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Saline stress in maize grown in soil under different mulches

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ABSTRACT: The use of mulch in the soil attenuates saline stress in corn plants. The objective of this study was to evaluate the effect of irrigation with brackish water in soil under different plant mulches on the productive performance of corn. The study was carried out under field conditions, at the Piroás experimental farm at the Universidade da Integração Internacional da Lusofonia Afro-Brasileira, UNILAB, Redenção, Ceará, Brazil, from August to November 2020. The design was in a 5 × 3 factorial scheme, with four replications, the first factor being the electrical conductivity of the water, in which A1, A2, A3, A4, and A5, refers to 1.0, 2.0, 3.0, 4.0, and 5.0 dS m^{-1}, respectively, and the second factor the different types of mulch (no mulch - NM; mulch with banana leaves - MBL, and mulch with spontaneous plants - MSP. The following were evaluated: ear mass with and without straw, mass of 1,000 grains, length and diameter of the ear, and yield. Saline stress reduces the mass of 1,000 grains, the length and diameter of the ear of corn, the mass of the ear with and without straw in the presence mulch of weeds and banana leaves. The use of mulch of weeds and banana leaf mulch is more efficient for a smaller reduction in the weight of 1,000 grains compared to the control treatment (without mulch). Banana leaves and spontaneous plants associated with water of 1.0 and 3.0 dS m^{-1} enabled higher yield compared to the treatment without mulch.

Key words: salinity; soil protection; *Zea mays* L.

Estresse salino na cultura do milho cultivada em solo sob diferentes coberturas mortas

RESUMO: O uso da cobertura morta vegetal no solo atenua o estresse salino em plantas de milho. Objetivou-se avaliar o efeito da irrigação com água salobra em solo sob diferentes coberturas mortas vegetais no desempenho produtivo da cultura do milho. O estudo foi realizado em condições de campo, na fazenda experimental Piroás da Universidade da Integração Internacional da Lusofonia Afro-Brasileira, UNILAB, Redenção, Ceará, no período de agosto a novembro de 2020. O delineamento foi em esquema fatorial 5 × 3, com quatro repetições, sendo o primeiro fator a condutividade elétrica da água, em que A1, A2, A3, A4 e A5, se refere a 1,0; 2,0; 3,0; 4,0 e 5,0 dS m^{-1}, respectivamente e o segundo fator os diferentes tipos de coberturas mortas (sem cobertura morta - SC; cobertura com folhas de bananeira - CFB e cobertura com plantas espontâneas - CPE. Foram avaliadas: massa de espiga com e sem palha, massa de 1.000 grãos, comprimento e diâmetro da espiga e a produtividade. O estresse salino reduz a massa de 1.000 grãos, o comprimento e o diâmetro da espiga do milho, a massa da espiga com e sem palha na presença da cobertura morta vegetal de plantas espontâneas e de folhas de bananeira. O uso da cobertura morta de plantas espontâneas e de folhas de bananeira é mais eficiente para um menor decréscimo na massa de 1.000 grãos em relação ao tratamento controle (sem cobertura morta vegetal). As coberturas com folhas de bananeiras e plantas espontâneas associada a água de 1,0 e 3,0 dS m^{-1} possibilitaram maiores produtividade em relação ao tratamento sem cobertura morta.

Palavras-chave: salinidade; proteção do solo; *Zea mays* L.

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Introduction

The maize crop (*Zea mays* L.) originated in Central America and is produced in virtually every region of the world, and can be used for food, feed, and bioenergy production (Carvalho et al., 2019). Grain cultivation is highly widespread in Brazil, being grown on 18.4 million hectares in 2021, reaching an average yield of 5.7 thousand kg ha^{-1}, where Brazil is the third largest world producer, behind only the United States and China, which have a harvested area of 32.8 and 45.1 million hectares, and an average yield of 11.8 and 6.3 thousand kg ha^{-1}, respectively (FAO, 2023).

The Brazilian semiarid region is characterized as a region where evapotranspiration exceeds rainfall, that is, the scarcity of available water resources and the increase in demand for water have resulted in the use of most good quality sources, which leads many producers to use inferior quality water for crop irrigation. However, these sources have higher saline levels, such as brackish well water (Gheyi et al., 2016).

