ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 8, Issue, 09, pp.37689-37695, September, 2016

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

RESEARCH ARTICLE

TOLERANCE OF PASSION FRUIT SPECIES UNDER SALT STRESS

***,[1]Regianados Santos Moura, [1]Hans Raj Gheyi, [2]Maurício Antonio Coelho Filho, [2]Onildo Nunes de Jesus, [3]Francisco Vanies da Silva Sá and [1]Lucas Kennedy Silva Lima**

[1]Federal University of Recôncavo of Bahia, Cruz das Almas, Bahia, Brazil
[2]Empresa Brasileira de Pesquisa Agropecuária- EMBRAPA, Cruz das Almas, Bahia, Brazil
[3]Federal University of Campina Grande, Campina Grande, Paraíba, Brazil

ARTICLE INFO

Article History:
Received 20th June, 2016
Received in revised form
29th July, 2016
Accepted 11th August, 2016
Published online 20th September, 2016

Key words:

Growth analysis,
Selection of genotypes,
Passiflora spp.

ABSTRACT

This study aimed to evaluate the growth of passion fruit seedlings under different levels of irrigation water salinity, in an experiment conducted in a protected environment. The treatments were distributed in a completely randomized design, in a 5 x 3 factorial scheme, referring to five levels of irrigation water salinity: 0.3, 1.4, 2.5, 3.6 and 4.7 dS m^{-1} and three species of *Passiflora*: *gibertii*, *cincinnata* and *edulis* cv. 'Gigante Amarelo', with four replicates, analyzed for plant height, stem diameter, dry matter of root, shoot and total. The absolute and relative growth rates of passion fruit species are affected by irrigation water salinity. Stem diameter is the variable most sensitive to the increase in irrigation water salinity. For satisfactory growth, seedlings of *P. gibertii*, *P. edulis* and *P. cincinnata* can be irrigated with waters of up to 3.69, 2.14 and 1.87 dS m^{-1}, respectively. Among the studied species, *Passiflora cincinnata* is considered as moderately tolerant to salinity while the *Passiflora gibertii* and *Passiflora edulis* are tolerant to salinity.

Citation: Regianados Santos Moura, Hans Raj Gheyi, Maurício Antonio Coelho Filho, Onildo Nunes de Jesus, Francisco Vanies da Silva Sá and Lucas Kennedy Silva Lima. 2016. "Tolerance of passion fruit species under salt stress", *International Journal of Current Research*, 8, (09), 37689-37695.

INTRODUCTION

Passion fruit is native to Tropical America and is among the fruit crops with great economic expression in the world, being intensely cultivated in countries with tropical and subtropical climate, as in Brazil, which stands out as the largest consumer and producer (823 thousand tons) of the fruit, and the yellow passion fruit (*P. edulis*) is the most predominant species, with about 95% of the orchards in the country (Silva *et al*., 2012). The Northeast region is the largest producer in the country, accounting for 71% of the national production, especially the state of Bahia, which leads the ranking of harvested area, with 29,938 ha and production of 320,945 t (IBGE, 2015). Yellow passion fruit is sensitive to high levels of salinity, according to the results found in the literature, Araújo *et al.* (2013), evaluating the production of yellow passion fruit seedlings observed that their growth was affected from the electrical conductivity of irrigation water (EC_w) of 2.1 dS m^{-1}onwards. Casierra-Posada, Peña-Olmos and Tejedor (2011) consider yellow passion fruit as "tolerant" to salinity in germination phase and "moderately tolerant" to salinity in the other growth stages. The most remarkable effects of salinity on the plants are reflected in alterations in the osmotic potential, ionic toxicity and imbalance in the absorption of nutrients, causing generalized reduction in the growth, with serious damages to the agricultural activity (Sousa, Cavalcante, Cavalcante, Cavalcante and Nascimento, 2008; Ahmed and Montani, 2010). There is the need to adopt techniques and practices that reduce the negative effects of salinity on the passion fruit crop, in order to reduce the deleterious effects on growth and production of the species, because the commercial species of passion fruit are sensitive to salinity; however, most of the wild species have proved to be more resistant to pests, diseases and water deficit (Melletti, Cavichoioliand Pacheco, 2012). Hence, in the last 10 years, cultivars and hybrids have been produced in Brazil aiming to increase the productive capacity, compared with the low national yield, which is still below 15 t ha^{-1}. The wild species *P. cincinnata* Mast and *P. gibertii* N.E. Brow are widely used in plant breeding programs, because they are vigorous and have the genes of resistance to biotic and abiotic stresses (Melletti *et al.,* 2012).

