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Mulch with sugarcane bagasse and bamboo straw attenuates salt stress in cowpea cultivation[1]

Cobertura morta com bagaço de cana e palha de bambu atenua o estresse salino no cultivo do feijão-caupi

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HIGHLIGHTS:
- *Saline stress did not affect the initial growth of the cowpea crop.*
- *The use of mulch provides better morphological results in the cowpea crop.*
- *Vegetal mulches as soil protection (sugarcane bagasse and bamboo straw) attenuated effect of salts on gas exchange of cowpea.*

ABSTRACT: This study aimed to evaluate the effect of saline stress on the growth and gas exchange of the cowpea crop in a substrate with and without mulch. The experiment was carried out in Redenção, CE, Brazil. The experimental design was completely randomized in a 5 × 3 factorial scheme, with five replicates. The treatments consisted of five electrical conductivities of irrigation water (1.0; 2.0; 3.0; 4.0, and 5.0 dS m^{-1}) in substrates without and with mulch (sugarcane bagasse and bamboo straw). The analyzed variables were the number of leaves, stem diameter, leaf area, photosynthesis, transpiration, stomatal conductance, water-use efficiency, root dry matter, shoot dry matter, and electrical conductivity of the saturation extract. Using mulch generates positive effects for cowpea shoot growth, regardless of the irrigation water salinity. However, bamboo straw as soil cover minimizes the effects of salts on root dry matter. Soil cover with bamboo straw and sugarcane bagasse minimizes the effects of salts on leaf gas exchange variables, especially at higher electrical conductivity of the irrigation water. Mulches with crop residues from sugarcane bagasse and bamboo straw reduce the electrical conductivity of the soil saturation extract.

Key words: *Vigna unguiculata* L., salinity, soil protection

RESUMO: Objetivou-se avaliar o efeito do estresse salino no crescimento e nas trocas gasosas do feijão-caupi, em substrato com e sem cobertura morta vegetal. O experimento foi realizado em Redenção, CE, Brasil. O delineamento experimental foi inteiramente casualizado em esquema fatorial de 5 x 3, com cinco repetições. Os tratamentos foram constituídos de cinco condutividades elétricas da água de irrigação (1,0; 2,0; 3,0; 4,0 e 5,0 dS m^{-1}) em substrato sem e com cobertura morta vegetal (bagaço de cana de açúcar e palha de bambu). As variáveis analisadas foram: número de folhas, diâmetro do caule, área foliar, fotossíntese, transpiração, condutância estomática, eficiência do uso da água, massa seca da raiz e da parte aérea e a condutividade elétrica do extrato de saturação do solo. O uso de cobertura morta gera efeitos positivos para o crescimento do feijão-caupi, independentemente da salinidade da água de irrigação. Porém, o uso de palha de bambu como cobertura do solo minimiza os efeitos dos sais na matéria seca das raízes. A cobertura do solo com palha de bambu e bagaço de cana-de-açúcar minimiza os efeitos dos sais para as variáveis de trocas gasosas foliares, principalmente em maiores valores de condutividade elétrica da água de irrigação. A cobertura morta com resíduos de bagaço de cana-de-açúcar e palha de bambu reduz a condutividade elétrica do extrato de saturação do solo.

Palavras-chave: *Vigna unguiculata* L., salinidade, proteção do solo

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INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is a legume with a worldwide distribution, found mainly in tropical regions (Andrade et al., 2020). Brazil is one of the largest producers, and North and Northeast are highlighted as the main producing regions (Penha Filho et al., 2017). According to Públio Júnior et al. (2017), cowpea responds in different ways to the soil, climate, and irrigation conditions, due to its physiological and morphological traits.

In semiarid regions, high temperatures and irregularly distributed rainfall, besides the predominance of crystalline rocks in the subsoil, impose brackish and saline conditions for groundwater, wherein periods of water scarcity, these become the only water supply option for agricultural production (Cruz et al., 2016).

Saline water use is one of the abiotic stresses that most limit plant growth and development, and consequently, agricultural production worldwide (Souza et al., 2019). Salt stress cause stomatal closure, reducing transpiration rate, internal CO_2 concentration, and photosynthetic rates (Sá et al., 2018). It should be noted that according to Ayers & Westcot (1999), the cowpea crop has a salinity threshold of 2.3 dS m^{-1}.

