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CRESCIMENTO E DESENVOLVIMENTO DE CULTIVARES DE FEIJÃO-CAUPI EM FUNÇÃO DA SALINIDADE DA ÁGUA DE IRRIGAÇÃO

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1 RESUMO

A salinidade do solo e da água constituem uma das principais restrições abióticas na produção de alimentos. O presente trabalho foi desenvolvido na Universidade Federal do Piauí, em Alvorada do Gurguéia, PI, com o objetivo de avaliar o efeito da salinidade da água de irrigação na morfofisiologia de cultivares de feijão-caupi. Foram estudados cinco níveis de salinidade da água de irrigação (0,01, 1,41, 2,81, 4,21 e 5,61 dS m^{-1}); três cultivares: BRS Tumucumaque, BRS Guariba e BRS Imponente em dois períodos de cultivo. Utilizou-se o delineamento em blocos completos casualizados no esquema de parcelas subsubdivididas, com quatro repetições. Foram avaliados massa seca da parte aérea (MSPA), área foliar (AF), índice de área foliar (IAF), taxa de crescimento da cultura (TCC), taxa de crescimento relativo (TCR) e taxa de assimilação liquida (TAL). Houve efeito significativo da interação entre os fatores em todas as variáveis analisadas. MSPA, AF e IAF aos 25 DAS (dias após a semeadura), apresentaram reduções lineares aos aumentos da salinidade. BRS Tumucumaque apresentou maior tolerância aos efeitos da salinidade na fase final de crescimento, com os maiores índices de salinidade limiar para TAL, TCR e TCC. Enquanto a BRS Guariba foi mais tolerante na fase inicial de crescimento.

Palavras-chave: *Vigna unguiculata*, estresse salino, morfologia.

SILVA JÚNIOR, J. V. S.; BEZERRA, A. A. C.; SILVA, E. M.
GROWTH AND DEVELOPMENT IN COWPEA CULTIVARS IN FUNCTION OF IRRIGATION WATER SALINITY

2 ABSTRACT

The salinity of soil and water is one of the main abiotic restrictions in food production. This present study was developed at the Federal University of Piauí, in Alvorada do Gurguéia, PI, Brazil, with the objective to evaluate the effect of irrigation water salinity on the morphophysiology of cowpea cultivars. Five salinity levels of the irrigation water were

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studied (0.01, 1.41, 2.81, 4.21, and 5.61 dS m^{-1}); three cultivars: BRS Tumucumaque, BRS Guariba and BRS Imponente in two cultivation periods. A randomized complete block design was used in the split-split plot arrangement, with four replications. Dry mass aerial part (MSPA), leaf area (AF), leaf area index (IAF), crop growth rate (TCC), relative growth rate (TCR) and liquid assimilation rate (TAL) were evaluated. There was a significant effect of the interaction between factors in all variables analyzed. MSPA, AF and IAF at 25 DAS (days after sowing), showed linear reductions to increases in salinity. BRS Tumucumaque showed greater tolerance to the salinity effects in the final growth phase, with the highest threshold salinity indexes for TAL, TCR and TCC. While the BRS Guariba was more tolerant in the initial growth phase.

Keywords: *Vigna unguiculata,* saline stress, morphology.

3 INTRODUCTION

Soil and water salinity and their associated problems constitute one of the main abiotic constraints on global food production and are particularly critical in semiarid and arid regions (MINHAS et al. , 2020) . In these regions, where water scarcity is recurrent, saline groundwater is used in irrigated agriculture (HOFFMAN; SHALHEVET, 2007; MINHAS; GUPTA, 1992; RHOADES; KANDIAH; MASHALI, 1992, 2000) and/or wastewater reuse (QADIR et al., 2010; TANJI; KIELEN, 2002) is common practice .

More than 20% of cultivated land worldwide is affected by salinity stress, and 25% of the groundwater used for irrigation is considered saline (GUPTA; HUANG, 2014; SADEGHIPOUR, 2017) . In Brazil, saline areas are predominant in the Northeast Region or, more specifically, in the “Drought Polygon”, which makes up 57% of the total area of the semiarid region where the irrigated perimeters are located (SÁ, 2016) .

Owing to its importance as a source of employment and income and its nutritional potential, high protein, energy, dietary fiber and mineral content, as well as its ease of production and accessibility, cowpea [*Vigna unguiculata* (L.) Walp.] is one of the main food crops cultivated, especially in tropical and subtropical regions that present rainfall instability and low technological levels, as is the case for some locations in the Northeast Region of Brazil (BEZERRA et al., 2014; FROTA; SOARES; ARÊAS, 2008; ROCHA et al., 2009) .

The area cultivated with cowpea in Brazil in the 2018/2019 harvest was approximately 1,276.2 thousand hectares, with an estimated production of 637.7 thousand tons (FEIJÃO, 2019) . In Northeast China, despite being the main producing region, irrigation is needed to obtain satisfactory yields. (BEZERRA et al., 2010; SÁ et al., 2017) .

Cowpea is classified as moderately tolerant to irrigation water salinity, with a threshold salinity of 3.3 dS m $^{-1}$ (AYERS; WESTCOT, 1999) . Researchers have reported that the use of saline water for irrigation causes an increase in soil salinity, reducing the processes of absorption, transport, assimilation and distribution of nutrients, resulting in a reduction in plant development and yield as a result of reduced photosynthesis, transpiration and stomatal conductance (BEZERRA et al., 2010; NEVES et al., 2009; SADEGHIPOUR, 2017; SILVA et al., 2013, 2011) .

The ability of plants to adapt to the effects of salt includes changes at the leaf level related to their morphological, physiological and biochemical characteristics, according to which numerous plants adapt to high salinity and low water availability in the soil (ÇIÇEK; ÇAKIRLAR, 2008). Some Cowpea varieties were developed to adapt to certain abiotic diversities, such as drought, salinity and high amounts of temperature and radiation (SILVEIRA et al., 2003) , which, alone or together, can cause oxidative damage to plants (FOYER; NOCTOR, 2000) .

Cowpea growth depends directly on the leaf area and dry matter accumulated by the plant, since these factors represent the “factory” and the “final product”, respectively (BEZERRA, 2005) . However, the large amount of accumulated biomass will not always be transformed into a high grain yield because vegetative development is more favored in soils with high nutrient levels, especially nitrogen, which are constantly moist than as a result of the formation of pods and grains (FREIRE FILHO et al. , 2005) .

Therefore, it is assumed that irrigation water salinity influences the morphological and growth variables of cowpea cultivars. Therefore, the objective of this study was to evaluate the effects of irrigation water salinity on the morphophysiological traits of three cowpea cultivars.

4 MATERIAL AND METHODS

The experiment was carried out under irrigated cultivation in the experimental area of the Alvorada do Gurguéia School Farm - FEAG, belonging to the Federal University of Piauí (UFPI), in the municipality of Alvorada do Gurguéia-PI, located at 08° 22' 28”S, 43° 51' 34”W and 229 meters above sea level, from August 20--30, 2017 (first cultivation), and from August 25--4, 2018 (second cultivation). The climate of the region, according to the Thornthwaite and Mather classification, is classified as C1, which is characterized as dry subsumed, megathermal, with a small water surplus (ANDRADE JÚNIOR et al ., 2004) .

The soil of the experimental area was classified according to the Brazilian soil classification system (SANTOS et al. , 2013) as Neossolo Quartz sand. Before being planted in the first crop, a composite soil sample was collected from the 0.00–0.20 m layer, and in the second crop, a composite sample was collected from the 0.00–0.20 m layer of each plot for physicochemical characterization of the soil in the experimental area at the Soil Laboratory of the Professora Cinobelina Campus. Elvas of the Federal University of Piauí - CPCE/UFPI (Tables 1 and 2), according to the methodology described in the Soil Analysis Methods Manual (TEIXEIRA et al., 2017) . For the composite sample of the first crop, sixty simple samples were randomly collected in the experimental area. For the composition of the composite samples in August 2018, twelve simple samples were randomly collected, three per plot per replicate.