****Corresponding author: Regianados Santos Moura,***
Federal University of Recôncavo of Bahia, Cruz das Almas, Bahia, Brazil.

Therefore, the present study aimed to evaluate the effects of irrigation water salinity on the absolute and relative growth rates of different passion fruit species in the seedling stage.

MATERIAL AND METHODS

The experiment was carried out from October to December 2015 in a protected environment at the Nucleus of Soil and Water Engineering (NEAS) of the Federal University of Recôncavo of Bahia (UFRB), located in Cruz das Almas-BA, Brazil (12º40'19" S; 39º06'23" W; 220 m). Relative air humidity and mean temperature during the experiment were equal to 71% and 21.6 ºC, respectively, which are considered as adequate for passion fruit cultivation. The treatments were distributed in a completely randomized design, in a 5 x 3 factorial scheme, corresponding to five levels of irrigation water salinity (0.3, 1.4, 2.5, 3.6 and 4.7 dS m^{-1}) and three *Passiflora* species [*P.gibertii*, *P. cincinnata* and *P. edulis* cv. *'*Gigante Amarelo'], with four replicates.

Initially, these species were sown in polyethylene trays containing the commercial substrate Vivatto® and irrigated with water from the municipal supply system (EC_w = 0.30). After 20 days of emergence of the seedlings, they were transplanted to plastic tubes made of PET bottles, with capacity for 2 dm^3. In order to make the tubes, the bottles had their bottom part removed and were turned upside down on a metal structure. The bottom part of the tube, where the bottle lid was located, was perforated to allow drainage. The tubes were filled with a 3-cm-thick layer of gravel at the bottom and a mixture of soil and decomposed bovine manure, in the proportion of 10:1(weight basis), respectively. The soil used in the composition of the substrate was collected from the experimental area of the NEAS/UFRB (sandy loam Yellow Latosol). In the substrate consisting of soil and decomposed bovine manure, there were no problems of salinity, and the mixture presented following chemical attributes: pH = 7.0; P = 139.00 mg dm^{-3}; exchangeable K^+, Ca^{2+}, Mg^{2+} and Na^+ = 3.08, 1.65, 0.87 and 0.87 $cmol_c$ dm^{-3}, respectively, and OM = 7.00g kg $^{-1}$, determined according to the methodologies recommended by Embrapa (1997). Irrigations started 10 days after transplanting (DAT), using salinized water according to the treatments. Waters of different salinity levels were prepared by the dissolution of NaCl in freshwater from the local supply system, according to the pre-established treatments, and irrigations were performed on alternate days following equation 1:

$$VI = \frac{(VA - VD)}{0.9} \quad (1)$$

where: VI – water volume to be applied in irrigation; VA – volume of water applied in the previous irrigation; VD – volume of water drained after the previous irrigation, and "0.9" – factor to reestablish the water content to field capacity and to obtain the leaching fraction of 0.10. Drainage water was collected in a container attached to the base of each pot. At 30 and 60 days after the beginning of irrigations with saline waters, passion fruit plants were evaluated for growth and phytomass accumulation, determined through the absolute and relative growth rates (AGR and RGR) in plant height (PH), stem diameter (SD), root dry matter (RDM), shoot dry matter (SDM), total dry matter (TDM) and RDM/SDM ratio. Plant height was considered as the distance from the base until the apical meristem. Stem diameter was measured at a height of 5 cm from the base of the plant. The dry material (roots and shoots) was obtained after drying in a forced-air oven at 65 ºC until constant mass. The AGR and RGR were obtained according to the equations 2 and 3, described by Benincasa (2003):

$$AGR = \frac{(V2 - V1)}{(T2 - T1)} \quad (2)$$

$$RGR = \frac{Ln(V2) - Ln(V1)}{(T2 - T1)} \quad (3)$$

where: V1 is the variable at time T1 and V2 is the same variable at time T2.