Some practices have been used to mitigate salt stress in crops. Among them, mulch, plant material applied to the soil, which can minimize excessive water losses, keep the soil moist, and avoid sudden soil temperature changes (Sousa et al., 2018a). Assessing the amaranth growth, Costa et al. (2008) found a mitigating effect on initial growth and dry biomass production.

Therefore, this study aimed to evaluate the effect of saline stress on the growth and gas exchange of cowpea, growing in a substrate with and without mulch.

MATERIAL AND METHODS

The experiment was carried out in the field, in the didactic vegetable garden Professor Luís Antônio da Silva, at the University for International Integration of the Afro-Brazilian Lusophony (UNILAB), in Redenção (4º13'21" S and longitude 38º43'32" W and 92 m of altitude), CE, Brazil. According to Köppen (1923) classification, the climate of the region is Aw-type; a tropical climate with a dry winter season, a mean temperature of the warmest month above 38 ºC and the coldest month below 20 ºC.

The experimental design was completely randomized in a 5 x 3 factorial scheme, with five replicates. The treatments consisted of five electrical conductivities of irrigation water (ECw) (1.0; 2.0; 3.0; 4.0, and 5.0 dS m^{-1}) in three substrates, without and with mulch (sugarcane bagasse - SB and bamboo straw - BS).

Seeds of the BRS Tumucumaque cowpea cultivar were used. This cultivar has a semi-erect growth-type and a white-smooth commercial grain. Sowing was carried out manually; five seeds were placed per pot at a depth of 5 cm, in polyethylene pots, with 14 L capacity, on a substrate prepared in the proportion of 5:3:2 (sand, sandy soil, and manure, respectively - volume basis). The soil chemical analysis results according to the methodology by Teixeira et al. (2017) are shown in Table 1.

The meteorological data obtained along the experimental period are shown in Table 2.

Thinning was carried out on the eighth day after sowing (DAS) and mulch insertion at 15 DAS. Irrigation water was prepared by dissolving salts (NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$), in the equivalent ratio of 7:2:1 obeying the relationship between the electrical conductivity of water (ECw) and its concentration ($mmol_c\ L^{-1}$ = EC × 10), according to the methodology described by Rhoades et al. (2000). Irrigation was applied manually daily, with a graduated container, applying a leaching of 15%, using the weighing method described by Puértolas et al. (2017). The water volume was supplied every 24 hours to keep the soil in the field capacity, monitored by tensiometers, installed at 10 cm in each experimental unit.

The total irrigation depths applied during the experiment are presented in Table 3.

At 35 DAS, the analyzes of the number of expanded leaves per plant (NL), stem diameter (SD), and leaf area (LA) were carried out. The leaf area was determined following the method proposed by Lima et al. (2008) to estimate the leaf area of cowpea.

At 35 DAS, photosynthesis (A), transpiration (E), and stomatal conductance (gs) on fully expanded sheets were assessed using an infrared carbon dioxide analyzer (portable IRGA model LI-6400XT, LI-COR Biosciences Inc., Lincon, Nebraska, USA), in an open system, with the airflow of 300 mL min^{-1} in the period from 09:00 to 10:30 hours, using constant active light intensity (PAR) (1300 μmol photons $m^{-2}\ s^{-1}$), CO_2 concentration constant (350 ppm) with an ambient air temperature of 30 °C and relative air humidity, on average 85%. The instantaneous water-use efficiency (WUE) was determined from the ratio A/E.

Table 2. Mean values of temperature and relative air humidity during the experiment

Temperature (ºC)		Relative air humidity (%)		Rainfall (mm)
Max	Min	Max	Min	Total
32.4	30.6	60	52	2.2

Table 3. Total water depth applied in each treatment

Treatments (dS m^{-1})	Mulches		
	Sugarcane bagasse	Bamboo straw	Without cover
	Total depth applied (L)		
1.0	19.6	20.3	22.1
2.0	19.6	20.3	22.1
3.0	19.6	20.3	22.1
4.0	19.6	20.3	22.1
5.0	19.6	20.3	22.1

