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Growth of wild passion fruit (*Passiflora foetida* L.) rootstock under irrigation water salinity[1]

Crescimento de porta-enxerto de maracujazeiro silvestre (*Passiflora foetida* L.) sob salinidades da água de irrigação

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HIGHLIGHTS:

Rootstocks of Passiflora foetida *can be considered salinity tolerant.*
Irrigation of P. foetida *rootstocks can be performed using water with electrical conductivity of up to 4.0 dS m*$^{-1}$*.*
The salinity tolerance of P. foetida *rootstocks is associated with plant age.*

ABSTRACT: Wild passion fruit species, due to the greater tolerance to environmental stresses, reveal potential as interspecific rootstocks. *Passiflora foetida* is a wild species potentially tolerant to salinity. Therefore, the objective with the study was to evaluate the effects of irrigation water salinity on the growth of wild passion fruit (*P. foetida* L.) rootstocks. The experiment was carried out in a protected environment. The treatments consisted of the electrical conductivity of the irrigation water (0.3; 1.0; 2.0; 3.0 and 4.0 dS m^{-1}), distributed in randomized blocks. The assessments were performed at 7, 14, 21, 28 and 35 days after transplanting and consisted of: stem height and diameter, number of leaves, average leaf size, leaf area, and dry matter of shoots, roots and total. In younger rootstocks, the deleterious effects of salinity on height growth and leaf components were observed under lower electrical conductivities, with tolerance increasing with age. However, dry biomass accumulation was more severely restricted by salinity with increasing rootstock age. *P. foetida* rootstocks are salinity tolerant and can be irrigated with water of up to 4.0 dS m^{-1}.

Key words: wild passion fruit, water salinity, salinity tolerance

RESUMO: Espécies silvestres de maracujazeiro, devido à maior tolerância aos estresses ambientais, revelam potencial como porta-enxerto interespecífico, *P. foetida* é uma espécie silvestre potencialmente tolerante à salinidade. Portanto, o objetivo com a pesquisa foi avaliar os efeitos da salinidade da água de irrigação no crescimento de porta-enxertos de maracujazeiro-bravo (*P. foetida* L.). O experimento foi realizado em ambiente protegido. Os tratamentos consistiram na condutividade elétrica da água de irrigação (0,3; 1,0; 2,0; 3,0 e 4,0 dS m^{-1}), distribuídos em blocos casualizados. As avaliações foram realizadas aos 7, 14, 21, 28 e 35 dias após o transplantio e consistiram em: altura e diâmetro do caule, número de folhas, tamanho médio da folha, área foliar, massas das matérias secas da parte aérea, das raízes e total. Nos porta-enxertos jovens, os efeitos deletérios da salinidade sobre o crescimento em altura e os componentes foliares foram observados sob menores condutividades elétricas, sendo a tolerância aumentada com a acréscimo da idade. Entretanto, o acúmulo de biomassa seca foi restringido com maior severidade pela salinidade com o aumento da idade dos porta-enxertos. Os porta-enxertos de *P. foetida* são tolerantes à salinidade e podem ser irrigados com água de até 4,0 dS m^{-1}.

Palavras-chave: maracujazeiro silvestre, salinidade hídrica, tolerância à salinidade

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Introduction

The species *Passiflora edulis* is the most commercially and economically important passion fruit in Brazil, the world's largest producer and consumer (Faleiro et al., 2020). In the national scenario, the Northeast region stands out with 71.2% (491,326 tons) of production (IBGE, 2021). However, this region has low yield (14.535 t ha^{-1}), far below the potential of the crop, which can exceed 50 t ha^{-1} (Faleiro et al., 2020).

Among the limiting factors to production in this region, the low rainfall, the high spatial-temporal variability of rainfall and the high concentration of soluble salts in irrigation water stand out. The excess of salts affects both the production of seedlings (Andrade et al., 2019; Bezerra et al., 2019; Souza et al., 2020) and plants of *P. edulis* in the field (Bezerra et al., 2020).