The data of TDM production were used to calculate the salinity tolerance index (STI), comparing the saline treatments with the control (EC_w = 0.3 dS m^{-1}), according to the following equation suggested by Fageria, Soares Filho, and Gheyi (2010):

STI (%)

$$= \frac{Total\ dry\ matter\ production\ in\ the\ saline\ treatment}{Total\ dry\ matter\ production\ in\ the\ control\ treatment}\ x\ 100 \quad (4)$$

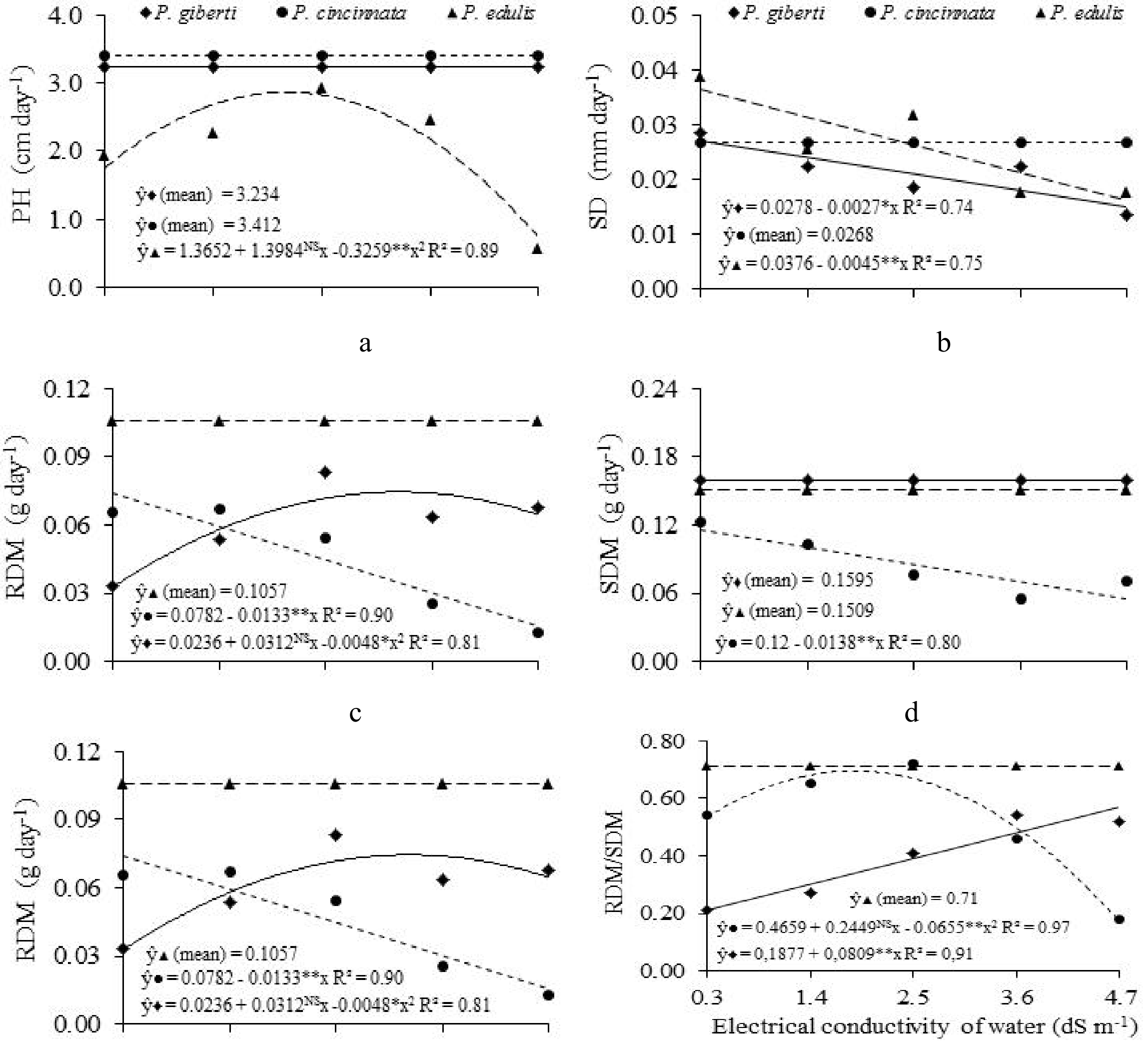
The data were subjected to analysis of variance by F test and polynomial regression for the salinity levels was performed when the effect was significant. The data were processed using the program Sisvar (Ferreira, 2011).