Table 1. Chemical characteristics of the substrate used in the experiment

pH H_2O	P	H + Al^{3+}	Ca^{2+}	Mg^{2+}	Na^+	K^+	SB	CEC	V	OM	ECse
	(mg dm^{-3})	($cmol_c\ dm^{-3}$)							(%)	(g dm^{-3})	(dS m^{-1})
5.9	30	0.87	2.2	1.1	1.04	2.07	6.4	7.2	89	7.03	0.8

CEC - Cation exchange capacity; SB - sum of bases; V - Base saturation; OM - Organic matter; ECse - Electrical conductivity of the soil saturation extract

In the same period (35 DAS), plants were harvested and packed in paper bags for 72 hours in an air-forced circulation oven at 60 °C until they reached constant mass. Then, they were weighted using an electronic digital scale ($p < 0.001$ g) to determine the shoot dry matter (SDM) and root dry matter (RDM).

After plant collection, the soil of each pot was homogenized, and samples were used to determine the electrical conductivity of the saturation extract (ECse), adopting the method recommended by Richards (1954).

The results were subjected to analysis of variance, and the means of substrates were compared by Tukey test, whereas effect of ECw was evaluated by regression analysis, using the program ASSISTAT 7.7 Beta (Silva & Azevedo, 2016).

RESULTS AND DISCUSSION

About the plant growth, there was an interaction between the electrical conductivity of irrigation water and mulch only for root dry matter. Leaf area, number of leaves, stem diameter, shoot dry matter, and electrical conductivity of the saturation extract were affected only by soil cover (Table 4).

According to Figure 1A, the highest value of the leaf area was obtained under the bamboo straw - BS mulch (598.20 cm²) and sugarcane bagasse – SB (578.20 cm²), differing statistically from without cover - WC (403.2 cm²). This high value of the leaf area can be explained by the greater water retention in the soil, reducing water evaporation and keeping the soil moist for a longer time, mitigating the harmful effects of water stress on plants (Lima Neto et al., 2013). The present result is similar to that obtained by Souza et al. (2016) in cowpea plants of the BRS Pujante cultivar in treatments using crop residues such as mulch.

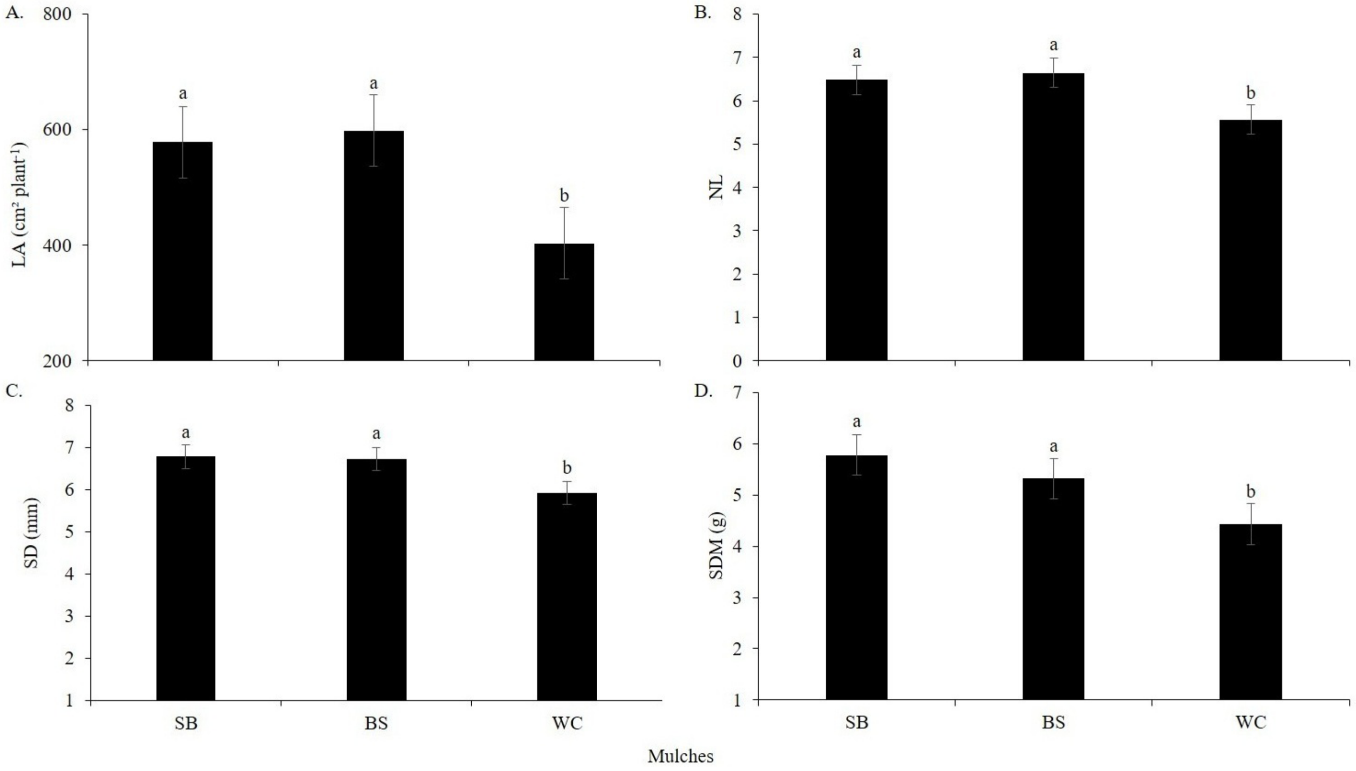
Table 4. Summary of analysis of variance for the variables leaf area (LA), number of leaves (NL), stem diameter (SD), shoot dry matter (SDM), root dry matter (RDM), and electrical conductivity of the saturation extract (ECse) in cowpea plants irrigated with saline water using mulches