Strategies that enable the maintenance of agricultural activity, such as the use of tolerant materials, are essential. Tolerance to abiotic and biotic factors can be found in wild species (Silva et al., 2017; Hurtado-Salazar et al., 2018), but these generally have lower yield than those cultivated, in addition to production characteristics not accepted by the market. Therefore, wild species have been studied for their potential to be used as rootstocks (Silva et al., 2018a; Souto et al., 2022).

The grafting of cultivated species onto wild species can ensure the viability of passion fruit cultivation, allowing the combination of desirable characteristics between the species (Bernardes et al., 2020). Among the potential wild species for grafting is *P. foetida* (Silva Filho et al., 2019; Bernardes et al., 2020), which has leaf trichomes and glands on the leaves and petioles that enable salinity tolerance (Crochemore et al., 2003), besides having compatibility with *P. edulis* (Silva et al., 2018a).

Therefore, the objective with the study was to evaluate the effects of irrigation water salinity on the growth of wild passion fruit (*P. foetida* L.) rootstocks.

Material and Methods

The experiment was carried out in a protected environment (6° 58' 5" South Latitude, 35° 42' 59" West Longitude and 504 m elevation), from November to December 2019, in the agricultural production sector, fruit growing laboratory, at the Center for Agricultural Sciences, Federal University of Paraíba, municipality of Areia, state of Paraíba, Brazil.

During the experimental period, the air temperature and relative humidity were monitored daily with an Incoterm Digital Thermo-Hygrometer (Figure 1).

The treatments were arranged in a 5 x 5 factorial scheme, referring to the electrical conductivity of the irrigation water – ECiw (0.3; 1.0; 2.0; 3.0 and 4.0 dS m^{-1}) (Bezerra et al., 2019) and the times of evaluations (7, 14, 21, 28 and 35 days after

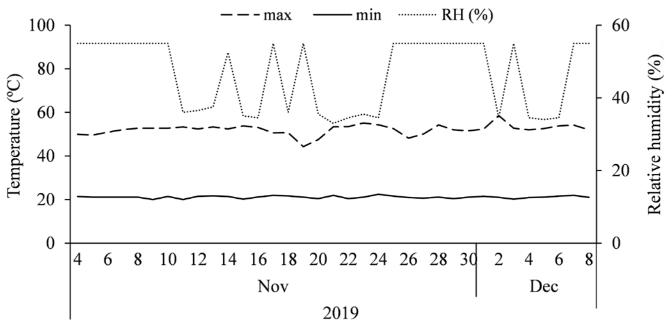


Figure 1. Maximum and minimum daily values of air temperature (A) and average daily values of air relative humidity (RH) (B) during the experiment

transplanting), adopting a randomized block design with four replicates, with a total of 200 rootstocks being evaluated.

The seeds of wild passion fruit (*P. foetida*) were extracted from fruits collected from plants located in the municipality of Cerro Corá, Rio Grande do Norte, Brazil. Sowing was done in tubes of 180 cm^3, filled with fine sand and organic compost in the respective proportion of 3:1. At 35 days after sowing, when the rootstock had two pairs of definitive leaves, they were transplanted into black polyethylene containers measuring 15 x 8 cm in height and diameter, respectively, with volume of 750 cm^3.

The substrate used was prepared by mixing the first 0.2 m of an Entisol with aged bovine manure in a ratio of 3:1 (v:v), respectively. The substrate was analyzed for chemical attributes (fertility) according to methodologies compiled by Teixeira et al. (2017), with the results presented in Table 1. Subsequently, fertilization with single superphosphate (20% P_2O_5, 20% Ca, 12% S) was carried out to raise the phosphorus content to 300 mg kg^{-1} (Novais et al., 1991).

The water was prepared by mixing strongly saline water (ECiw = 27.8 dS m^{-1}), collected in a tubular well in the municipality of Casserengue, Paraíba, Brazil, to non-saline water (ECiw = 0.3 dS m^{-1}), from the supply system of the municipality of Areia-PB, checked with a digital conductivity meter from Instrutherm, CD-850 model. Irrigation, after sowing and until one week after transplanting to the definitive containers, was carried out with non-saline water. Then, the water was used according to the treatments with a depth based on the evaporation of a mini tank installed inside the greenhouse, providing 100% of the evaporation (Pereira et al., 2007).