RESULTS AND DISCUSSION

There was a significant influence of the interaction of water salinity levels versus passion fruit species for all analyzed variables in the period of 30 to 60 days, at 0.05 probability level (Figures 1 and 2). For the AGR in PH of the species *P. cincinnata* and *P. gibertii*, the data did not fit to any mathematical model; thus, the variation was represented by the mean values of3.417 and 3.234 cm dia^{-1}, respectively. *P. edulis* reached maximum absolute growth of 2.86 cm day^{-1} when irrigated with water of 2.14 dS m^{-1}, showing a result 16.30% lower compared to *P. cincinnata* and 11.56% compared with *P. gibertii* (Figure 1A).

This difference with respect to the response to salinity among species of the same genus was also observed in other crops, such as citrus by Brito *et al.* (2008), Fernandes *et al.* (2011) and Brito *et al.* (2014), and papaya by Mesquita *et al.* (2014). The data of AGR in SD of *P. cincinnata* did not adjustsatis factorily to any model and showed a mean growth rate of 0.0268 mm day^{-1}, from 30 to 60 days postirrigation with saline water.

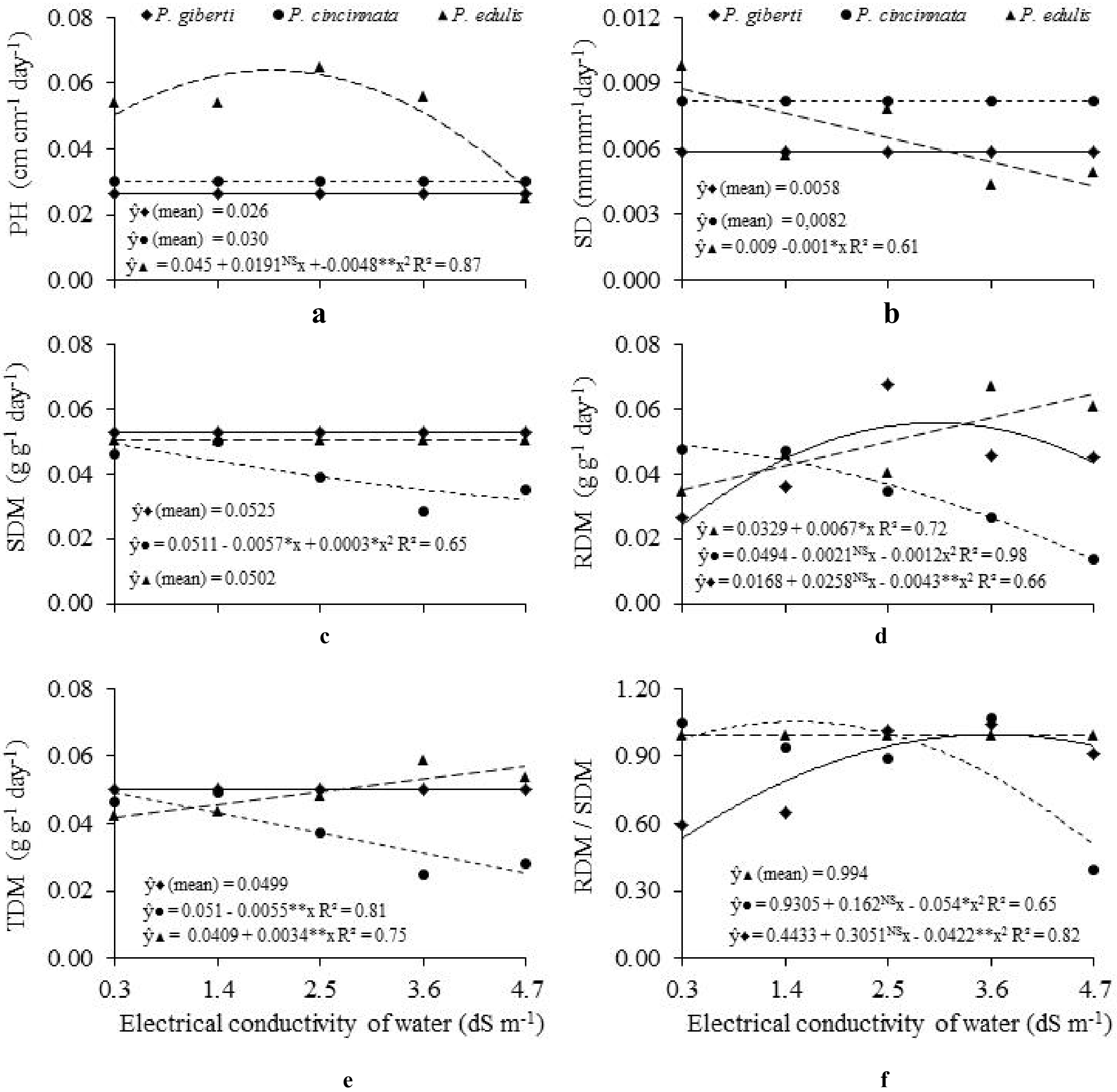
However, in *P. gibertii* and *P. edulis* obtained a decreasing linear growth and the highest rates (0.026 and 0.036 mm day^{-1}) were observed at the lowest salinity level (EC_w = 0.3 dS m^{-1}), with reductions of 9.71 and 11.97% with per unit increase in water salinity, respectively (Figure 1B).