Variation sources	DF	Mean square					
		LA	NL	SD	SDM	RDM	ECse
Salinity (S)	4	3203.42^{ns}	27.40^{ns}	22.10^{ns}	51.7^{ns}	0.30^{ns}	5.60^{ns}
Mulches (M)	2	4356.04**	8.50**	5.70**	11.80**	0.19**	1.37**
S × M	8	601,13^{ns}	0.40^{ns}	0.70^{ns}	1.40^{ns}	0.06**	0.14^{ns}
Residue	60	225.34	0.50	0.50	0.80	0.02	0.16
CV (%)		15.34	11.58	11.50	17.62	23.04	21.64

DF - Degrees of freedom; CV - Coefficient of variation; *, ** and ns - Significant at $p \leq 0.05$ and $p \leq 0.01$ and not significant, respectively, by F test

Moreover, soil mulch (SB and BS) had positive effect on the number of leaves (NL), statistically differing concerning the control treatment (Figure 1B). This result may be justified because plants without cover suffered higher evaporation due to greater soil exposure, which intensified the water loss, causing a water deficit and, consequently, reducing the number of leaves (Bertino et al., 2015). The present result conforms with obtained by Souza et al. (2016), who showed a lower number of leaves of cowpea plants when grown without mulch.

Assessing the stem diameter (Figure 1C), the mulches with sugarcane bagasse and bamboo straw obtained 6.78 and 6.72 mm; they were statistically higher than the control (5.92 mm). Sousa et al. (2017) state that mulch is an important moisture retention source, favoring chemical reactions, and nutrient availability, favoring stem development compared to crops without mulch. These results are similar to those



SB - Sugarcane bagasse; BS - Bamboo straw; WC - Without cover; Means followed by different letters differ significantly by Tuckey test at $p \leq 0.05$

Figure 1. Leaf area - LA (A), number of leaves - NL (B), stem diameter - SD (C), and shoot dry matter - SDM (D), in cowpea plants irrigated by saline water under three mulches

obtained by Costa et al. (2008), who found that the use of mulch promoted an increase in stem diameter in amaranth plants.

The use of mulch differed statistically from the control, promoting the major accumulation of shoot dry matter (Figure 1D); the cowpea plants with sugarcane bagasse had 5.78 g, bamboo straw 5.32 g, and without mulch 4.43 g. The lower values obtained can be justified due to the lack of soil covering, generating water losses due to higher evaporation, and the lower water availability for plants (Sousa et al., 2017).

Similar results were found by Costa et al. (2015) and Melo Filho et al. (2017) in the sorghum and pitomba (*Talisia esculenta*) crops, respectively, where higher values of stem diameter were obtained with the use of soil mulching. These same authors describe that the covering with cultural remains provided greater soil microbial activity, favoring a greater availability of nutrients and, consequently, greater stem development.