Table 1the first planting of the crop. Alvorada do Gurguéia, PI. August 2017.

pH	H+Al	Al	Here	Mg	SB	T	PST	MO
H_2O	------------------------	cmol $_c$ dm $^{-3}$	-----------------------				%	g kg $^{-1}$
5.8	1.05	0.00	1.36	0.10	1.46	2.52	0.00	5.5
P	K	In the	V	m	Clay	Silt		Sand
------------ mg dm $^{-3}$ --------			-------%-------		---------------- g/kg ----------------			
11.42	12.15	0.00	56.4	0.0	75	14		910

SB = sum of exchangeable bases; T = cation exchange capacity at pH 7.0; PST = percentage of exchangeable sodium; MO = organic matter; V = base saturation index; m = aluminum saturation index.

Table 2 Second planting of the crop. Alvorada do Gurguéia, PI. August 2018.

Install ment	**pH**	**H+Al**	**Al**	**Her e**	**Mg**	**SB**	**T**	**PST**	**MO**
	H_2O	**--------------------**	**cmol $_c$ dm $^{-3}$**	**--------------------**				**%**	**g kg $^{-1}$**
CE $_0$	6.3	1.33	0.00	1.66	0.12	1.82	3.15	0.40	5.6
CE $_1$	5.4	1.05	0.00	1.63	0.12	1.93	2.98	5.13	5.4
CE $_2$	6.1	1.26	0.00	1.62	0.12	2.04	3.30	8.11	5.7
CE $_3$	6.2	0.96	0.00	1.60	0.13	2.15	3.11	12.68	5.6
CE $_4$	6.1	1.14	0.00	1.59	0.12	2.32	3.46	16.83	5.7
Install ment	P	K	In the	V	m	Clay		Silt	Sand
	-------- mg dm $^{-3}$ --------			-------%-----		--------------- g/kg --------------			
CE $_0$	11.05	11.03	2.90	57.8	0.0	76		13	910
CE $_1$	11.18	11.07	35.14	64.8	0.0	77		11	911
CE $_2$	11.70	11:30	61.45	61.8	0.0	74		17	908
CE $_3$	10.95	10.58	90.76	69.1	0.0	76		11	912
CE $_4$	11.43	10.94	133.96	67.1	0.0	71		18	910

SB = sum of exchangeable bases; T = cation exchange capacity at pH 7.0; PST = percentage of exchangeable sodium; MO = organic matter; V = base saturation index; m = aluminum saturation index.

Five salinity levels of irrigation water with electrical conductivity (EC) equal to 0.01 (EC_0, water from the artesian well that supplies FEAG), 1.41 (EC_1), 2.81 (EC_2), 4.21 (EC_3) and 5.61 (EC_4) dS m^{-1} (main factor), and three cowpea cultivars (C) (secondary factor) were studied: BRS Tumucumaque (C_1), BRS Guariba (C_2) and BRS Imponente (C_3), during two growing periods (PCs) (tertiary factors): 2017 and 2018.

Cowpea cultivars were chosen for this study because they belong to the same commercial class, have the same maturity period, and have the same growth rate. Furthermore, the studied cultivars present good grain yields in both rainfed and irrigated crops, and 'BRS Imponete', despite being a new cultivar on the market, has export potential (Table 3).

Table 3 cowpea cultivars used in the experiment. Alvorada do Gurguéia, PI. August 2017 **.**

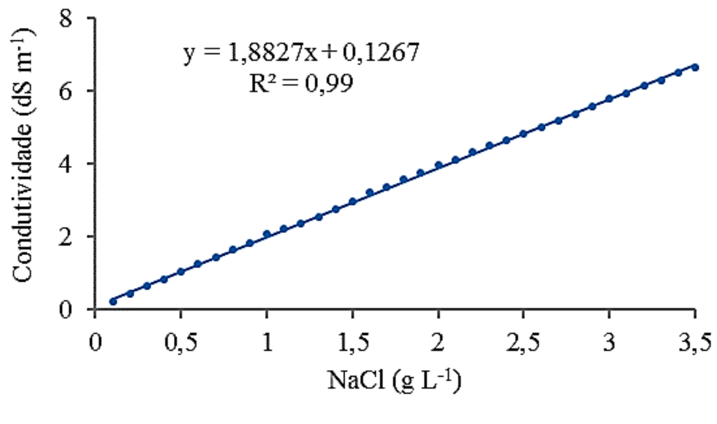
Cultivate	Commercial Class	Maturation cycle (days)	Plant size	Mass of 100 grains (g)	Performance of grains (kg ha $^{-1}$)
BRS Tumucumaque	White	67-70	Semierect	19.5	1,100 *
BRS Guariba	White	65-70	Semierect	19.5	1,475 **
Imposing BRS	White	65-70	Semierect	34.4	1,027 ***

Source: Embrapa - * = average North, Northeast and Central-West; ** = average Piauí, rainfed cultivation; *** = under experimental conditions and under irrigation.

The total area occupied by the experiment was 1,350.00 m2 (45 × 30 m). The plots measured 9 × 6 m (54.0 m^2), and the subplots measured 3 × 6 m (18.0 m^2), with a useful area of 10.00 m2 (2 × 5 m). The subplots consisted of six rows of plants, with the useful area formed by the four central rows of each subplot, of which the two central rows were used for nondestructive evaluations and the two lateral rows were used for destructive evaluations. The spacing adopted was 0.50 m between rows and 0.10 m between plants within the row, with a population of 200,000 plants ha^{-1}. A randomized complete block design was used in a split-subdivided plot scheme, with four replications.

The predefined EC levels were obtained by adding salt (NaCl) to the irrigation water, considering the artificial salinity curve (Figure 1). NaCl was diluted in 30 disposable cups of 200 mL at concentrations of 0.1 to 3.0 g NaCl L^{-1}, with an interval between dilutions of 0.1 g L^{-1}, and EC readings were taken with the aid of a conductivity meter (Model ION Con500). With the data obtained, an equation was constructed, from which the mass of NaCl to be added to the water to obtain the EC of each level was determined.

Figure 1 Artificial salinity curve. Alvorada do Gurguéia, PI. 2017**.**



As the EC is influenced by the environment, even with the mass of NaCl for each level defined by the equation, it was necessary to observe the behavior of the EC after the solutions were prepared, making, when necessary, adjustments to the mass values to start the experiments.

The germplasm bank of the Cowpea Improvement Program of the Brazilian Agricultural Research Corporation (Embrapa) Meio-Norte was subjected to chemical treatment through the use of fipronil + thiophanate methyl + pyraclostrobin at a proportion of 200 mL/100 kg of seeds to avoid attack by pathogens present in the soil and/or insects.

Sowing was carried out manually on August 20, 2017 (first crop), and on August 25, 2018 (second crop), with two seeds distributed per hole to ensure a preestablished initial stand. Thinning was carried out ten days after sowing (DAS), leaving only one plant per hole. During thinning, excess plants were cut below the cotyledonary node, thus avoiding regrowth and damage to the root system of the remaining plants. At 15 DAS, salt stress began.

In the first cycle, the area was cleared, and the soil was prepared via a rotary hoe followed by plowing. In the second cycle, hand hoes and rakes were used to remove plant debris from the experimental area. To preserve the irrigation system and maintain the same plot and subplot demarcation as in the previous period, no plowing was performed in the second period. Soil amendments and/or chemical or organic fertilizers were not applied during either period.

Weed control was achieved through two manual weeding sessions (at 18 and 32 DAS) involving hoes in and around the experimental area. Weeds were manually removed to avoid competition with the crop for water and nutrients.

For insect pest control, a survey of the entomofauna was carried out from the first week after germination through weekly sampling throughout the crop cycle. Twenty (20) plants/subplot were randomly sampled, after which the number of plants infested with insect pests was quantified.

Insecticide applications were carried out for the first crop (2017) at 17, 28, 37, 44 and 52 DAS and at 22, 36 and 50 DAS for the second crop (2018), depending on the success in terms of pest control, using neonicotinoids at a dose of 69.6 g ai/ha.