^{NS}, * and ** = not significant and significantat 1 and 5% ($p < 0.01$ and $p < 0.05$) probability, respectively.

Figure 1. Absolute growth rate (AGR) of the variables plant height -PH (A), stem diameter - SD (B), shoot dry matter- SDM (C), root dry matter - RDM (D), total dry matter- TDM (E) and root dry matter/shoot dry matter ratio –RDM/SDM (F) of passion fruit seedlings under different levels of irrigation water salinity in the period of 30 to 60 days post transplanting

The reduction in diameter causes growth inhibition or delay, since it is influenced by the decrease in water availability in the soil, leading the plant to demand more energy to absorb water for its development (Leonardo, Broetto, Bôas, Almeida and Marhcese, 2007). The data of AGR in SDM of *P. gibertii* and *P. edulis*did not fitto any model, with mean gain of dry matter of 0.159 and 0.151 g day^{-1} whereas *P. cincinnata* showed a decrease of 11.5% with per unit increase in water salinity (Figure 1C). The reduction in SDM of the passion fruit species under saline stress was possibly due to the osmotic effect of the salts and the probable accumulation of potentially toxic ions (Na^+ and Cl^-) in the leaf tissues, with consequences in the transpiration and photosynthetic activities triggered by stomatal closure and decrease in CO_2 diffusion inside the cells, reducing the growth and the allocation of plant phytomass (Souza, Machado, Silveira and Ribeiro, 2011; Lima *et al.*, 2014). There was a quadratic response of the AGR in RDM for *P. gibertii*, which showed a maximum RDM gain of 0.074g day^{-1} at EC_w of 3.25 dS m^{-1}. However, *P. cincinnata* showed a decreasing linear response to the EC_w levels, with a reduction of 77.02% in the growth rate under irrigation water of 4.7 dS m^{-1} in relation to the lowest saline level (0.3 dS m^{-1}). Nonetheless, there was no mathematical fit of the AGR in RDM for *P. edulis*, which was represented by the mean value of 0.105 g day^{-1}, results superior to those obtained for other species independent of the salinity levels tested (Figure 1D). The reduction of the AGR in RDM for *P. cincinnata* can be explained by the high saline concentration in the root zone, causing osmotic stress and toxicity by the chloride and sodiumions, which result in loss of turgor and reduction in the rates of cell elongation and division (Mahmoud and Mohamed, 2008). On the other hand, the increase of the AGR in RDM for *P. gibertii* until 3.25dS m^{-1} can be attributed to the osmotic adjustment and the physical conditions of the substrate, which contained 10% of decomposed bovine manure in its composition, promoting adequate aeration along with the leaching fraction of 0.10. Similar result was reported in the 'Havaí' papaya crop, for which Mesquita *et al*. (2014) observed the highest growth rate in RDM (0.105 g day^{-1}) at estimated electrical conductivity of 1.89 dS m^{-1}, which was three times higher than the growth (0.034 g day^{-1}) obtained at the lowest salinity level (0.5 dS m^{-1}). The AGR in TDM for *P. cincinnata* showed a decreasing linear response with the increase in salinity, with highest rate of 0.19 g day^{-1} at EC_w of 0.3 dS m^{-1} and reduction of 13.99% with unit increase in water salinity amounting to 63.16% decrease at the highest saline level. This response can be justified by the osmotic stress, which has immediate effect on plant growth and greater influence on the growth rates, in comparison to the ionic stress. In addition, there was no satisfactory adjustment for the AGR in TDM of *P. gibertii* and *P. edulis*, which showed mean values of 0.2197 and 0.2556 g day^{-1}, respectively (Figure 1E). For the AGR in RDM/SDM ratio, the three species showed different behaviors. *P. gibertii* showed positive linear response to the increment in water salinity levels. There was no mathematical fit for the AGR in RDM/SDM ratio of *P. edulis*, which showed mean value of 0.71. The *P. cincinnata* showed increase until the EC_w of 1.87 dS m^{-1}, with later reduction from this point onwards (Figure 1F). This suggests that *P. cincinnata* uses "physiological mechanisms" in situations of stress to delay the development of the root system and shoots, accumulating photoassimilates in its stem to be later used under favorable conditions, since it is a species native to semiarid regions. Salinity-tolerant plants are able to accumulate large amounts of salts in their tissues, extracting from the soil and in certain conditions may also be used in the phytoremediation of these soils (Santos *et al.,* 2011). For *P. cincinnata*, it can be inferred that this species has a mechanism of adaptation to saline stress, accumulating its reserves in the stem and reducing the growth in roots and shoots. According to Munns and Tester (2008), one of the effects attributed to the saline stress is the reduction in phytomass accumulation, which also reflects in the metabolic cost of energy associated with the adaptations to saline stress, also including the synthesis of organic solutes for the protection of macromolecules and osmoregulation, regulation of ionic transport and distribution in various organs and inside the cells, besides maintenance of the integrity of cell membranes. The other damages most found in the literature are the reduction in leaf area (Nascimento *et al*., 2011), delay in the development of apical buds and reduction in the number of leaves.



^{NS}, * and ** = not significant and significantat 1 and 5% ($p < 0.01$ and $p < 0.05$) probability, respectively

Figure 2. Relative growth rate (RGR) of the variables plant height - PH (A), stem diameter - SD (B), shoot dry matter - SDM (C), root dry matter – RDM(D), total dry matter - TDM (E) and root dry matter/shoot dry matter – RDM/SDM ratio (F) of passion fruit seedlings under different levels of irrigation water salinity in the period of 30 to 60 days after transplanting