The evaluations were carried out at 7, 14, 21, 28 and 35 days after transplanting, with random sampling of two rootstocks per plot. The following variables were determined: height, distance between the collar and the apical bud of the stem, with a millimeter ruler; stem diameter at collar level, with digital caliper; number of leaves, by counting the expanded leaves; leaf

Table 1. Chemical attributes of the substrate used to produce *Passiflora foetida* rootstocks

pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	SB	$H^+ + Al^{3+}$	Al^{3+}	CEC	V	ESP	OM
	(mg dm^{-3})	(cmol$_c$ dm^{-3})								(%)		(g kg^{-1})
7.50	8.72	0.86	0.09	4.38	2.08	7.41	0.00	0.00	7.42	100	1.21	28.33

pH - Hydrogen potential in water (1:2.5); P - Phosphorus; K^+ - Potassium; and, Na^{2+} - Sodium with Mehlich 1 extractant; Ca^{2+} - Calcium; Mg^{2+} - Magnesium; and, Al^{3+} - Aluminum with 1 M KCl extractant; $H^+ + Al^{3+}$ - Hydrogen and aluminum with 0.5 M calcium acetate extractant at pH 7.0; SB - Sum of bases = $K^+ + Na^+ + Ca^{2+} + Mg^{2+}$; CEC - Cation exchange capacity = SB + $H^+ + Al^{3+}$; V - Base saturation = (SB/CEC) x 100; ESP - Exchangeable sodium percentage = (Na^+/CEC) x 100; OM - Organic matter = organic carbon x 1.724, Walkley-Black method area, using the method of images of leaf blades and processed in ImageJ software (National Institutes of Health, 2015); average leaf size, relationship between leaf area and number of leaves; and the mass of dry matter of the roots, shoot (stem + leaves) and total (root + shoot), after drying in an oven at 65 °C.

Data were initially analyzed for normality using the Kolmogorov-Smirnov test ($p \leq 0.05$), with the variables with continuous and discrete distribution transformed into functions $\log(y + 1)$ and $\sqrt{(x + 1)}$, respectively, when normality was not met. Then, the data were subjected to analysis of variance and polynomial regression. Statistical analyses were performed using SAS® University Edition software.