The trial was conducted with a surface drip irrigation system. To compose the irrigation system, drip tape was used with a spacing of 0.50 m between lines and 0.30 m between emitters, a nominal emitter flow rate of 1.6 L h $^{-1}$, 50 mm weldable PVC pipes for the main branch (feeder network) and 32 mm for the secondary branches, 50 and 32 mm ball valves to control the opening and closing of the water, a pressure gauge and a hydrometer installed at the beginning of each plot to control the pressure and flow of the water administered in each plot, a screen filter to contain possible particles that could cause clogging of the drippers, a water tank with a capacity of 15,000 liters for storing well water, five water tanks with volumes of 1000 L each for storing/handling the water mixtures at the saline concentrations established for irrigation (according to the saline levels presented), a piezometer graduated, installed in each water tank (1000 L) to correctly measure the volume of water to be applied in each treatment and a 1/3 hp centrifugal pump installed to pump water from the water tanks to the irrigation system.

Before planting, the soil was irrigated until it reached field capacity. Irrigation management was carried out via reference evapotranspiration (ETo) and the crop coefficient (Kc). Kc values were determined considering the recommendations in the literature for the different phenological stages (BASTOS et al ., 2008) . Throughout the crop cycle, the rule was implemented daily, with the application of replacement depths equivalent to 100% crop evapotranspiration (ETc).

The irrigation depths were calculated via an electronic spreadsheet, in which the daily ETo values were recorded via the Penman–Monteith method, which uses climate data (Figures 2 and 3) obtained from an automatic agrometeorological station belonging to the National Institute of Meteorology (INMET), which is installed in the municipality of Alvorada do

Gurguéia, PI, approximately 7 km from the experimental area.

Figure 2. Average temperature (Tmed), average relative humidity (URmed), reference evapotranspiration (ETo), crop evapotranspiration (ETc) and precipitation. Alvorada do Gurguéia, PI. 2017 .

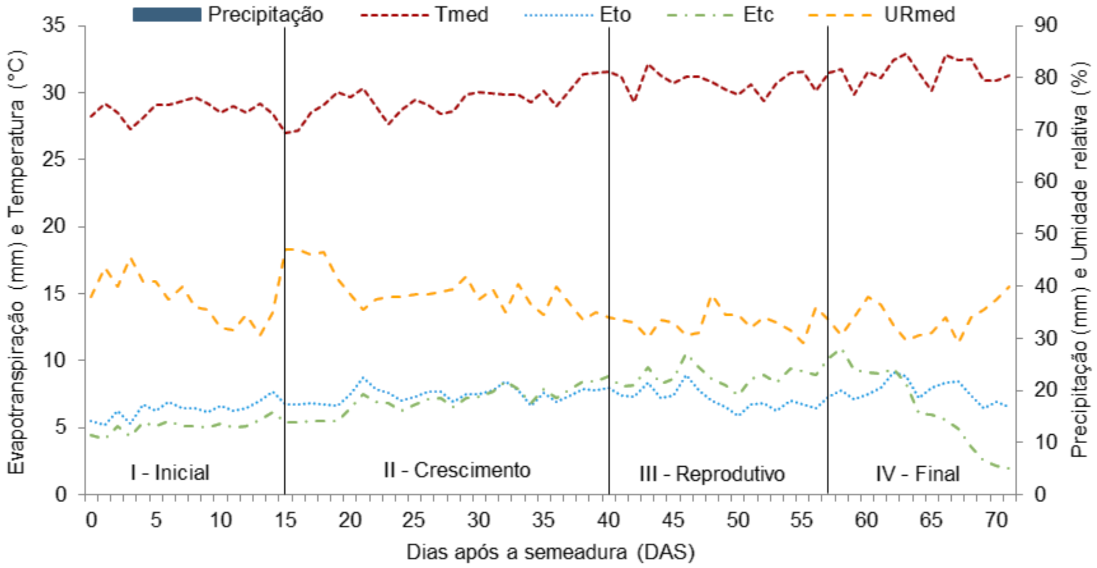
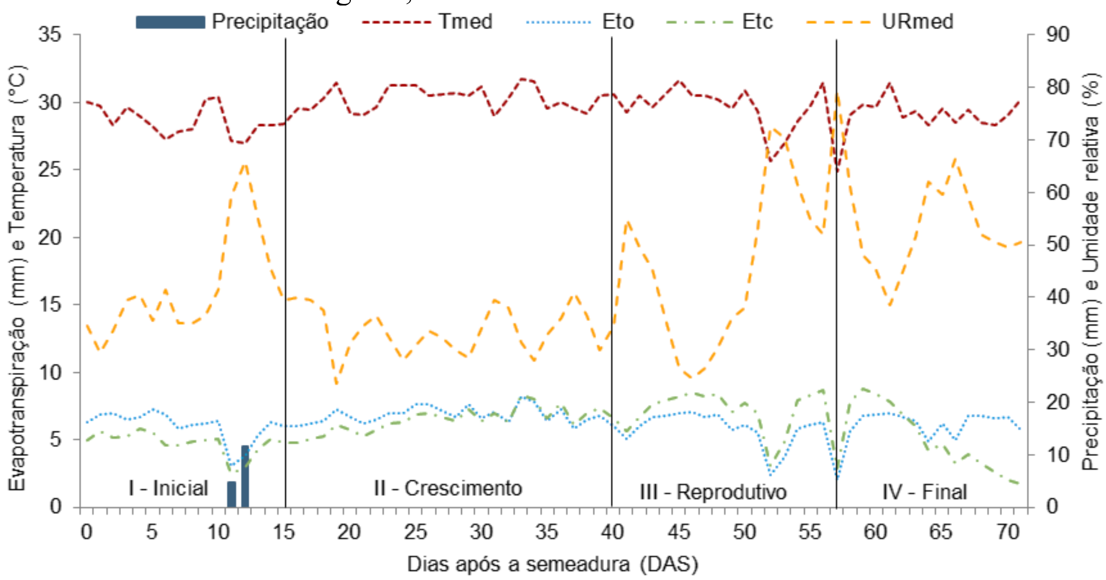


Figure 3. Average temperature (Tmed), average relative humidity (URmed), reference evapotranspiration (ETo), crop evapotranspiration (ETc) and precipitation. Alvorada do Gurguéia, PI. 2018 .



The quantities of water to be used in each treatment were stored in 1,000 L water tanks prior to each irrigation cycle, according to the volume to be applied. The salts were weighed on a 0.1 g precision scale, dissolved in 20 L buckets, and then immediately added to the water tanks at the corresponding salinity levels, after which they were mixed thoroughly to ensure good homogenization. The EC was measured through daily readings via a portable conductivity meter to maintain and better control the salinity levels of each treatment throughout each growing cycle. The application of saline stress began at 15 DAS.

At 25 and 40 DAS, the following variables were evaluated: aerial part dry mass (ADM, in g); leaf area (LA, in cm²); leaf area index (LAI); crop growth rate (CGR, in g $^{m^2}$ day $^{-1}$); relative growth rate (RGR, gg $^{-1}$ day $^{-1}$); and net assimilation rate (NGR, in g m² day $^{-1}$).

The crop growth rate was obtained via Equation (1):

$$TCC = \frac{MS_2 - MS_1}{S} \cdot \frac{1}{T_2 - T_1} \quad (1)$$

where DM_1 and DM_2 are the average dry matter of the aerial parts of four plants per plot at 25 and 40 DAS, respectively; S is the area of the land occupied by the plant; and t_1 and t_2 are the times in days corresponding to 25 and 40 DAS, respectively.

The relative growth rate was obtained via Equation 2:

$$TCR = \frac{ln\, MS_2 - ln\, MS_1}{T_2 - T_1} \quad (2)$$

where ln is the Napierian logarithm; DM $_1$ and DM $_2$ are the dry matter of the aerial part at 25 DAS and 40 DAS, respectively; and $_1$ and t $_2$ are the times in days that correspond to 25 DAS and 40 DAS, respectively.

The net assimilation rate was obtained via Equation 3:

$$TAL = \frac{MS_2 - MS_1}{A_2 - A_1} x \frac{lnA_2 - lnA_1}{t_2 - t_1} \quad (3)$$

where DM_1 and DM_2 are the dry matter of the aerial part at 25 and 40 DAS, respectively, in g; A_1 and A_2 are the leaf areas of the plant at 25 and 40 DAS, respectively, in m^2; t_1 and t_2 are the times in days that correspond to 25 and 40 DAS, respectively; and ln is the Napierian logarithm.