The RGR in PH for *P. gibertii* and *P. cincinnata* in the period of 30 to 60 days was not affected by the studied saline levels, with mean values of 0.026 and 0.030 cm cm^{-1} day^{-1}, respectively, evidencing that this variable is not sensitive to salinity for studies on these species. *P. edulis* reached a maximum relative growth of 0.064 cm cm^{-1} day^{-1} when irrigated with water of 1.99 dS m^{-1}, being 2.46 and 2, 13 times superior to *P. gibertii* and *P. cincinnata*, respectively (Figure 2A). These results of *P. edulis* agree with those found by Mesquita, Rebequi, Cavalcante and Souto (2012a), who observed that the relative growth in height of *P. edulis* in the period of 25 to 65 days after emergence decreased with the increase in water salinity from 0.5 to 4.0 dS m^{-1}, with extreme values of 0.08 and 0.083 cm cm^{-1} day^{-1} at the estimated electrical conductivities of 0.5 and 1.0 dS m^{-1}, in the soil without and with biofertilizer, respectively. There was no significant influence of salinity levels on RGR in SD of *P. gibertii* and *P. cincinnata*, with mean growth rate of 0,0058 and 0,0082 mm mm^{-1} day^{-1}, respectively. The *P. edulis* showed decreasing linear relative growth rate, with maximum value of 0.0087 mm mm^{-1} day^{-1} at the level of 0.3 dS m^{-1} and a drastic decrease of 50.57% when subjected to the highest EC_w level (4.7 dS m^{-1}) (Figure 2B). The effects of salinity on plant growth are associated with its interference in the processes of net CO_2 assimilation, translocation of carbohydrates to sink tissues and deviation of energy sources to other processes, such as osmotic adjustment, synthesis of compatible solutes, repair of damages caused by salinity and maintenance of basic metabolic processes (Paranychianakis and Chartzoulakis, 2005).

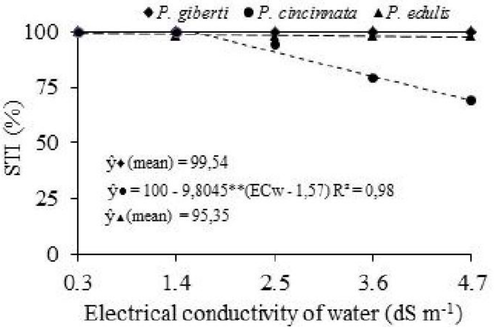
For the RGR in SDM, there was a decreasing quadratic behavior of *P. cincinnata*, with reduction of 37.5% (0.048 to 0.030 g g^{-1} day^{-1}) as EC_w increased from 0.3 to 4.7 dS m^{-1} (Figure 2C). As mentioned earlier the growth was affected negatively as a result of the osmotic effect, accompanying a decrease in the growth rate of the leaf area over time. While the data of *P. gibertii* and *P. edulis* did not fit to any mathematical model satisfactorily and were represented by the mean value of 0.052 e 0,050g g^{-1} day^{-1} (Figure 2C). The RGR in RDM for *P. gibertii* showed the highest gain of 0.055 g g^{-1} day^{-1} at EC_w of 3.00dS m^{-1}. The *P. cincinnata* showed a decreasing quadratic response to the increment in EC_w levels, with a maximum value of 0.046 g g^{-1} day^{-1} at EC_w of 0.875dS$m^{-1}$and 71,73% decrease occurred at the highest saline level (EC_w = 4.7 dS m^{-1}). On the other hand, the *P. edulis* showed a positive linear response as the EC_w levels increased, with a value of 0.064 g g^{-1} day^{-1} for the highest saline level (EC_w = 4.7 dS m^{-1}), with increment of 82,85% compared with the irrigation water of lowest EC_w (0.3 dS m^{-1}) (Figure 2D). These results do not agree with those reported by Mesquita *et al.* (2012b), who observed a drastic reduction in the RGR in RDM, for the period of 25 to 65 days after emergence, with increase in the salinity of the water with and without biofertilizer, reaching a maximum value of 0.055 g g^{-1} day^{-1} at a water salinity of 0.5 dS m^{-1} for the yellow passion fruit (*P. edulis*).