Salinity is considered an abiotic stress that causes reduced water absorption by plants and osmotic potential, resulting in disturbances in water relations, interfering directly in the absorption and assimilation of nutrients by plant species (Souza et al., 2019; Sousa et al., 2021), modifying the physiological and biochemical functions of plants, causing the closure of stomata, reduced transpiration and photosynthesis, consequently compromising the quality and yield of agricultural crops (Sousa et al., 2022; Zhang et al., 2022a).

It is noteworthy that current studies have used management techniques that enable the use of agricultural crops in areas affected by salinity, among them is the use of vegetative mulch. The use of these cultural residues on the soil surface reduces its temperature, in addition to mitigating erosion rates, increases soil organic carbon and nutrient concentrations, increasing the infiltration rate and the amount of water at field capacity (Souza et al., 2018; Tang et al., 2021). In evaluating the productivity of maize crop irrigated with brackish water in soil with vegetative mulch, Goes et al. (2021) concluded that use of mulch up to 45 days after sowing provided higher productive performance.

Therefore, the objective of this study was to evaluate the effect of irrigation with brackish water in soil under different mulches on the productive performance of maize crop.

Materials and Methods

The study was carried out under field conditions at the Piroás experimental farm, belonging to the Universidade da Integração Internacional da Lusofonia Afro-Brasileira (UNILAB), Redenção, Ceará, Brazil. The region has the Aw' type climate, being considered rainy tropical, very hot (Köppen, 1923). Figure 1 shows the meteorological data for the period during which the experiment was conducted (August to November 2020).

The soil of the experimental area is classified as 'Argissolo Vermelho Amarelo' (EMBRAPA, 2018), with a density of 1.4 dm^{-1} and sandy loam textural class. The chemical attributes are shown in Table 1.

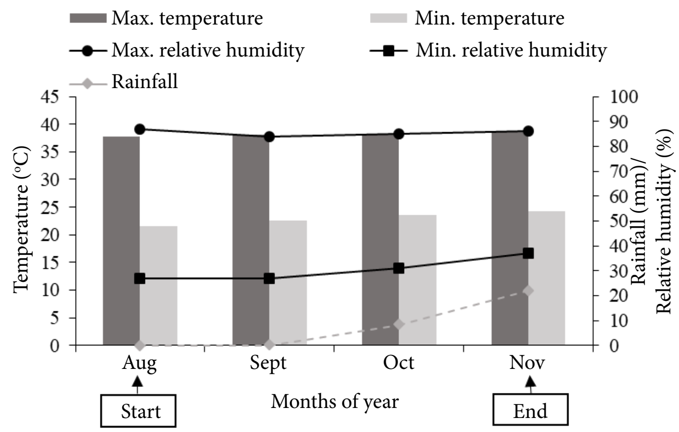


Figure 1. Values of temperature, relative humidity, and rainfall during the experiment.

Sowing of maize was done manually in the second half of the year 2020. Four seeds were used per hole of the super early variety BRS Caatingueiro, at spacing of 1.0 × 0.3 m, between rows and between plants, respectively. Each row was 12 m long, totaling 40 plants per plot (12 m²). At eight days after sowing (DAS) was performed the thinning and leaving only one plant per pit, in a length of 12 m.

The experimental design adopted was in randomized blocks in a 5 × 3 factorial scheme, with four replications, the first factor was the electrical conductivity of the irrigation water (ECw), where A1 = 1.0, A2 = 2.0, A3 = 3.0, A4 = 4.0, and A5 = 5.0 dS m^{-1} and the second factor was the different types of mulch, where NM - no mulch; MBL - mulch with banana leaves, and MSP - mulch with spontaneous plants. The mulches were inserted at the beginning of the reproductive phase (45 DAS) and were maintained until the end of the maize crop cycle.

The irrigation system used was the drip type. The amount of water applied was calculated based on the crop coefficient (Kc) (Doorenbos & Kassam, 1994), and reference

Table 1. Chemical characteristics of the soil before the beginning of the treatments.