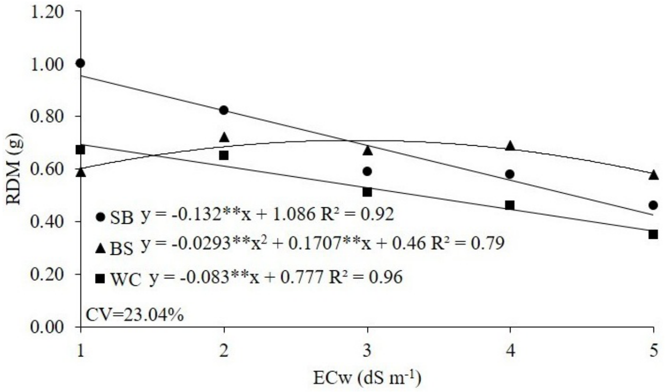
The increase in the electrical conductivity of irrigation water had a negative influence on the RDM. The linear model was the one that best fitted for sugarcane bagasse and without cover. For bamboo straw mulch, the data fitted to the quadratic polynomial model, obtaining maximum values of 0.70 g of dry matter for electrical conductivity of the irrigation water equal to 2.91 dS m^{-1} (Figure 2).

The results obtained in the treatment without cover possibly show the effect of salts on the soil, especially Na$^+$, reducing the rate of water infiltration, stimulating the formation of a layer with greater density, which hinders growth, respiration, and root expansion (Schossler et al., 2012; Sá et al., 2018).

Sousa et al. (2018a), when assessing the interaction between irrigation water salinity and mulch, found similar results in corn plants grown in soil without mulch. Also, Costa et al. (2008), when used saline water to irrigate the amaranth crop, did not obtain a positive effect of the mulch for this variable.

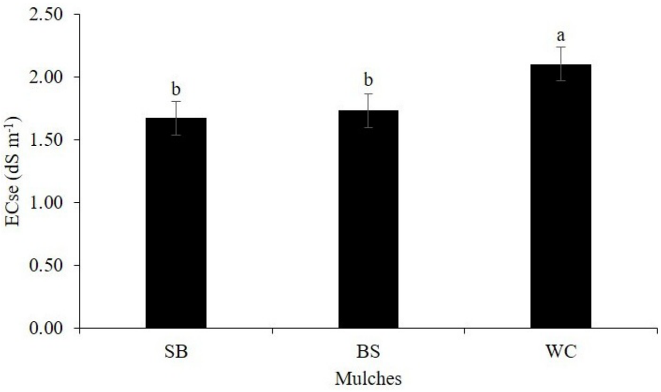
Furthermore, the treatment without mulch showed higher electrical conductivity of the soil saturation extract (2.1 dS m^{-1}) and differed statistically from bamboo straw (1.73 dS m^{-1}) and sugarcane bagasse (1.67 dS m^{-1}) (Figure 3).

The reduction in the electrical conductivity of the soil saturation extract (ECse) due to the use of mulching with bamboo straw and sugarcane bagasse corroborates the statement by Melo Filho et al. (2017). These authors emphasize that the soil mulch reduces evaporation available to plants, reducing additions in salt concentrations. Nevertheless, Sousa et al. (2019), when evaluating the effect of saline stress in plants without mulch, obtained an increase in ECse with an increase in the electrical conductivity of irrigation water.



SB - Sugarcane bagasse; BS - Bamboo straw; WC - Without cover; *, ** - Significant at $p \leq 0.01$ by F test, respectively; CV - Coefficient of variation

Figure 2. Root dry matter (RDM) of cowpea plants as a function of irrigation water electrical conductivity (ECw) under different types of mulches



SB - Sugarcane bagasse; BS - Bamboo straw; WC - Without cover; Means followed by same letters do not differ significantly Tuckey test at $p \leq 0.05$

Figure 3. Electrical conductivity of the soil saturation extract (ECse) in three mulches

All leaf gas exchange variables were affected by the interaction between the electrical conductivity of irrigation water and soil mulch, at $p \leq 0.01$ by the F-test (Table 5).

The linear model was the best fit for the photosynthesis of cowpea plants in the areas with sugarcane bagasse and bamboo straw as mulching. The quadratic polynomial model obtained a maximum value of 28.04 mmol m^{-2} s^{-1} for the electrical conductivity of 1.27 dS m^{-1} without mulch (Figure 4A).

