornamental sunflower plants irrigated with saline water as a function of application of silicon.

The instantaneous efficiency of carboxylation (EiC) reduced when irrigating ornamental sunflower plants with saline water, obtaining the highest value (0.0955) in plants irrigated with water of lower salinity (0.5 dS m^{-1}); from this ECw there was a decrease of 27.43% in plants irrigated with water from 3.5 dS m^{-1} compared to those irrigated with water from 0,5 dS m^{-1} (Figure 1E). In the bean crop, Oliveira et al. (2017) also observed that the instantaneous efficiency of carboxylation was reduced with increasing salinity in the irrigation water.

The increase in ECw reduced the levels of chlorophyll a (Figure 2A), total chlorophyll (Figure 2B) and chlorophyll a/chlorophyll b ratio (Figure 2C), obtaining the highest indices (4.84; 5.80 and 5.2), respectively, in plants irrigated with saline water from 0.5 dS m^{-1}. From this ECw there was a decrease of 22.10; 17.24 and 32.69% in chlorophyll A type, total chlorophyll and chlorophyll a/chlorophyll b ratio in plants irrigated with water from 3. dS m^{-1} compared to those irrigated with water of 0.5 dS m^{-1} (Figure 2). These results were also observed by Lima et al. (2017) in castor bean plants subjected to salinity levels.

The reduction in chlorophyll levels due to irrigation with saline water can be attributed to the acclimatization of ornamental sunflower plants to saline stress, as the plants can reduce energy expenditure and, consequently, capture less light energy, thus avoiding possible photo-oxidative stresses (Tabot & Adams, 2013), which was observed in the present work. In addition, these reductions may also indicate an increase in the synthesis of chlorophyllase, an enzyme that acts in the degradation of the molecules of this photosynthetic pigment.

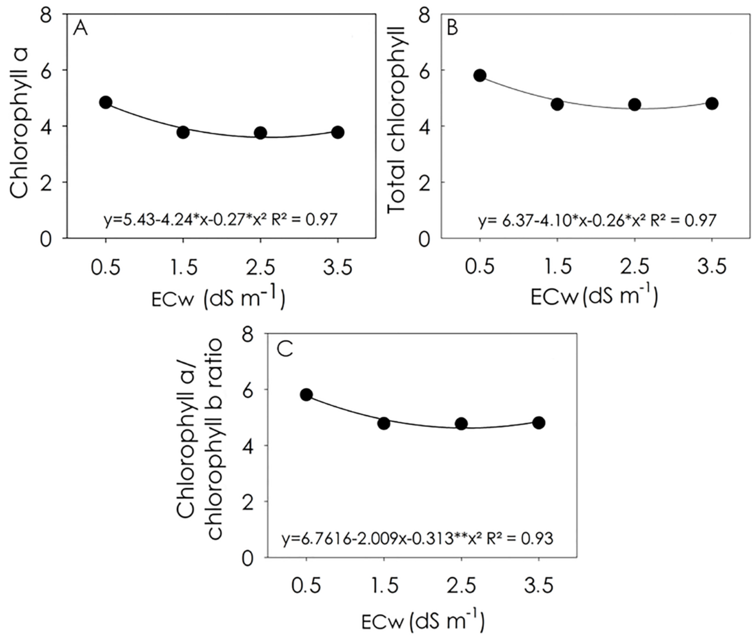

Figure 2. Chlorophyll a (A), total chlorophyll (B) and chlorophyll a/ chlorophyll b ratio (C) of ornamental sunflower plants irrigated with saline water.

The silicon did not influence the floral induction of the ornamental sunflower, verifying the absence of effects for the appearance of the floral bud, flowering index, total opening of the floral bud and external diameter of the capitulum of the ornamental sunflower plants. In turn, irrigation with saline water promoted an increase in the number of days for the appearance of the floral bud (Figure 3A) and in the flowering index (Figure 3B), obtaining 47 days for the appearance of the floral bud in plants irrigated with lower salinity water (0.5 dS m^{-1}), from this ECw there was an increase of 11.93% (5 days) in the number of days in plants irrigated with water of 3.5 dS m^{-1} in relation to those irrigated with water from 0.5 dS m^{-1}.