Characteristics	Values
OM (g kg^{-1})	15.62
N (g kg^{-1})	0.98
P (mg kg^{-1})	15.0
K^+ (cmol$_c$ kg^{-1})	1.6
Ca^{2+} (cmol$_c$ kg^{-1})	6.0
Mg^{2+} (cmol$_c$ kg^{-1})	1.9
Na^+ (cmol$_c$ kg^{-1})	0.23
H^++Al^{3+} (cmol$_c$ kg^{-1})	2.31
Al (cmol$_c$ kg^{-1})	0.2
SB (cmol$_c$ kg^{-1})	8.3
CEC (cmol$_c$ kg^{-1})	12.04
V (%)	80.81
ECse (dS m^{-1})	0.31
pH	6.6

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

evapotranspiration (ETo) estimated by the class A tank method, installed near the experimental area, with a 2 day irrigation shift.

Brackish water was prepared using the salts of NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$, in the proportion of 7:2:1 (Medeiros, 1992), obeying the relationship between ECw and its concentration ($mmol_c L^{-1}$ = EC × 10) according to Richards (1954). For irrigation, drippers were used with a flow rate of 8 L h^{-1}, spaced at 0.30 m, and the distribution uniformity coefficient (DUC) of approximately 92%.

The irrigation time was estimated from Equation 1:

$$It = \frac{ET_c \times D_r \times 60}{A_e \times q} \quad (1)$$

where: It - irrigation time (min); ET_c - crop evapotranspiration (mm); D_r - dripper spacing; A_e - application efficiency (0.9); and, q = flow (L h^{-1}).

A leaching fraction of 0.15 (Ayers & Westcot, 1999) was added to the applied slurry.

At the end of the crop cycle (100 DAS) six maize plants from each useful plot were harvested, identified, and the following variables were evaluated: ear mass with straw - EMWS, ear mass without straw - EMWoS, mass of 1,000 grains - MG1,000 (with the aid of an analytical balance, expressed in grams), ear length - EL (measured with a ruler graduated in centimeters), ear diameter (by a digital caliper expressed in millimeters) - ED, and yield - YIE.

To evaluate normality, the data obtained were submitted to the Kolmogorov-Smirnov test ($p \leq 0.05$). After checking normality, the data were subjected to analysis of variance by F test, i.e., in cases of significance, for ECw or interaction, regression analysis was performed, while the plant mulch data were subjected to Tukey test ($p \leq 0.05$), using Assistat software 7.7 Beta (Silva &Azevedo, 2016).

Results and Discussion

According to the analysis of variance (Table 2), there was interaction between the factors brackish water (BW) and different dead mulches (DM) for the variables ear mass with straw (EMWS), ear mass without straw (EMWoS), ear length (EL), ear diameter (ED), and the yield (YIE) at the 1% probability level ($p < 0.01$) and isolated effect at the 5% probability level ($p < 0.05$) for the variable mass of 1,000 grains (MG1,000).

It can be seen in Figure 2, that the values of ear mass with straw were influenced by the interaction of the factors electrical conductivity of irrigation water and the different dead mulches. The treatments without mulch and with mulch of spontaneous plants showed a decreasing linear effect with the increase in the electrical conductivity of the water, while for the banana straw mulch, the model that best fitted was the quadratic polynomial, revealing an estimated value of EMWS of 154.59 g for an electrical conductivity of 2.58 dS m^{-1}. The rates of decreases per unit of concentration for the NM and MSP variables were 8.89 and 15.38%, respectively. There was also a decrease in straw ear mass from the lowest to the highest salt level of 39.56 and 61.53% for NM and MSP, respectively.