Plants under salt stress have significant reductions in photosynthesis due to the partial closure of stomata, linked to osmotic effects and toxicity in metabolism caused by ions (Taiz et al., 2017).

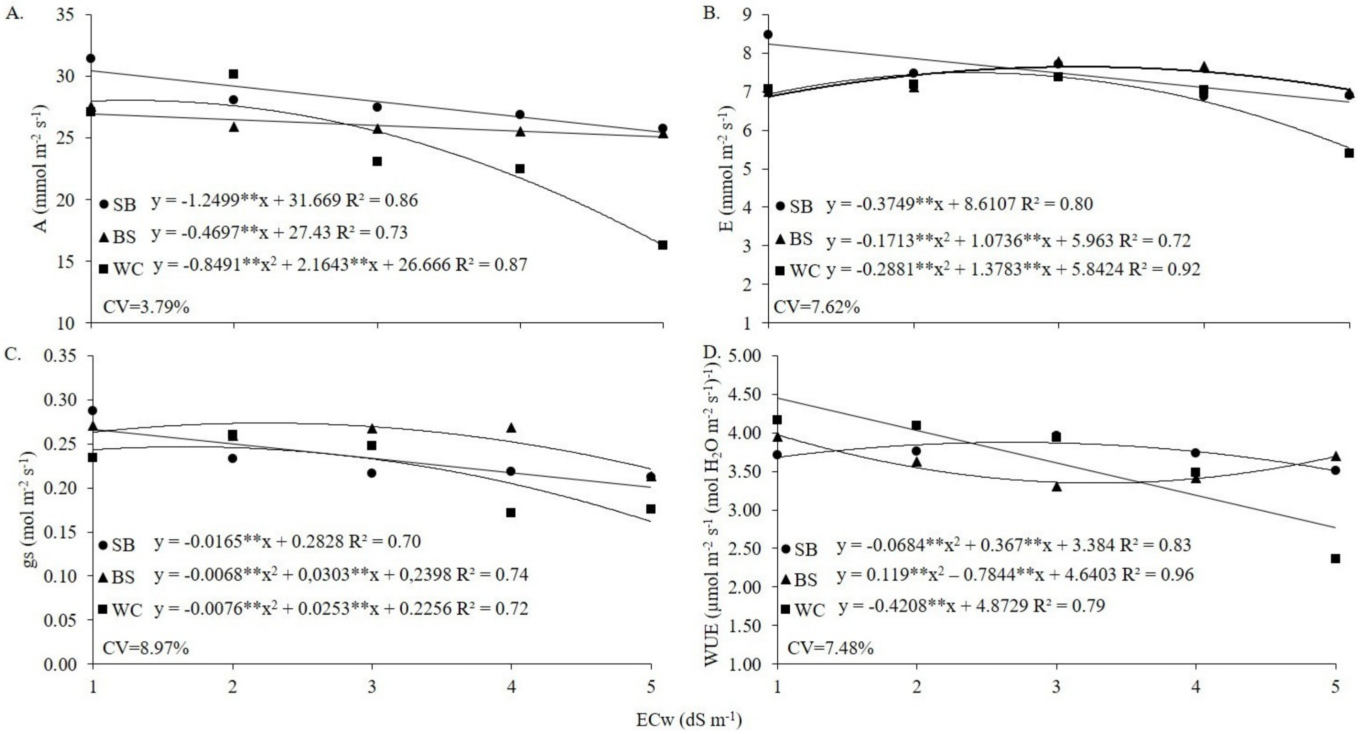
This result improves the information contained in the research conducted by Oliveira et al. (2017) when reporting reductions with the increase in the salts concentration and, consequently, in osmotic potential, triggering a stomatal closure. The results obtained corroborate Prazeres et al. (2015) who reported a reduction in cowpea crop photosynthesis irrigated with saline water in soil without mulch.