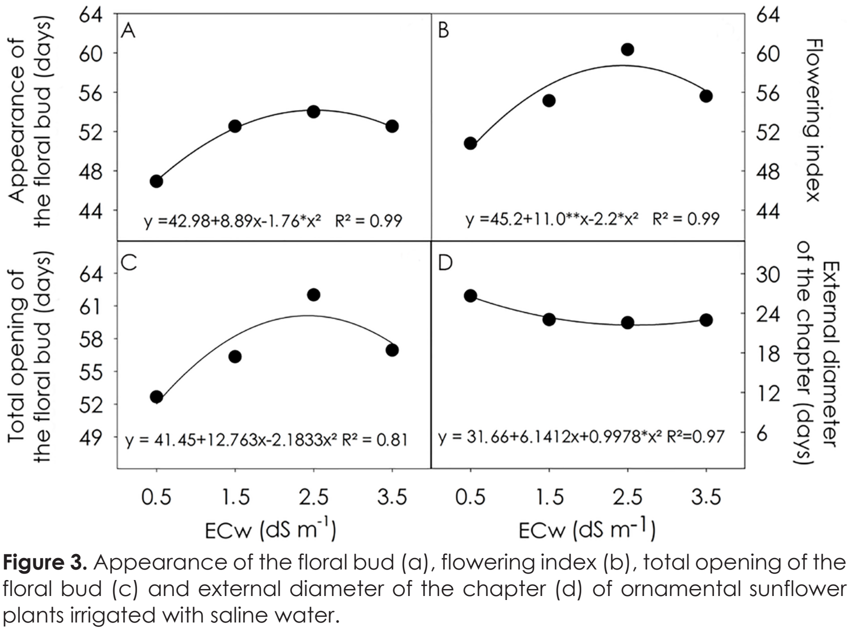

Figure 3. Appearance of the floral bud (a), flowering index (b), total opening of the floral bud (c) and external diameter of the chapter (d) of ornamental sunflower plants irrigated with saline water.

Ornamental sunflower plants showed a reduction in the cycle (50 days to the beginning of flowering), when irrigated with water from 0.5 dS m^{-1}, and, from this ECw onwards, the plants needed more days to flower, and irrigation with water from 2.5 dS m^{-1} the one that provided the greatest number of days (60 days) for the flowering of ornamental sunflower plants (Figure 3B).

The total opening of the floral bud increased when the sunflower plants were irrigated with saline water, obtaining the lowest number of days (52 days) with irrigation with water from 0.5 dS m^{-1}. By increasing the ECw to 2.5 dS m^{-1} an increase of up to 15.06% was observed in the number of days for the total opening of the floral bud, in plants irrigated with water from 2.5 dS m^{-1} compared to those irrigated with water from 0.5 dS m^{-1} (Figura 3C).

The external diameter of the head reduced when irrigating the ornamental sunflower plants with higher salinity, obtaining the highest value (26.66 mm) in plants irrigated with water with lower salinity (0.5 dS m^{-1}); from this ECw, there was a decrease of 27.43% in plants irrigated with water of 2.5 dS m^{-1} in relation to those irrigated with water of 0.5 dS m^{-1} (Figure 3B).

The increase in the beginning of flowering of ornamental sunflower plants was also observed by Nobre et al. (2010) in sunflower, where they found an increase of 0.73 days per unit increase in ECw (dS m^{-1}) for the beginning of flowering. It is possible that the delay in flowering of sunflower plants was caused by the reduction of the osmotic potential of the soil solution caused by salts, making it difficult for water to enter the plant cells and, consequently, impairing the performance of the culture (Tester & Davenport, 2003).

Hurtado et al. (2019) demonstrated that silicon mitigated the deleterious effects of saline stress on biomass gain in ornamental sunflower plants, however, the demonstrated mechanism for this stress relief was a decrease in Na+ influx concomitant with an increase in nutrient influx. In this study, on the other hand, it can be observed that this adjustment is not accompanied by photosynthetic changes or gas exchanges, in addition, delays and losses in flowering are also not attenuated by silicon, showing that for this species the gains in total biomass not necessarily translate into increased productivity.

Conclusions

Salinity negatively affects photosynthetic activity and flowering of ornamental sunflower plants, so that plants irrigated with saline water (3.5 dS m^{-1}) delayed the appearance of the floral bud, the flowering rate and the total opening of the flower. floral button. The application of silicon in ornamental sunflower plants is not effective to attenuate the deleterious effects of salinity on plant physiology. In addition, the addition of silicon is also not able to repair the losses in terms of flowering caused by saline stress in the species.

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