The leaf area was determined via the disc method, which uses a punch with an area of 6.26 cm^2, with ten leaf discs per plant being computed (SOUZA et al., 2012). The leaf discs and the remaining aerial parts of the plant were subsequently packaged separately in paper bags and placed in a forced air circulation oven at 65 °C for 72 hours. After the drying period, the samples (leaf discs, leaves and stems) were weighed via an analytical balance (0.001 g). The dry mass of the aerial part was obtained by the sum of the masses obtained from the samples described above.

The data were subjected to analysis of variance, applying the F test at 5% probability to verify the significant effect, or not, of each factor and the interaction between them on the evaluated variables. For the qualitative factor, the Tukey test at 5% probability was applied via the SISVAR statistical program (FERREIRA, 2011) . For the quantitative factor, regression analysis was performed, choosing between the linear and quadratic models, which best fit the data on the basis of the observed significance level and the highest coefficient of determination.

5 RESULTS AND DISCUSSION

The analysis of variance revealed that there was a significant interaction effect ($p<0.01$) between the electrical conductivity of irrigation water (EC), cultivar (C) and cultivation period (PC) for the variables dry mass of the aerial part (MSPA $_{25}$), leaf area (AF $_{25}$) and leaf area index (IAF $_{25}$) according to the F test, which was evaluated at 25 DAS. The coefficients of variation (CVs) ranged from 1.22 to 4.65%, indicating excellent precision of the results obtained (Table 4).

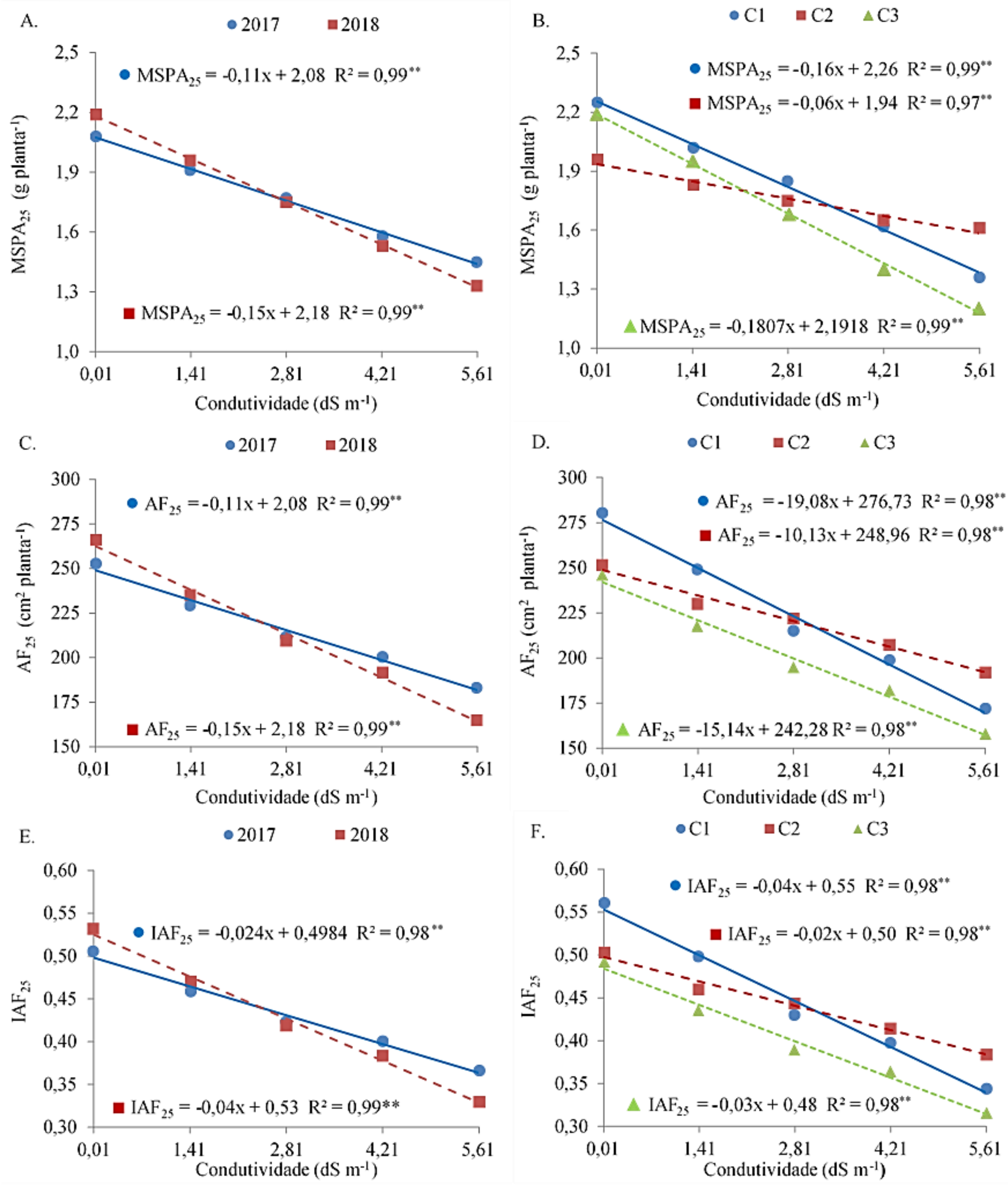
Table 4. Summary of analyses of variance for shoot dry mass ($MSPA_{25}$), leaf area (AF_{25}), and leaf area index (IAF_{25}) of three cowpea cultivars (C) subjected to five levels of irrigation water electrical conductivity (EC) and two growing periods (PCs) at 25 days after sowing (DAS). Alvorada do Gurguéia, PI. 2019.

Source of Variation	GL	Mean Squares [1]		
		$MSPA_{25}$	**AF_{25}**	**IAF_{25}**
Block	3	$7x10^{-3ns}$	55.10^{ns}	$2x10^{-4ns}$
Electrical conductivity (EC)	4	2.10^{**}	25959.82^{**}	0.10^{**}
Residue 1	12	$7x10^{-3}$	26.53	$1x10^{-4}$
Cultivar (C)	2	0.18^{**}	6563.59^{**}	0.03^{**}
CE x C	8	0.16^{**}	850.84^{**}	$3x10^{-3**}$
Residue 2	30	$5x10^{-3}$	13.21	$5x10^{-5}$
Cultivation period (CP)	1	$7x10^{-4ns}$	129.65^{**}	$5x10^{-4**}$
CE x PC	4	0.05^{**}	905.87^{**}	$4x10^{-3**}$
C x PC	2	$2x10^{-3ns}$	2.17^{ns}	$1x10^{-5ns}$
CE x C x PC	8	$2x10^{-3**}$	20.33^{*}	$8x10^{-5**}$
Residue 3	45	$6x10^{-4}$	6.95	$3x10^{-5}$
Averages	-	1.75 (g)	214.44 (cm²)	0.43
CV_1 (%)	-	4.65	2.40	2.43
CV_2 (%)	-	4.03	1.69	1.69
CV_3 (%)	-	1.45	1.23	1.22

[1] CE, in dS m^{-1}; CV_1 = coefficient of variation for plot; CV_2 = coefficient of variation for subplot; CV_3 = coefficient of variation for subplot; ^{ns} = not significant; *, ** = significant at the 5% and 1% probability levels, respectively.

An analysis of the dry mass of the aerial parts evaluated at 25 DAS ($MSPA_{25}$) in terms of the interaction between the electrical conductivity of the irrigation water (EC 0.01 to 5.61 dS m^{-1}) and the cultivation period (PC 2017 and 2018) verified that the three cultivars presented significant linear reductions ($p < 0.01$), with an average of 30.3% in the first cultivation and 39.3% in the second cultivation (Figure 4A and B).