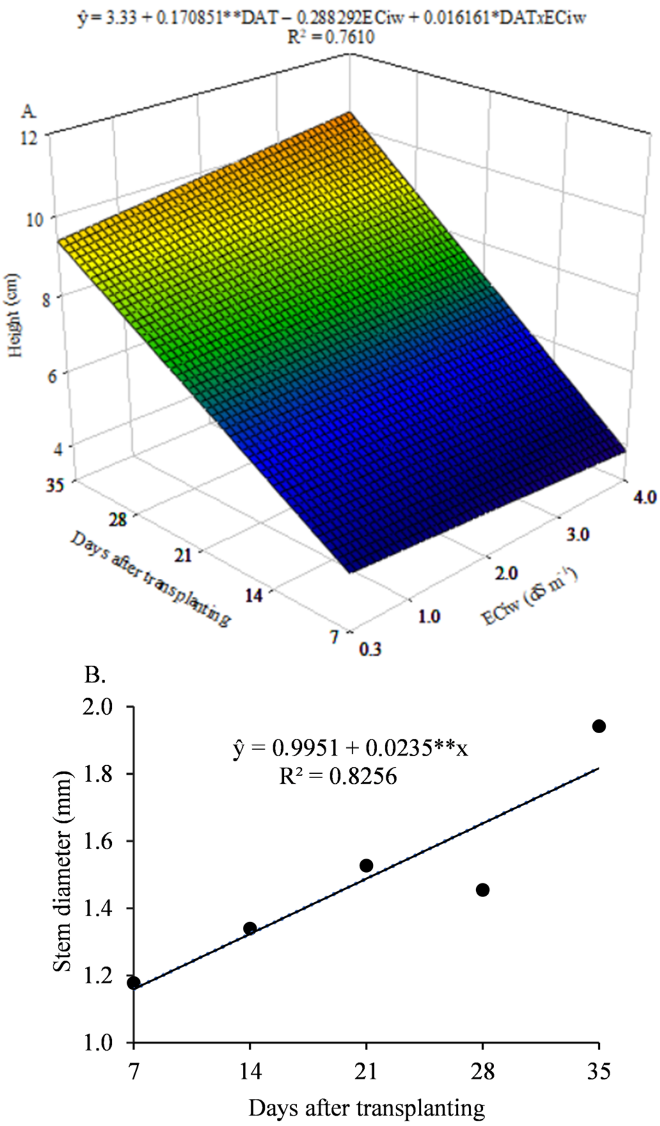
Results and Discussion

The interaction between the electrical conductivity of the irrigation water and the evaluation time was significant for most of the variables studied (height, stem diameter, leaf area, average leaf size and shoot dry matter, and total), except for the number of leaves, which was affected only by the evaluation period (Table 2).

The growth in height of the *P. foetida* rootstock decreased by 0.18 cm with a unit increase in the electrical conductivity of the irrigation water, in the evaluation carried out at seven days after transplanting, from 4.47 to 3.83 cm under irrigations with 0.3 and 4.0 dS m^{-1}, respectively (Figure 2A). The negative effect of salinity was observed only until 18 days after transplanting, increasing by 0.28 cm every 1 dS m^{-1} increment in the electrical conductivity of the water at 35 days after transplanting, increase from 9.39 to 10.42 cm with the increase in the electrical conductivity of water from 0.3 to 4.0 dS m^{-1}.

The growth in stem diameter of the *P. foetida* rootstock increased by 0.02 mm daily, an increase of 57% from 7 to 35 DAT, reaching a maximum of 1.82 mm (Figure 2B). Even if there was interference from the electrical conductivity of the irrigation water, there was no functional relationship of this factor alone ($F = 0.08$; $p = 0.7773$) nor associated with the evaluation times ($F = 0.20$; $p = 0.6562$).

With *P. edulis* (yellow passion fruit), a cultivated species, Oliveira et al. (2015), Nascimento et al. (2017) and Bezerra et al. (2019) obtained reductions in both height and diameter of the seedlings as a function of the electrical conductivity of the irrigation water. Oliveira et al. (2015) evaluated the cv. BRS Gigante Amarelo at 60 days after sowing and obtained reductions in height from 8.26 to 5.21 cm (-37%) and in diameter from 1.80 to 1.50 mm (17%) when increasing



* and ** - Significant at $p \leq 0.05$ and ≤ 0.01 by the F-test, respectively

Figure 2. Height of wild passion fruit (*Passiflora foetida* L.) rootstock as a function of electrical conductivity of irrigation water – ECiw and days after transplanting - DAT (A), and stem diameter as a function of days after transplanting (B)

the irrigation water conductivity from 0.3 to 3.5 dS m^{-1}, respectively.

The reductions with the cultivar Guinezinho (Nascimento et al., 2017) were 64% (20.8 to 7.5 cm) in height and 33% (2.7 to 1.8 mm) in the diameter of the seedlings evaluated at 60 days after emergence under the conductivities of 0.43 and 4.5 dS m^{-1}, respectively. As the electrical conductivity of irrigation

Table 2. Summary of analysis of variance (mean square) for height (H), stem diameter (SD), number of leaves (NL), average leaf size (ALS), leaf area (LA), and for matter of shoots (SDM), roots (RDM) and total (TDM) of *P. foetida* rootstocks as a function of electrical conductivity of irrigation water (ECiw) and days after transplanting (DAT)