This effect of using mulch as soil protection promotes a reduction in water evaporation during irrigation, which reduces the precipitation of soluble salts in the root zone. Studies that prove the positive effect of inserting mulch into

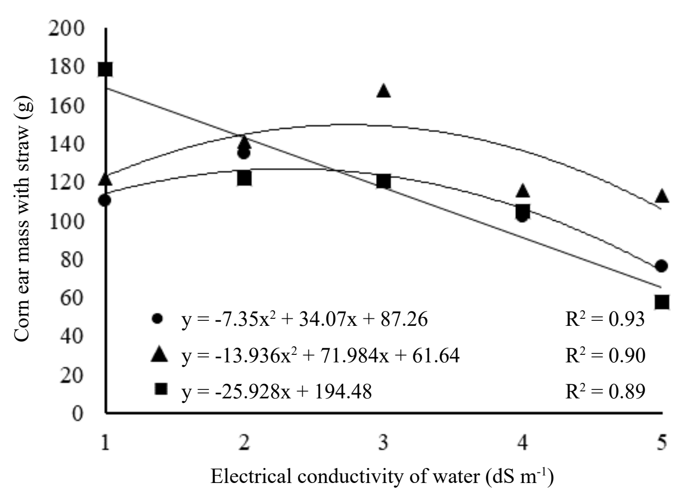


Figure 2. Corn ear mass with straw subjected to saline levels of irrigation water (ECw) in soil with different mulches. No mulch (●), mulch with banana leaves (▲), and mulch with spontaneous plants (■).

Table 2. Summary of the analysis of variance for ear mass with straw (EMWS), ear mass without straw (EMWoS), mass of 1,000 grain (MG1,000), ear length (EL), ear diameter (ED), and the yield (YIE) of maize plants subjected to irrigation with brackish water and different mulches.

SV	DF	Mean square					
		EMWS	EMWoS	MG1,000	EL	ED	YIE
Brackish water (BW)	4	6,061.36**	9,470.8**	1,329.59*	4.56**	12.61**	5,055,023.93**
Mulch (M)	2	2,723.58**	5,790.30**	1,806.19*	9.71**	140.04**	31,511,464.87**
BW × M	8	2,705.91**	2,005.60**	726.37ns	3.375**	13.84**	675,225.15**
Treatments	14	3,667.14**	4,679.18**	1,052.98*	4.83**	31.52**	2,280,344.76**
Residue	45	95.15	41.13	443.56	0.49	1.01	13,135.86
Total	59	-	-	-	-	-	-
CV%	-	8.2	6.59	8.34	5.5	2.63	3.87
OA%	-	119.02	97.27	252.67	12.74	38.4	2960.73

SV - Source of variation; CV - Coefficient of variation; OA - Overall average; DG - Degree of freedom; ** Significant at 1% probability level ($p < 0.01$); * Significant at 5% probability level ($p < 0.05$).

the soil during the reproductive phase were also found by Goes et al. (2021). These same authors concluded that the use of weed mulching in the reproductive phase of corn crop irrigated with 3.0 dS m^{-1} brackish water provided similar effect as in the present study. On the other hand, Costa et al. (2021) working with the same mulch, observed that the use of water with lower salinity increased the yield of mass of the spike with banana leaf.

It can be seen in Figure 3 that for banana leafless ear mass, the best fitting model was the linear decreasing model, where the rates of decreases per unit concentration for NM, MBL, and MSP were 12.23, 9.53, and 19.46%, respectively. In the period (1.0 to 5.0 dS m^{-1}), the reduction rates were 48.93, 38.13, and 77.85%, respectively. This reduction may be linked to the saline stress induced by irrigation that triggers progressive disturbances, such as osmotic, nutritional and toxicity stresses, directly affecting the components of production (Sousa et al., 2022).

Corroborating this study, Goes et al. (2021) also found lower mass of the ear without straw in corn plants when

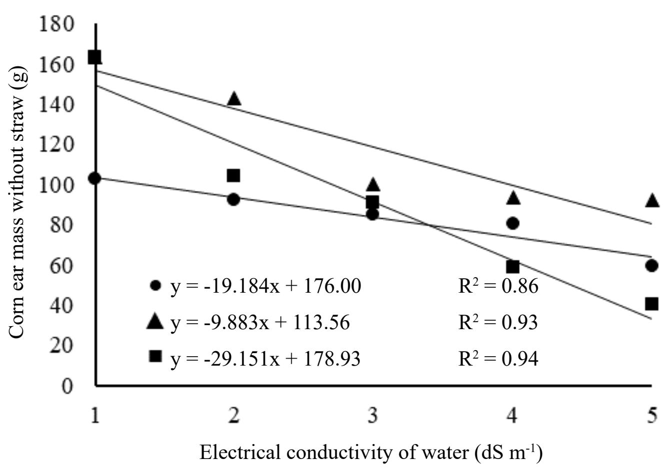


Figure 3. Corn ear mass without straw subjected to saline levels of irrigation water (ECw) in soil with different mulches. No mulch (●), mulch with banana leaves (▲), and mulch with spontaneous plants (■).