Figure 4. A) and B) Dry mass of the aerial part (MSPA $_{25}$), C) and D) leaf area (AF $_{25}$) and E) and F) leaf area index (LAI) at 25 days after sowing (DAS) of three cowpea cultivars: BRS Tumucumaque (C $_{1}$), BRS Guariba (C $_{2}$) and BRS Imponente (C $_{3}$), subjected to five levels of electrical conductivity of irrigation water (EC) in two growing periods (2017 and 2018). Alvorada do Gurguéia, PI. 2019.



Significant linear reductions ($p<0.01$) in MSPA $_{25}$ were detected in the interaction between increased salinity, represented by EC, and cowpea cultivar. The BRS Imponente cultivar was the most sensitive to increases in salinity, presenting the greatest reduction (45.2%), whereas the BRS Guariba cultivar presented the smallest reduction (17.9%), which allows us to infer that among the three cultivars analyzed, the BRS Guariba cultivar presented greater stability to the negative effects of increases in the EC of irrigation water (Figure 4B).

Oliveira et al. (2013) and Silva *et al.* (2009) worked with studied cowpea genotypes subjected to saline stress and reported a decrease in leaf and stem dry matter when subjected to increases in EC. Aquino et al. (2017) evaluated the effects of irrigation water salinity on three cowpea genotypes and reported average reductions of 45.8 and 44.2% in leaf dry matter and stem dry matter, respectively, when the EC increased from 0.55 to 4.80 dS m^{-1}. Sousa et al. (2010) evaluated the morphophysiological responses of some crops, including cowpea, to saline stress, and the authors reported reductions in shoot dry matter on the order of 69.0% as the EC level increased to 8.0 dS m^{-1}.

The increase in EC promoted significant linear reductions (p<0.01) in the leaf area evaluated at 25 DAS (AF_{25}) in the three cowpea cultivars, with averages of 27.5% in the first crop and 38.0% in the second crop (Figure 4C and D). The cv. BRS Tumucumaque was the most sensitive to the effects of salinity, presenting the greatest reduction (38.6%), whereas the cv. BRS Guariba presented the smallest reduction (23.7%), indicating that this cultivar presented the greatest balance among the three cultivars evaluated in terms of the negative effects of increases in the EC of the irrigation water (Figure 4D).

These data are similar to those reported by Aquino et al. (2017) , who evaluated the morphophysiological responses of cowpea genotypes with respect to irrigation water salinity and observed linear decreases at 25 DAS, with a 30.9% reduction in AF at the level of 6.4 dS m^{-1} of EC in the irrigation water.

According to Tester and Davenport (2003) , the decrease in leaf area is possibly related to one of the plant's adaptation mechanisms to saline stress, which aims to reduce the transpiring surface area. According to Oliveira et al. (2012) and Feitosa et al. (2015) , plants subjected to saline stress present morphological and anatomical changes, such as reductions in leaf area. Such modifications are important for maintaining high water potential in the plant, which is obtained through the reduction of the transpiration process.

A significant effect (p<0.01) was observed for the electrical conductivity of the irrigation water and cultivation period for the LLAI at 25 DAS (LAI_{25}) (Table 4). The increase in the electrical conductivity of the irrigation water linearly reduced the LAI_{25} of the cowpea plants, which presented an average of 27.5% in the first cultivation period (2017) and 38.0% in the second period (2018) (Figure 4E).

The electrical conductivity level had a significant interaction effect (p<0.01) with cultivar for the LAI_{25} (Table 4). The cv. BRS Tumucumaque was the most sensitive to the effects of salinity, presenting the greatest reduction (38.7%), whereas the cv. BRS Guariba presented the smallest reduction (23.7%) (Figure 4F).

The occurrence of salinity stress causes changes in plant characteristics from the moment of occurrence until maturity (MUNNS, 2002) . Plant cells shrink and dehydrate immediately after stress is imposed but recover hours later (YADAV et al ., 2019) . Despite this recovery, cell elongation and, to a lesser extent, cell division are affected, resulting in a slower growth rate of roots and leaves. One week after salinity stress, lateral shoot growth is affected, and months later, clear differences in overall growth and injury can be observed in plants subjected to salinity stress compared with those not stressed. This response is due to changes in the cell–water ratio, which results from osmotic changes outside the root (osmotic effect), leading to a reduced capacity of plants to absorb water (YADAV et al ., 2019) .

Significant interactions ($p<0.01$) between the levels of electrical conductivity of the irrigation water (EC), cultivar (C) and growing period (PC) were also identified for the MSPA $_{40}$, AF_{40} and IAF_{40} traits via the F test when these parameters were evaluated at 40 DAS in the two growing periods (2017 and 2018), indicating that these variables are affected by the joint effects of these factors. The CVs ranged from 1.12 to 4.49%, indicating excellent reliability for the results obtained (Table 5).

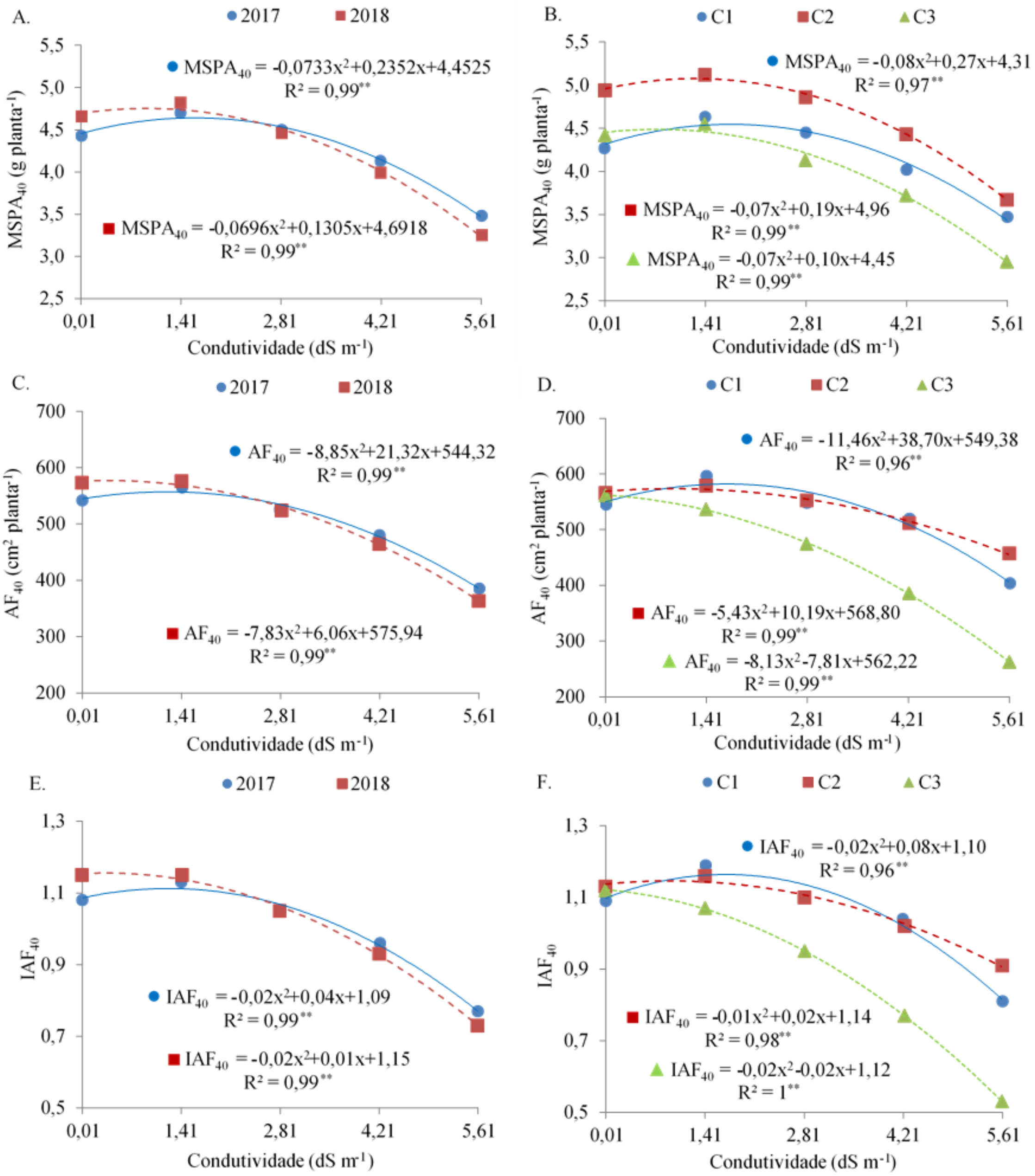
Table 5. Summary of analyses of variance for shoot dry mass ($MSPA_{40}$), leaf area (AF_{40}), and leaf area index (IAF_{40}) of three cowpea cultivars (C) subjected to five levels of irrigation water electrical conductivity (EC) and two growing periods (PCs) at 40 days after sowing (DAS). Alvorada do Gurguéia- PI, 2019.