SV	DF	H[1]	SD	NL[2]	ALS[1]	LA[1]	SDM[1]	RDM[1]	TDM[1]
Block	3	0.0124*	0.1554**	0.4401**	0.0000^{ns}	0.0490**	0.0056**	0.0012**	0.0051**
ECiw	4	0.0085*	0.0530^{ns}	0.0139^{ns}	0.0143^{ns}	0.0189*	0.0042**	0.0010**	0.0061**
DAT	4	0.3401**	1.6347**	2.0777**	0.4216**	1.3617**	0.0678**	0.0241**	0.1275**
ECiw × DAT	16	0.0210**	0.0658**	0.0454^{ns}	0.0254**	0.0373**	0.0017**	0.0009**	0.0024**
Residual	72	0.0033	0.0265	0.0395	0.0089	0.0070	0.0003	0.0002	0.0004
CV (%)		6.53	10.93	6.67	10.61	4.87	18.15	31.76	14.78
Mean		7.07	1.48	8.02	7.43	62.24	0.28	0.11	0.39

SV - Source of variation; DF - Degree of freedom; CV - Coefficient of variation; ^{ns}, * and ** - Non-significant and significant at $p \leq 0.05$ and 0.01 by the F test, respectively; [1] and [2] - Data transformed into the functions log (y + 1) and $\sqrt{(x + 1)}$, respectively, as they did not fit the normal distribution according to the Kolmogorov-Smirnov test ($p \leq 0.05$)

water increased from 0.3 to 4.0 dS m^{-1}, there were reductions of 58% (9.8 to 4.1 cm) in height and 28% (2.9 to 2.1 cm) in the diameter of the seedlings at 80 days after sowing, respectively (Bezerra et al., 2019).

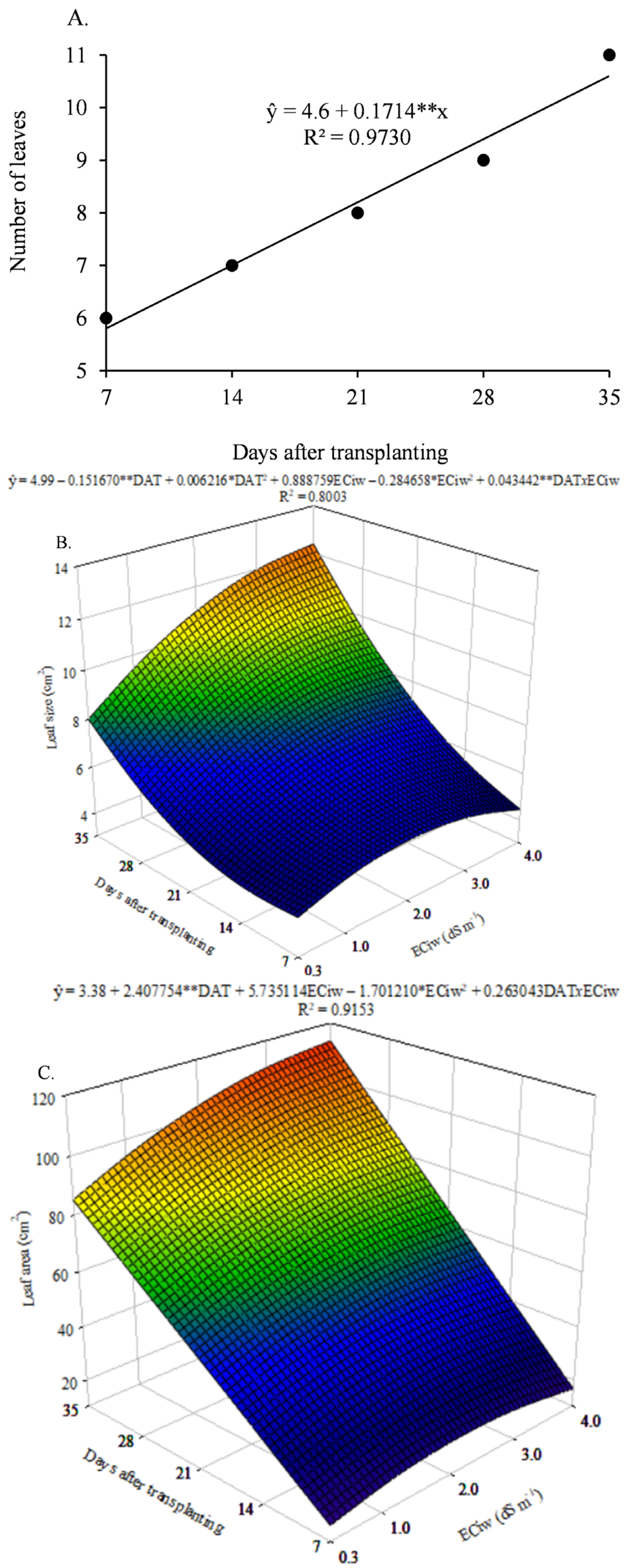
Thus, the potential of *P. foetida* under conditions of high content of soluble salts in water to the detriment of *P. edulis* is highlighted. For this wild species, in addition to having its growth in height stimulated by salinity, the values surpassed the averages obtained for *P. edulis* cultivars under high salinity levels. The positive effect of salinity on growth in height was observed from 18 days after transplanting, 11 days under irrigation with saline water (Figure 2A), a period possibly sufficient for the species to acclimatize. The presence of leaf trichomes and numerous leaf and petiolar glands in this species (Crochemore et al., 2003; Silva et al., 2013) possibly facilitate salinity tolerance. These structures, glands, papillae and trichomes, allow tolerance to excess salts through the salt exclusion mechanism (Hurtado-Salazar et al., 2018), as sodium exclusion or leaf tissue tolerance contribute to salinity tolerance (Kotula et al., 2019).