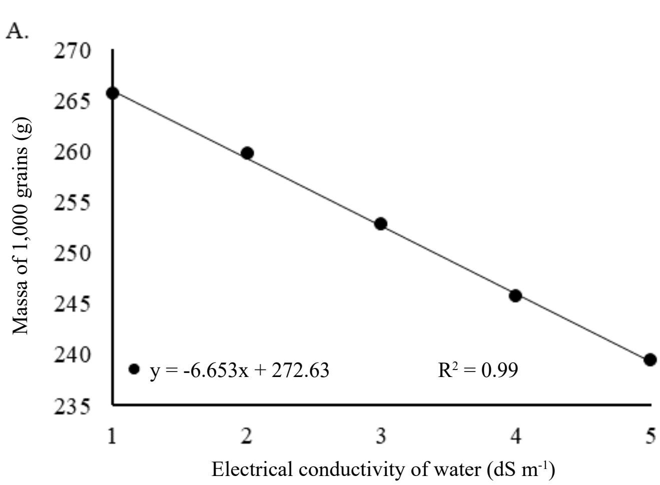
irrigated with water of higher salinity, but with less intensity in the presence of spontaneous mulch. Similar result for the reduction of ear mass without straw was reported by Rodrigues et al. (2020) when he did not use mulch on the soil in maize crop irrigated with brackish water.

For the mass of 1,000 grains, there was an isolated effect for the factors electrical conductivity of irrigation water and types of mulch. There was a reduction of 10.01% from the water with lower salinity to the water with 5.0 dS m^{-1} (Figure 4A), i.e. salinity resulted in a decrease in the average values of mass of 1,000 grains, as demonstrated by Goes et al. (2021) working with the same crop under field conditions in soil without mulching.

For the effect of plant mulch, it can be seen in Figure 4B, that the banana leaf mulch performed significantly better on average than the mulch with spontaneous plants and the control treatment (no mulch) for a smaller decrease in mass of 1,000 grains. The benefits of mulches are associated with maintaining moisture, as well as helping to regulate the temperature range of the soil, and promoting mineralization. These soil microenvironment effects favor crop productivity and water use efficiency (Qin et al., 2019; Luo et al., 2020). Corroborating with the present study, Zhang et al. (2022b), using different ground covers on corn crops, showed an increase in mass of 1,000 grains when compared to treatments without soil protection.

Figure 5 shows that there was an interaction between the factors electrical conductivity of irrigation water and dead coverage for the variable ear length, where the best model was a decreasing linear model. Analyzing the results, it can be seen that the treatment without cover was the most affected by water salinity, with a reduction for the variables (NM, MBL, and MSP), according to the estimated equations were 25.62, 11.19 and 12.54%, respectively, in the interval from the lowest (1.0 dS m^{-1}) to the highest salinity (5.0 dS m^{-1}).

This result is similar to the study developed by Costa et al. (2021) growing corn under saline stress and with the use of soil mulch, i.e., these same authors found a reduction in



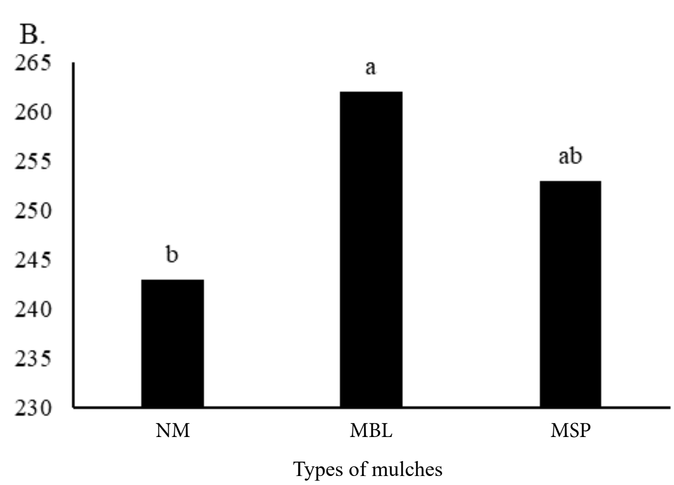


Figure 4. Mass of 1,000 grains of corn subjected to saline levels of irrigation water in soil no mulch (NM), mulch with banana leaves (MBL), and mulch with spontaneous plants (MSP).