The RGR in TDM for *P. cincinnata* showed decreasing linear response as the EC_w levels increased, with a maximum value of 0.049 g g^{-1} day^{-1} for the lowest level (0.3 dS m^{-1}) and a decrease of 46.93% when irrigation water with the highest saline level (4.7 dS m^{-1}) was applied (Figure 2E). For *P. edulis*, there was a positive linear response as the EC_w levels increased, with a value of 0.057 g g^{-1} day^{-1} for the highest EC_w level (4.7 dS m^{-1}), i.e., an increment of 35.71% in relation to the control. There was no significant influence of water salinity levels on RGR in TDM of *P. gibertii*, with mean growth of 0,0499 g g^{-1} day^{-1} (Figure 2E). The different responses observed in the relative growth in TDM of the different passion fruit species, based on the lowest saline level studied either through linear or quadratic equations, are due to the reduction in the growth potential of each species under the salinity levels. Casierra-Posada *et al.* (2011) reported that the growth of seedlings of banana passion fruit (*Passifloratripartita var.* Mollissima) under increasing levels of salinity, besides reducing plant height and dry matter, also altered the dry matter in different plant organs, as an adaptive mechanism to salinity. Nyagah and Musyimi (2009), in the germination of *P.edulis*, observed a direct relationship between the concentration of salt and the reduction in plumule and radicle growth. For the RDM/SDM ratio, the results indicate that the species *P. gibertii* obtained maximum value (0.99) at EC_w of 3.63 dS m^{-1}. For *P.edulis*, there was no satisfactory adjustment, with a mean value of 0.994. On the other hand, *P. cincinnata* showed the highest value (1.05) at EC_w of 1.5 dS m^{-1} and lowest (0.50) at water salinity level of 4,7dS m^{-1} (Figure 2F).

This once again confirms that the species *P. cincinnata* reduces its growth in dry matter of both roots and shoots when subjected to high levels of salinity. In a general analysis of the data, for all studied variables of AGR, except stem diameter, in the studied period (30 to 60 days), the species *P. edulis* showed higher growth with EC_w ranging from 0.3 to 2.14 dS m^{-1} and *P. gibertii* 4.7 dS m^{-1} for RDM/SDM ratio, whereas *P. cincinnata* showed growth in RDM/SDM ratio with EC_w of 1.87 dS m^{-1}, indicating that these species have growth potential under saline stress (Figure 1). For RGR, the species *P. edulis* and *P. gibertii* showed a behavior similar to that for AGR, with higher growth of the variables at EC_w ranging from 0.3 to 4.7 and 3.0 to 3.69 dS m^{-1}, respectively. However, *P. cincinnata* showed growth only for RDM and RDM/SDM ratio with EC_w 0.8 and 1.5 dS m^{-1} respectively. Ribeiro, Moreira, SeabraFilho and Menezes (2016) observed that, in the emergence stage, *P. edulis* tolerated EC_w of up to 1.5 dS m^{-1}. On the other hand, *P. cincinnata* demonstrates increasing negative impacts on the growth of dry matter when subjected to salinity (Figure 2C, D, E e F).

With regard to the salinity tolerance index (STI) in the first 60 days after transplanting, there was no significant influence of the salinity levels on the tolerance of *P. gibertii* and *P. edulis*, which reached indices of 99.5 and 95.3%, respectively. However, the tolerance of *P. cincinnata* was reduced from the level of 1,57dS m^{-1}onwards by 9.80% per unit increase in irrigation water salinity, reaching an index of 69.32% at EC_w of 4.7 dS m^{-1} (Figure 3). According to Almodares, Hadi and Dosti (2007), some plants are sensitive to salinity in the initial stage, because the mechanism of tolerance to salinity is not yet totally developed, a fact observed in *P. edulis* plants, which increased their tolerance to saline stress in the juvenile stage.

As to *P. cincinnata*, it is possible that the accumulation of salts in the substrate due to the continuous irrigation events may have reached the crop threshold salinity, demonstrating higher sensitivity in comparison to the other studied species. However, according to Fageria *et al.* (2010), the STI of 69.32% observed for *P. cincinnata* indicates moderate tolerance to salinity, even under EC_w level of 4.7 dS m^{-1}.



** significant at 1% (p <0.01) probability

Figure 3. Salinity tolerance index (STI) during 60 days after transplanting of passion fruit seedlings under different levels of irrigation water salinity

Conclusions

The absolute and relative growth rates in plant height, stem diameter and accumulation of dry matter in different parts of the passion fruit species are affected by irrigation water salinity, stem diameter being the variable most sensitive to increase in water salinity. The seedlings of *Passiflor agibertii*, *Passiflora edulis* and *Passiflora cincinnata* can be irrigated with waters of up to 3.69, 2.14 and 1.87 dS m^{-1}, respectively for satisfactory growth. The salinity tolerance index, based on total dry matter production, indicates *Passifloracincinnata* as moderately tolerant to salinity while the species *P. gibertii* and *P. edulis* are considered as tolerant.

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