The salinity of the irrigation water had no effect on the production of leaves in *P. foetida* rootstocks (Table 2), with an effect only as a function of age, with a maximum of 11 leaves, an increase of 83% in the period from 7 to 35 days after transplanting (Figure 3A). The average size of leaves (Figure 3B) and leaf area (Figure 3C) increased with the increase in the electrical conductivity of the water, with greater increases in the older rootstocks.

The leaf components are correlated with each other, but with different intensities. Therefore, the variations between the effects of the electrical conductivity of irrigation water on *P. foetida*. Pearson's correlation between the number of leaves and the average leaf size was 0.35 ($t = 3.75$; $p = 0.0003$), that is, the variation of this represents only 13% (determination coefficient) of the variation in the number of leaves. Meanwhile, between the number of leaves and the leaf area, a correlation of 0.74 ($t = 11.01$; $p < 0.0001$) was obtained, meaning a variation of one component in relation to the other of 55%. The correlation between leaf size and leaf area was 0.86 ($t = 16.53$; $p < 0.0001$), representing that the variation in leaf size explains 74% of the variation in leaf area.

Plant development comprises the processes of growth, morphogenesis and knowledge. On the other hand, growth corresponds to the increase in size, resulting from the expansion and division of cells (Raven et al., 2014), so the greater leaf growth with increased water salinity and the non-difference between treatments for leaf development possibly occur because leaf growth depends on expansion and division, while leaf development depends on more processes.

In the first evaluations, it was observed that the increase in the electrical conductivity of the irrigation water restricted the growth of both leaves (Figure 3B) and leaf area (Figure 3C) of *P. foetida* rootstocks, being limited from the respective salinities of 2.2 and 2.1 dS m^{-1} at seven days after transplanting. However, from 30 days after transplanting, salinity only stimulated leaf growth and leaf area, leading to maximum averages of 8.00 cm^2 (Figure 3B) and 113.44 cm^{-2} (Figure 3C) at 35 days after transplanting under irrigation with water of 4.0 dS m^{-1}, increases of 55 and 33% compared to irrigation water conductivity of 0.3 dS m^{-1}, respectively.