Concerning the transpiration (Figure 4B), in treatments with bamboo straw and without cover mulch, the mathematical model that best fitted to data was a quadratic polynomial, with 7.64 mmol m^{-2} g^{-1} in the electrical conductivity of 3.13 dS m^{-1} and 7.49 mmol m^{-2} g^{-1} in 2.39 dS m^{-1}, respectively. The treatment with sugarcane bagasse as mulch showed a linear reduction in

Table 5. Summary of analysis of variance for photosynthesis (A), transpiration (E), stomatal conductance (g_s), and water use efficiency (WUE) in cowpea plants irrigated with saline water under mulch

Source of variation	DF	Mean square			
		A	E	g_s	WUE
Salinity (S)	4	68.01**	2.13**	0.00427**	0.88580**
Mulches (M)	2	110.36**	5.52**	0.00816**	0.09636**
S x M	8	33.26**	2.28**	0.00249**	0.88319**
Residue	45	43.77	0.29	0.00044	0.07489
CV (%)		3.79	7.62	8.97	7.48

DF - Degrees of freedom; CV - Coefficient of variation; ** - Significant at $p \leq 0,01$ by the F-test



SB - Sugarcane bagasse; BS - Bamboo straw; WC - Without cover; *, ** - Significant at $p \leq 0.01$ by F test, respectively; CV - Coefficient of variation

Figure 4. Photosynthesis - A (A), transpiration – E (B), stomatal conductance – gs (C), and water use efficiency – WUE (D) in cowpea plants according to irrigation water electrical conductivity (ECw) in each mulch

cowpea crop transpiration due to the increase in the salinity of the irrigation water. Cl^- and Na^+ in the irrigation water and its gradual application cause the stomatal closure of the plants, preventing transpiration (Souza et al., 2019).

The greater transpiration obtained in mulching treatments might be explained as a response to its ability to retain moisture in the soil, favoring, according to Taiz et al. (2017), the transport of water and minerals to the aerial part. However, results that demonstrate effects contrary to this study were observed by Sousa et al. (2018b) in the lima bean crop when irrigated with saline water in soil without mulch.

It can be noticed in Figure 4C that the quadratic polynomial model was better adjusted for the variable stomatal conductance in soil with bamboo straw as mulch and without mulching, with maximum values of 0.27 and 0.24 mol m^{-2} s^{-1} in the electrical conductivities of 2.22 and 1.66 dS m^{-1}, respectively. Besides, for the sugarcane bagasse treatment, the linear decreasing model was the one that best fitted to the increase of irrigation water electrical conductivity.

The effect of increasing salts in irrigation water provided lower values due to stress-induced stomatal closure, besides reducing CO_2 assimilation (Melo Filho et al., 2017; Magalhães et al., 2020). Similar results to the present study were verified by Sá et al. (2018) in bean plants in soil without mulch.

As for the variable water-use efficiency (Figure 4D), it is observed that the quadratic polynomial model was better-adjusted to sugarcane bagasse and bamboo straw as mulch with values of 3.87 μmol m^{-2} s^{-1} (mol H_2O m^{-2} s^{-1})$^{-1}$) for electrical conductivity of 2.68 dS m^{-1} and 3.34 μmol m^{-2} s^{-1} (mol H_2O m^{-2} s^{-1})$^{-1}$) to 3.29 dS m^{-1}, respectively. In the treatment without mulch, the decreasing linear model was the one that best represents the results obtained.

The lower WUE values on plants without mulch with the increase in salinity possibly show a lower osmotic potential; consequently, the plant absorbs little water due to the low suction force to overcome the osmotic pressure (Schossler et al., 2012).

Mulching with sugarcane bagasse and bamboo straw minimized the effects of salts on the WUE, obtaining higher values than the treatment without mulch, indicating that the mulch was efficient in keeping the soil moist. It should be noted that this result provided by the mulch coverings (sugarcane bagasse and bamboo straw) reduced the evaporation of water from the soil, providing greater water retention and consequently WUE. Lima et al. (2018) describe similarity to the data in this study for water-use efficiency at high salinity levels in cotton crops.

CONCLUSIONS

1. Using mulch generates positive effects for cowpea shoot growth, regardless of the salinity of irrigation water. However, bamboo straw as soil mulch minimizes the effects of salts on root dry matter.

2. Soil mulch with bamboo straw or sugarcane bagasse minimizes the effects of salts for the variables of leaf gas exchange, especially at higher electrical conductivity of the irrigation water.

3. Mulches with crop residues of sugarcane bagasse and bamboo straw reduce the electrical conductivity of the soil saturation extract.

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