Source of Variation	GL	Mean Squares [1]		
		MSPA 40	**AF 40**	**IAF 40**
Block	3	0.02 ^{ns}	2106.08 **	$8x10^{-3**}$
Electrical conductivity (EC)	4	7.36 **	122782.91 **	0.61 **
Residue $_1$	12	0.02	182.34	$7x10^{-4}$
Cultivar (C)	2	4.36 **	94688.56 **	0.38 **
CE x C	8	0.14 **	13815.89 **	0.06 **
Residue $_2$	30	0.04	377.32	$2x10^{-3}$
Cultivation period (CP)	1	$5x10^{-3ns}$	16.06 ^{ns}	$6x10^{-5ns}$
CE x PC	4	0.21 **	2777.58 **	0.01 **
C x PC	2	$8x10^{-4ns}$	62.66 ^{ns}	$3x10^{-4ns}$
CE x C x PC	8	0.02 **	161.54 **	$6x10^{-4**}$
Residue $_3$	45	$2x10^{-3}$	54.15	$2x10^{-4}$
Averages	-	4.24 (g)	500.04 (cm^2)	1.00
CV $_1$ (%)	-	3.34	2.70	2.71
CV $_2$ (%)	-	4.49	3.88	3.89
CV $_3$ (%)	-	1.12	1.47	1.47

[1] CE, in dS m^{-1}; CV $_1$ = coefficient of variation for plot; CV $_2$ = coefficient of variation for subplot; CV $_3$ = coefficient of variation for subplot; ^{ns} = not significant; ** = significant at the 1% probability level .

At 40 DAS, the salinity level had a significant quadratic effect ($p<0.01$) on the interaction effect with the growing period for the MSPA $_{40}$ of the studied cultivars. The MSPA of the three cultivars increased to an average level of 1.60 dS m^{-1} in the first cultivation and 0.94 dS m^{-1} in the second cultivation, with maximum estimated yields of 4.64 and 4.75 g $plant^{-1}$, respectively. At these levels, a marked reduction in MSPA $_{40}$ was observed due to the increase in the electrical conductivity of the irrigation water administered during each cultivation (Figure 5A and B).

Figure 5. A) and B) Dry mass of the aerial part (MSPA $_{40}$), C) and D) leaf area (AF_{40}) and E) and F) leaf area index (IAF_{40}) 40 days after sowing (DAS) of three cowpea cultivars, BRS Tumucumaque (C_1), BRS Guariba (C_2) and BRS Imponente (C_3), subjected to five levels of electrical conductivity of irrigation water (EC) during two growing periods (2017 and 2018). Alvorada do Gurguéia, PI. 2019.



The salinity of the irrigation water also varied with cultivar, with significant quadratic effects ($p<0.01$) for $MSPA_{40}$. Average increases in $MSPA_{40}$ were observed up to the threshold of 1.76 dS m $^{-1}$ for cv. BRS Tumucumaque, 1.27 dS m $^{-1}$ for cv. BRS Guariba, and 0.75 dS m $^{-1}$ for cv. BRS Imponente, in which maximum estimated yields of 4.55, 5.07, and 4.49 g plant $^{-1}$, respectively, were observed (Figure 5B).

The greatest reduction in MSPA $_{40}$ (34.3%) occurred in cv. BRS Imponente when the electrical conductivity of the irrigation water (EC) increased from the threshold presented by the cultivar to the maximum level studied (5.61 dS m^{-1}). For this same interval, the reduction in $MSPA_{40}$ of cv. BRS Tumucumaque (24.6%) was 20.7% lower than the average of the other two cultivars and was also 11.3% lower than the decrease observed in cv. BRS Guariba (27.3%) and 34.3% lower than the decrease in cv. BRS Imponente (Figure 5B). These results demonstrate greater tolerance of BRS Tumucumaque to the reductions imposed in $MSPA_{40}$ by increases in irrigation water EC in relation to those of the other two cultivars.

Sousa et al. (2010) evaluated the morphophysiology of some crops under saline stress, including cowpea, and reported a reduction in MSPA of approximately 69.0% as the EC increased to 8.0 dS m^{-1}. A reduction in shoot dry mass in plants subjected to saline stress has also been reported by other authors (ANDRADE et al., 2013; AQUINO et al., 2017; NEVES et al., 2009; OLIVEIRA et al., 2013) . The negative effect of salinity on leaf dry mass accumulation occurs due to a reduction in leaf blade expansion (OLIVEIRA et al ., 2017) .

An evaluation of the leaf area of the cultivars studied at 40 DAS (AF_{40}) revealed that increases in irrigation water salinity promoted interactions ($p<0.01$) with the cultivation period, with significant quadratic effects. The average reductions were 30.8% in the first cultivation (2017) and 37.0% in the second cultivation (2018) when the EC was increased from 1.20 (2017) and 0.39 (2018) to 5.61 dS m^{-1}, indicating a negative effect on the cultivars' responses to the increase in the salinity level of the irrigation water (Figure 5C).

The increases in EC also caused interactions with the cultivars, with significant quadratic effects ($p<0.01$) on AF_{40}. For this variable, the BRS Imponente cv. had as threshold salinity the minimum level studied (0.01 dS m^{-1}), with a maximum estimated yield of 564.10 cm^2 $plant^{-1}$. This same cultivar presented the greatest reduction (53.5%) when the EC was increased to the highest level (5.61 dS m^{-1}), indicating that it is more sensitive to increases in salinity (Figure 5D).

The BRS Tumucumaque and BRS Guariba cultivars presented threshold salinity levels of 1.69 and 0.94 dS m^{-1}, respectively. The estimated maximum AF_{40} yields at each threshold level for these two cultivars were 582.04 and 573.58 cm^2 $plant^{-1}$, respectively, indicating that the negative effects of EC increased at more advanced stages of cultivar development (Figure 5D).

For the interval between the threshold salinity level presented by each cultivar and the EC of 5.61 dS m^{-1}, the reduction in AF_{40} of the cultivar cv. BRS Guariba (20.7%) was 50.7% lower than the average of the other two cultivars and was also 31.8% lower than the reduction observed in the cv. BRS Tumucumaque (30.3%) and 61.3% lower than the reduction observed for the cv. BRS Imponente (Figure 5D).

These data corroborate those of Aquino et al. (2017), who evaluated the morphophysiological responses of cowpea genotypes with respect to irrigation water salinity at 38 DAS and revealed quadratic decreases, with a reduction (38.8%) in AF at an EC level equal to 6.4 dS m^{-1}. Xavier et al . (2014) evaluated cowpea subjected to irrigation with saltwater and nitrogen fertilization and reported a 33.7% reduction in AF at an EC of 4.5 dS m^{-1}. Significant reductions in leaf area in response to increased EC can negatively impact a plant's productive potential (AQUINO et al., 2017) .

Under adverse conditions, plants develop adaptations that result in morphological and/or biochemical changes. Among these factors, a reduction in leaf area stands out, likely related to one of the mechanisms of adaptation to salt stress, in which plants seek to reduce their transpiring surface area. (TESTER; VENPORT, 2003). This behavior has already been confirmed by other authors in studies developed with the cowpea crop. (DUTRA et al., 2011; OLIVEIRA et al., 2013; SILVA *et al*., 2011) .