* and ** - Significant at $p \leq 0.05$ and 0.01 by the F test, respectively

Figure 3. Number of leaves (A) in wild passion fruit (*Passiflora foetida* L.) rootstock as a function of days after transplanting, and leaf size (B) and leaf area (C) as a function of the electrical conductivity of the irrigation water – ECiw and the days after transplanting - DAT

For most species, the increase in the electrical conductivity of irrigation water impairs leaf components, such as the average number and size of leaves and leaf area. As an example, we can cite the seedlings of *Annona squamosa* (Silva et al., 2018b), *P. edulis* (Bezerra et al., 2019) and *Carica papaya* (Nascimento Neto et al., 2020).

Among the Passifloraceae species, *P. edulis* has both the number of leaves and the leaf area reduced even under low electrical conductivity of the irrigation water, for instance 0.3 dS m^{-1} (Bezerra et al., 2019). On the other hand, *P. foetida* had a positive effect of salinity (Figure 3), and its leaf area surpassed that of *P. edulis* under irrigation with the same level of electrical conductivity of the water (4.0 dS m^{-1}) and evaluated at 80 days after sowing (Bezerra et al., 2019).

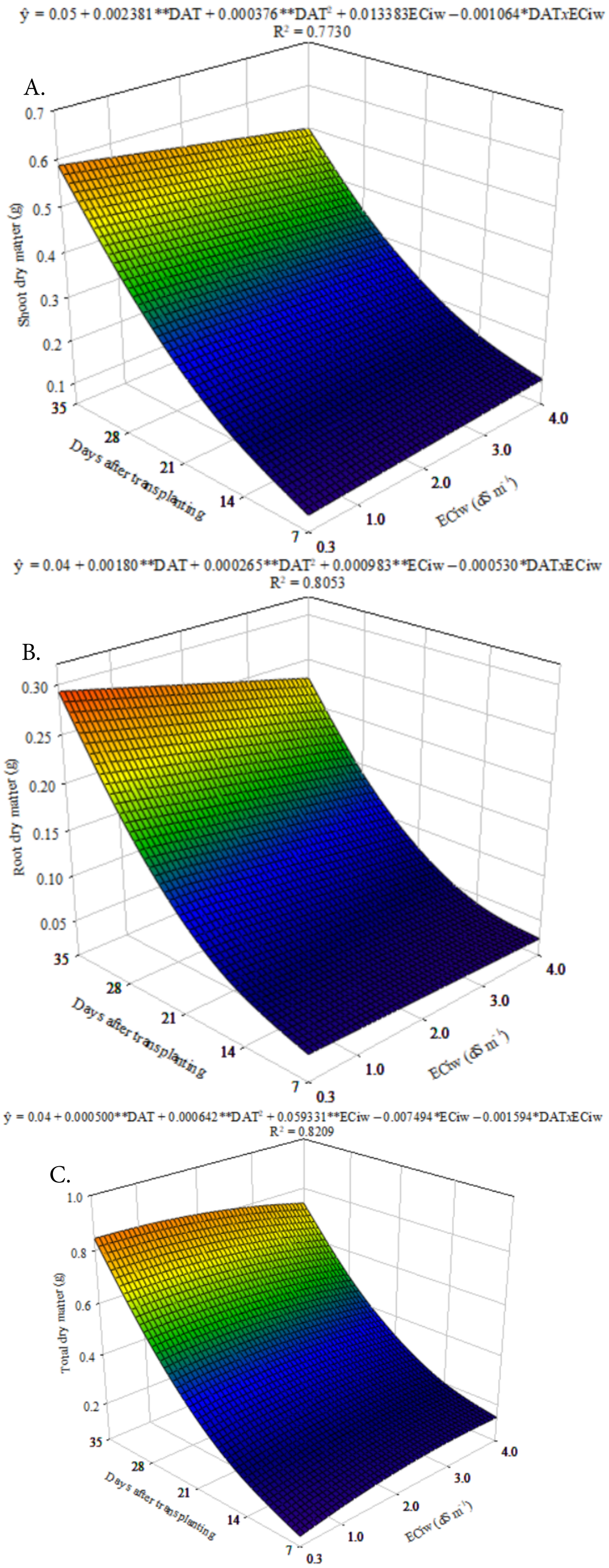
P. tarminianam, considered salinity tolerant, uses the mechanism of salt excretion through the lower leaves, possibly through the salt excretory glands, in addition to papillae and trichomes (Hurtado-Salazar et al., 2018). This is probably also one of the mechanisms of *P. foetida*, which has morphological characteristics similar to those of *P. tarminianam* (Crochemore et al., 2003; Silva et al., 2013).