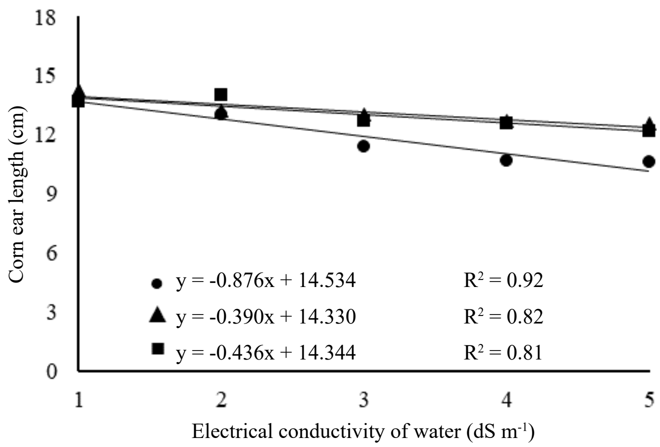


Figure 5. Corn ear length subjected to saline levels of irrigation water (ECw) in soil with different mulches. No mulch (●), mulch with banana leaves (▲), and mulch with spontaneous plants (■).

ear length with increasing saline stress, but with less intensity in soil with the presence of mulch at 90 DAS. Similarities regarding the reduction of ear length as a function of saline stress were also detected in a study by Freire et al. (2022) when irrigating corn.

By analyzing Figure 6, it can be identified that the mathematical model that best fitted was the decreasing linear model, whose treatments with and without covers are negatively influenced by the presence of salts in the water used for irrigation in the variable ear diameter. For the 1.0 dS m^{-1} level the NM variable shows an estimate of 37.114 mm, MBL = 42.248 mm, and MSP = 42.090 mm. The NM variable shows a reduction compared to MBL and MSP of 12.15 and 11.82%, revealing that the lack of soil protection contributes to triggering more severe saline stress. It is noteworthy that even with the gradual increase in the electrical conductivity of irrigation water, the diameter of the ear was not intensely compromised in the treatments with mulch with banana leaves. The reduction rates in the period (1.0 to 5.0 dS m^{-1}) for the variables MBL and MSP were 9.01 and 12.29% according to the estimated equations.

The performance of mulches as strategies to mitigate saline stress can be influenced by the material and density of the mulches (Lessa et al., 2021). However, studies conducted with brackish water in corn cultivation in soil without mulch by Costa et al. (2021), also detected a reduction in ear diameter.

The increase in the electrical conductivity of the irrigation water promoted a decrease in productivity, but in a smaller proportion in the treatments with the presence of vegetation cover, presenting the linear decreasing model for the treatments mulch with spontaneous plants (MSP) with maximum productivity of 4,500 kg ha^{-1} for water of lower salinity (0.8 dS m^{-1}) and 2,920 kg ha^{-1} for water of higher salinity, with a reduction of 29.15%, no mulch (NM), with maximum productivity of 3,000 kg ha^{-1} for water of lower salinity (0.8 dS m^{-1}) and 2,720 kg ha^{-1} for water of higher salinity, with a reduction of 35.25%, while for the treatment mulch with banana leaves (MBL), the quadratic polynomial model was the best fit, showing a maximum yield of 3,644.26 kg ha^{-1} at electrical conductivity of water of 1.3 dS m^{-1} (Figure 7).

The reduction in grain yield attributed to salinity may be associated with the metabolic energy cost and the attempt to adapt to salinity (Freire et al., 2022). However, the cover mitigates the evaporation of plant-available water, preventing the increase in salt concentration and promoting the depletion of salts on the soil surface and near the root zone of plants (Melo Filho et al., 2017).