In the EC × PC interaction, increases in the electrical conductivity (EC) of the irrigation water promoted quadratic decreases ($p<0.01$) in the leaf area index (LAI_{40}) of the three cowpea cultivars at 40 DAS (Figure 5F). The maximum estimated yields in the first growing period (1.11) and in the second period (1.16) were obtained with threshold conductivities of the irrigation water applied to each crop of 1.23 and 0.33 dS m^{-1}, respectively (Figure 5E).

The average reductions in LAI_{40} were 30.8% in the first cropping season (2017) and 36.8% in the second cropping season (2018) when the EC increased from the threshold level of each crop to 5.61 dS m^{-1}, indicating, overall, a negative effect on the response to increases in irrigation water EC (Figure 5E), which was much more intense in the second cropping season because of the higher residual NaCl content in the soil.

The increases in irrigation water salinity also caused interactions between EC and cultivar, promoting significant quadratic effects ($p<0.01$) on the LAI_{40}. The maximum estimated yields in the cultivars BRS Tumucumaque (1.16), BRS Guariba (1.15) and BRS Imponente (1.12) were obtained with threshold conductivities of irrigation water applied to each crop of 1.70, 0.90 and 0.01 dS m^{-1}, respectively (Figure 5F).

The greatest reduction in LAI_{40} (52.7%) occurred in cv. BRS Imponente when the EC increased from 0.01 to 5.61 dS m^{-1}. When the EC of the irrigation water increased from the threshold level of each cultivar to the highest salinity level studied, cv. BRS Guariba (21.5%) presented an average of 48.4% lower than the average of the other two cultivars, which was also 29.4% lower than the decrease observed in cv. BRS Tumucumaque (30.4%) and 59.3% lower than the reduction observed for cv. BRS Imponente (Figure 5F).

The analysis of variance revealed a significant interaction ($p<0.01$) between the factors electrical conductivity of irrigation water (EC) and cultivar (C) for the traits TCC, TCR and TAL according to the F test, which was evaluated at 25--40 DAS in the two cultivation cycles. The CVs ranged from 0.81 to 9.08%, indicating excellent reliability in the results obtained (Table 6).

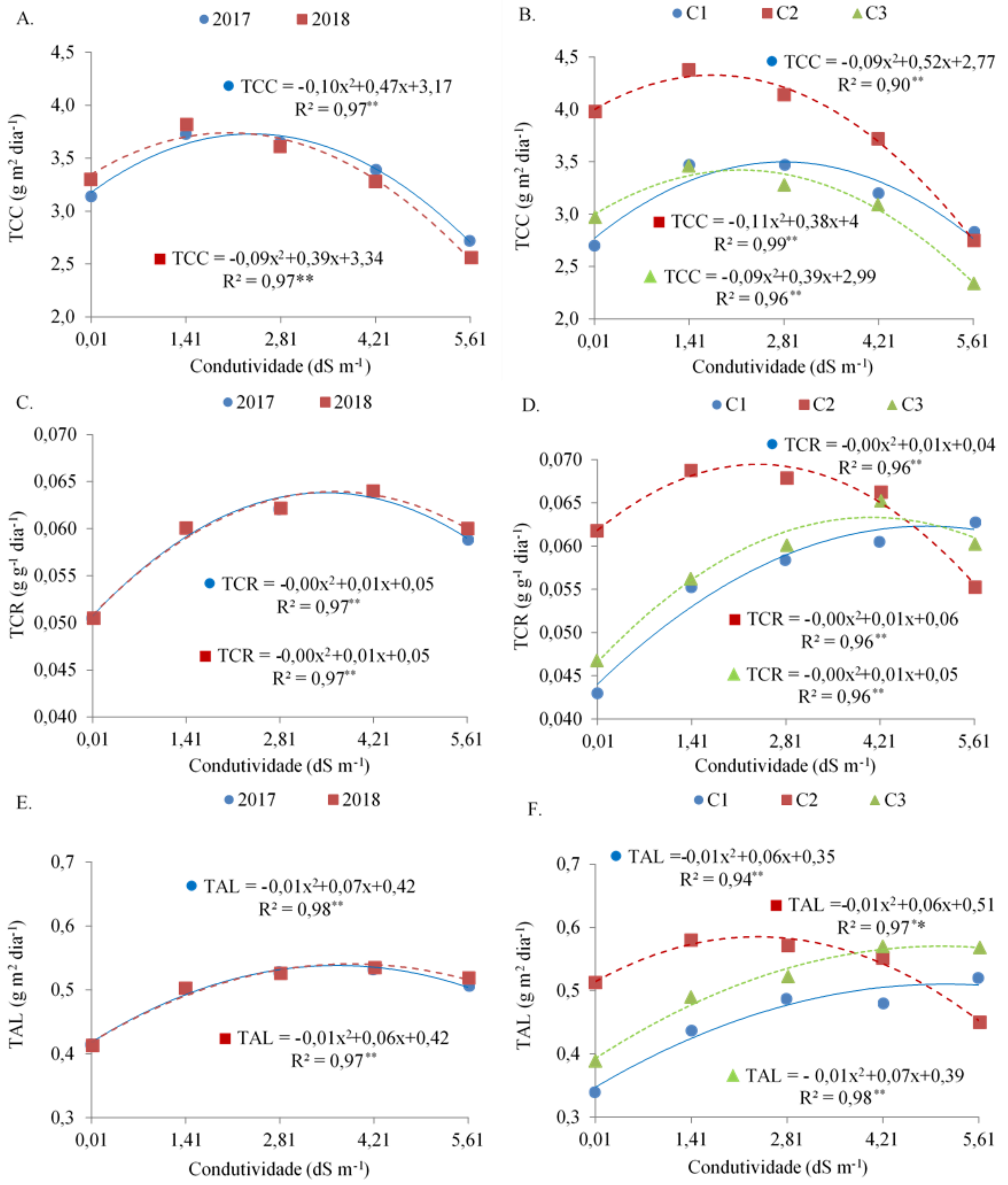
Table 6 Summary of analyses of variance for the crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NSR) of three cowpea cultivars (C) subjected to five levels of irrigation water electrical conductivity (EC) and two growing periods (CP), evaluated at 25 and 40 days after sowing (DAS). Alvorada do Gurguéia, PI. 2019.

Source of Variation	GL	Mean Squares [1]		
		Final Paper	**TCR**	**SUCH**
Block	3	0.05 ^{ns}	1x10 $^{-5ns}$	3x10 $^{-3ns}$
Electrical conductivity (EC)	4	4.66 **	6x10 $^{-4**}$	0.06 **
Residue $_1$	12	0.07	2x10 $^{-5}$	2x10 $^{-3}$
Cultivar (C)	2	6.89 **	7x10 $^{-4**}$	0.07 **
CE x C	8	0.51 **	2x10 $^{-4**}$	0.02 **
Residue $_2$	30	0.09	2x10 $^{-5}$	2x10 $^{-3}$
Cultivation period (CP)	1	3x10 $^{-3ns}$	2x10 $^{-6*}$	2x10 $^{-4**}$
CE x PC	4	0.11 **	2x10 $^{-6**}$	2x10 $^{-4**}$
C x PC	2	4x10 $^{-4ns}$	4x10 $^{-6**}$	3x10 $^{-4**}$
CE x C x PC	8	0.03 **	8x10 $^{-6**}$	5x10 $^{-4**}$
Residue $_3$	45	2x10 $^{-3}$	4x10 $^{-7}$	2x10 $^{-5}$
Averages	-	(g m ^{2} day $^{-1}$) 3.32	(g g $^{-1}$ day $^{-1}$) 0.06	(g m ^{2} day $^{-1}$) 0.50
CV $_1$ (%)	-	8.09	8.31	8.98
CV $_2$ (%)	-	8.82	7.31	9.08
CV $_3$ (%)	-	1.29	0.99	0.81

[1] CE, in dS m $^{-1}$; CV $_1$ = coefficient of variation for plot; CV $_2$ = coefficient of variation for subplot; CV $_3$ = coefficient of variation for subplot; ^{ns} = not significant; *, ** = significant at the 5% and 1% probability levels, respectively .