The shoot dry matter accumulation of the *P. foetida* rootstock, from 13 days after transplanting, decreased with the increase in the electrical conductivity of the irrigation water (Figure 4A). At 35 days after transplanting, the highest rate of reduction was obtained, estimated at 23.86 mg for each 1 dS m^{-1} increase in the electrical conductivity of the water, a reduction from 0.59 to 0.50 g, loss of 15%, with the respective electrical conductivities of water of 0.3 and 4.0 dS m^{-1}.

The dry matter of the roots showed a reduction since the first evaluation, intensifying in the following evaluations, with estimated loss of 2.73 and 17.57 mg for each unit increase in the electrical conductivity of the irrigation water at 7 and 35 days after transplanting, respectively (Figure 4B). At 35 days after transplanting, 0.29 and 0.23 g (-21%) of root dry matter were obtained when the rootstock was irrigated with water of 0.3 and 4.0 dS m^{-1}, respectively.

The total dry matter increased with the evaluated times, regardless of the electrical conductivity of the irrigation water, with the tolerance limit depending on the age of the seedlings (Figure 4C). At seven days, a reduction in the total dry matter of the rootstock was obtained from the irrigation water conductivity of 3.2 dS m^{-1}, while at 35 days after transplanting this limit was 0.3 dS m^{-1}. In this last evaluation, 0.84 and 0.74 g of total dry matter were obtained, a loss of 12%, when the rootstock was irrigated with water of 0.3 and 4.0 dS m^{-1} of electrical conductivity, respectively.

The reduction in the biomass production of seedlings of passion fruit, as in *P. edulis*, has been observed in numerous studies (Ribeiro et al., 2013; Bezerra et al., 2014; Nascimento et al., 2017; Souza et al., 2020). The classification of salinity tolerance by plants is a function of production loss (Fageria et al., 1985), which can be based on yield, biomass or other characteristic of interest. Continuous irrigation with saline water in the production of passion fruit seedlings increases the concentration of salts in the substrate, indirectly measured by the conductivity of the saturation extract (Bezerra et al., 2014). This excess of salts caused negative osmotic effects, as



* and ** - Significant at $p \leq 0.05$ and 0.01 by the F-test, respectively

Figure 4. Shoot dry matter (A), root (B) and total (C) of wild passion fruit (*Passiflora foetida* L.) rootstock as a function of the electrical conductivity of irrigation water – ECiw and of days after transplanting - DAT

it hinders the absorption of water, in addition to being toxic to plants through the excessive accumulation of ions.

Excess salts alter the physiology of seedlings, reducing stomatal conductance, transpiration and net assimilation of carbon dioxide (Silva et al., 2019). Thus, it leads to less accumulation of biomass, as evidenced in this study. However, it is necessary to quantify these losses in order to indicate a viable irrigation water conductivity level.

According to Fageria (1985), with a loss of up to 20% in yield, the crop can be classified as tolerant. For this study, the biomasses with variable classification regarding tolerance were considered. As at 35 days after transplanting, the seedlings lost 12% in total dry biomass (Figure 4C) and 15% in shoot dry matter (Figure 4A), under the electrical conductivity of irrigation water of 4.0 dS m^{-1}, *P. foetida* rootstocks were classified as salinity tolerant.

Conclusions

1. The effect of irrigation water electrical conductivity on *Passiflora foetida* L. rootstock production is related to seedling age.

2. To produce *P. foetida* L. rootstocks, water with electrical conductivity of up to 4.0 dS m^{-1} can be used, based on height growth, leaf growth, and dry biomass accumulation in shoots and total, so it is a species considered tolerant to salinity.

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