Similar trends to the present study were described by Goes et al. (2021) working with corn crop in soil mulch with spontaneous plants inserted during the reproductive phase, where irrigation with lower salinity water in the presence of mulch provided a yield of 4,220 kg ha^{-1}. On the other hand, Rodrigues et al. (2020) recorded a productivity below (1,523 kg ha^{-1}) that found in this study when using brackish water on corn crop in soil without vegetal mulch. Similarly, Freire et al.

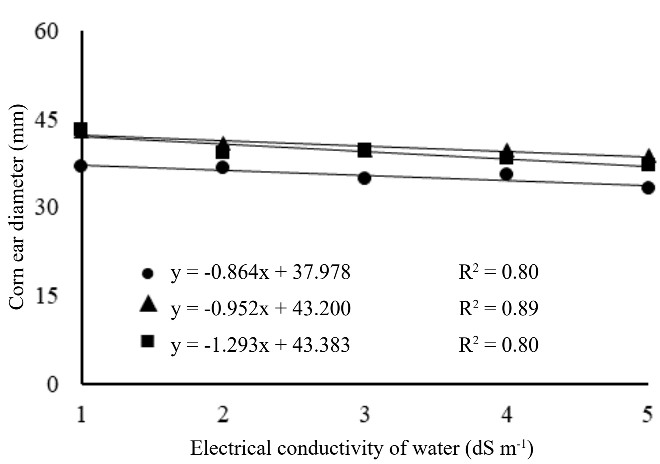


Figure 6. Corn ear diameter subjected to saline levels of irrigation water (ECw) in soil with different mulches. No mulch (●), mulch with banana leaves (▲), and mulch with spontaneous plants (■).

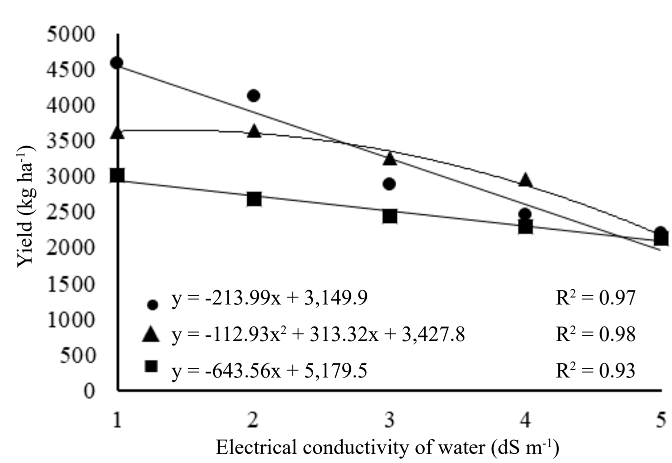


Figure 7. Corn yield subjected to saline levels of irrigation water (ECw) in soil with different mulches. No mulch (●), mulch with banana leaves (▲), and mulch with spontaneous plants (■).

(2022) when evaluating the effect of saline stress on corn crop under field conditions in soil without mulch, recorded a lower yield than in the present study (2,450.6 kg ha^{-1}).

Conclusions

Saline stress reduces the mass of 1,000 grain, length, and diameter of the corn ear, ear mass with and without straw in the presence of spontaneous plant mulch and banana leaves.

The use of volunteer plant and banana leaf mulch is more efficient for a smaller decrease in mass of 1,000 grain compared to the control treatment (no plant mulch).

The mulches with banana leaves and spontaneous plants associated with 1.0 and 3.0 dS m^{-1} water allowed higher yields compared to the treatment without mulch.

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Compliance with Ethical Standards

Author contributions: Conceptualization: GFG; GGS; Data curation: GFG; Formal analysis: GFG, CINL, RSN; Funding acquisition: GGS; Investigation: GFG, GGS; Methodology: GFG, GGS, FHRC, SPG; Project administration: GFG, GGS; Writing - original draft: GFG, GGS, FHRC, CINL; Writing - review & editing: GGS, RSN, SPG.

Conflict of interest: The authors declare that they have no conflict of interest.

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