An increase in irrigation water salinity caused an interaction between EC and the growing period, with significant quadratic effects ($p < 0.01$) on the crop growth rates (CGRs) of the three cowpea cultivars. The maximum estimated CGR yields in the first (3.73 g m² day^{-1}) and second growing seasons (3.74 g m² day^{-1}) were obtained with irrigation water conductivities of 2.38 and 2.05 dS m^{-1}, respectively, thus representing the average threshold salinity for each growing season. The average reductions were 27.6% in 2017 (first growing season) and 22.1% in 2018 (second growing season) when the EC increased from the threshold salinity level of each growing season to 5.61 dS m^{-1} (Figure 6A).

Figure 6. A) and B) Crop growth rate (CGR); C) and D) relative growth rate (RGR); and E) and F) net assimilation rate (NAR) of three cowpea cultivars: BRS Tumucumaque (C_1), BRS Guariba (C_2) and BRS Imponente (C_3), subjected to five levels of electrical conductivity of irrigation water (EC) and two cultivation periods (2017 and 2018). Alvorada do Gurguéia, PI. 2019.



An analysis of the interaction between EC and cultivar revealed that increases in the electrical conductivity (EC) of irrigation water also promoted significant quadratic effects ($p<0.01$) on the TCC (Figure 6B). The maximum estimated values for TCC in the cultivars BRS Tumucumaque (3.5 g m² day^{-1}), BRS Guariba (4.33 g m² day^{-1}), and BRS Imponente (3.42 g m² day^{-1}) were obtained with levels of 2.81, 1.76, and 2.17 dS m^{-1} of EC of irrigation water applied to each crop, respectively. These levels represent the threshold salinity of each cultivar in relation to the TCC (Figure 6B).

A constant increase in the TCC of the cultivars was observed when the irrigation water salinity was increased from 0.01 dS m^{-1} to the threshold salinity level of each cultivar. From these levels onward, there were reductions of 20.8, 36.5, and 31.3% in the TCCs of the BRS Tumucumaque, BRS Guariba, and BRS Imponente cultivars, respectively (Figure 6B).

A general analysis of Figure 6B clearly revealed that the use of irrigation water with relatively high salinity (5.61 dS m^{-1}) resulted in the lowest TCC values, regardless of cultivar, with the exception of the cultivar BRS Tumucumaque, which presented the lowest TCC at the lowest salinity level (0.01 dS m^{-1}). Notably, this cultivar presented greater tolerance to the deleterious effects of salinity, represented in this study by its highest threshold salinity level and lower percentage of TCC reduction in relation to the other cultivars studied.

The results obtained for TCC can be explained by the reductions observed in the dry mass of the aerial part (Figures 4A and B and 5A and B) and leaf area (Figures 4C and D and 5C and D), given that these variables are directly related to plant growth (BEZERRA et al ., 2014) .

In terms of the interaction effect between irrigation water salinity and growing season, increases in EC promoted significant quadratic effects ($p<0.01$) on the relative growth rates (RGRs) of the three cowpea cultivars. The maximum estimated RGR yields in the first (0.06 g g^{-1} day^{-1}) and second growing seasons (0.08 g g^{-1} day^{-1}) were obtained with threshold conductivities of the irrigation water applied to each crop of 3.41 and 3.65 dS m^{-1}, respectively (Figure 6C).

When the EC was increased by 0.01 to the threshold conductivity of each period, the average increases in RRT were 24.5% in 2017 and 18.5% in 2018, which are the first and second cultivation periods, respectively. From this point until the EC reached 5.61 dS m^{-1}, there were average decreases in RRT, with percentages of 8.6 and 4.9%, for the first and second cultivation periods, respectively (Figure 6C).

Increases in irrigation water salinity also promoted significant quadratic effects ($p<0.01$) for TCR in the interaction between EC levels and cultivar. The maximum estimated TCR yields in the cultivars BRS Tumucumaque (0.062 g g^{-1} day^{-1}), BRS Guariba (0.070 g g^{-1} day^{-1}) and BRS Imponente (0.064 g g^{-1} day^{-1}) were obtained, with conductivities of 4.69, 2.46 and 4.15 dS m^{-1}, respectively (Figure 6D).

When the EC was increased from 0.01 dS m^{-1} to the maximum yield level of each cultivar, cv. BRS Tumucumaque presented the greatest average increase in RCR (40.0%), followed by cv. BRS Imponente (35.6%) and cv. BRS Guariba (12.4%), which presented the lowest increase. From the maximum EC levels presented by each cultivar up to the EC of 5.61 dS m^{-1}, decreases were observed among the three cultivars, with an emphasis on cv. BRS Guariba, which presented a 12.4% reduction in RCR (Figure 6D).

The TCR considers the increase (increase in grams of dry phytomass) in relation to what the plant previously presented (preexisting material), that is, it is the measure of how quickly a plant grows compared with its initial size (BENINCASA, 2003) .

According to Larcher (2000) , growth processes are particularly sensitive to the effects of salt, so the growth rate and biomass production are good criteria for evaluating the degree of stress and the ability of plants to overcome salinity.

An analysis of the performance of the cultivars in terms of the interaction between the growing period and cultivar revealed that increases in the electrical conductivity (EC) of the irrigation water promoted significant quadratic effects ($p<0.01$) on the net assimilation rate (TAL) (Figure 6E and F). The maximum estimated yields (0.54 g m² day^{-1}) in the first and second growing periods were obtained with conductivities of 3.67 and 3.88 dS m^{-1} of the irrigation water applied to each crop, respectively (Figure 6E).

The average increases were 28.2 and 28.9% (in the first and second cultivation periods, respectively) when the EC was increased by 0.01 dS m^{-1} to the EC levels that obtained the maximum TAL yields in each period (3.67 and 3.88 dS m^{-1}, respectively). From these levels up to the maximum EC studied (5.61 dS m^{-1}), a small decrease was observed in both cultivation periods (Figure 6E).

Increases in irrigation water salinity also promoted significant quadratic effects ($p<0.01$) on the net assimilation rate (TAL) in the EC and cultivar interaction. The maximum estimated TAL yields in the cultivars BRS Tumucumaque (0.51 g m² day^{-1}), BRS Guariba (0.59 g m² day^{-1}) and BRS Imponente (0.57 g m² day^{-1}) were obtained with irrigation water electrical conductivity levels of 5.15, 2.37 and 5.04 dS m^{-1}, respectively (Figure 6F).

A general comparison between the two growing periods verified that the performance of the cultivars in the interactions between the CE and cultivar and the CE and growing periods in relation to AF_{25} (Figure 4C and D), AF_{40} (Figure 5C and D) and TCR (Figure 6C and D) remained similar to the performance of IAF_{25} (Figure 4E and F), IAF_{40} (Figure 5E and F) and TAL (Figure 6E and F) for these same interactions, presenting curves with the same behavior. It also presented an average reduction of 8.9% in the TCC, 9.0% in $MSPA_{25}$ and $MSPA_{40}$, 10.5% in AF_{25} and IAF_{25} and 7.8% in AF_{40} and IAF_{40}, both in the second cultivation period. This greater reduction in the second period is a result of the residual sodium levels in the plots (Table 2), which contributed to the increase in negative effects on plant development.

Under field conditions, the salt distribution is neither uniform with soil depth nor constant over time. This uneven salinity distribution is generally affected by irrigation practices and the amount and patterns of precipitation (MINHAS et al., 2020). In this study, the rainfall concentrations between the end of the first growing season and the beginning of the second season did not completely displace the salts (NaCl) that accumulated at the surface to the deeper soil layers.

6 CONCLUSIONS

Under the climatic and environmental conditions under which this study was conducted, increasing irrigation water salinity levels promoted linear reductions in the morphophysiological traits shoot dry mass, leaf area, and leaf area index of cowpea plants of the BRS Tumucumaque, BRS Guariba, and BRS Imponente cultivars when evaluated in the initial growth phase. The BRS Guariba cultivar is more tolerant, in the initial growth phase, to the negative effects of increased irrigation water salinity. The BRS Tumucumaque cultivar is more tolerant of the deleterious effects of increased irrigation water salinity in the final growth phase, presenting the highest threshold salinity indices for the net assimilation rate, relative growth rate, and crop growth rate.

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