Maize crop yield in function of salinity and mulch[1]

Produtividade da cultura do milho em função da salinidade e da cobertura morta vegetal

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HIGHLIGHTS:

The use of water with high salinity (4.0 dS m⁻¹) reduced the mass of the ear with and without straw and the diameter of the ear.
Vegetable mulch mitigates the deleterious effects of salts on productivity.
The presence of vegetation mulch increased mass of the ear with and without straw and the diameter of the ear.

ABSTRACT: Irrigation with saline water affects the agronomic performance of the maize crop; however, the use of vegetal mulch may mitigate salt stress and promote an increase in yield. In this way, this study aimed to evaluate the grain yield of the maize plants submitted to different water salinity levels in the presence and absence of mulch. The experiment was conducted in a randomized block design arranged in a 2 × 2 factorial scheme. The first factor was the salinity of the irrigation water (1.0 and 4.0 dS m⁻¹) and the second, with and without mulch, and five replicates. The variables analyzed were: unhusked ear mass, husked ear mass, cob mass, straw mass, husked ear diameter, husked ear length, and yield. The irrigation water with higher electrical conductivity affects negatively the ear mass with and without straw, ear diameter and ear length. The use of vegetation cover on the soil increased the unhusked ear mass with and without straw, ear diameter and length. The water with higher salinity (4.0 dS m⁻¹) reduces the maize grain yield but with less intensity in the presence of mulch.

Key words: *Zea mays* L., salt stress, soil cover

RESUMO: A irrigação com água salina afeta o desempenho agronômico da cultura do milho, no entanto, a utilização de cobertura morta vegetal pode mitigar o estresse salino e promover aumento na produtividade. Desta forma, objetivou-se avaliar a produtividade da cultura do milho submetido a diferentes níveis salinos na água de irrigação, na presença e ausência de cobertura morta vegetal. O delineamento utilizado foi de blocos ao acaso em esquema fatorial 2 × 2, sendo o primeiro fator a salinidade da água de irrigação (1,0 e 4,0 dS m⁻¹) e o segundo, com e sem cobertura morta e cinco repetições. As variáveis analisadas foram: massa da espiga com e sem palha e do sabugo, diâmetro da espiga, comprimento da espiga e a produtividade. A água de irrigação com maior condutividade elétrica afetou negativamente a massa da espiga com e sem palha, diâmetro e comprimento de espiga. O uso de cobertura vegetal no solo aumentou a massa da espiga com e sem palha, diâmetro e comprimento de espiga. A agua de maior salinidade (4,0 dS m⁻¹) reduz a produtividade da cultura do milho, porém com menor intensidade na presença da cobertura vegetal morta.

Palavras-chave: *Zea mays* L., estresse salino, proteção do solo

Introduction

Maize, also known as corn (*Zea mays* L.), can be used in human, animal, and bioenergy production (Lopes et al., 2019). It is considered moderately tolerant to irrigation with saline water with electrical conductivity of up to 1.7 dS m^{-1}, with no reduction in grain yield (Ayers & Westcot, 1999). Thus, investigating and using different varieties of corn that are more tolerant to salinity may promote the better performance of the plant in environments with salt.

Irrigation is a factor that allows achieving maximum production, especially in tropical regions with hot and dry climates, as is the case in the Brazilian Northeastern (Holanda et al., 2016). However, the scarcity of good quality water in this region promotes the use of salty water.

Salt stress causes a reduction in osmotic potential. It results in disturbances in water relations, changes in the absorption and use of essential nutrients (Oliveira et al., 2014), in physiological functions, causing the partial closure of stomata, limiting CO_2 assimilation, and reducing photosynthesis, consequently the yield of crops (Taiz et al., 2017; Rodrigues et al., 2020).

It is worth mentioning that strategies intended to mitigating salt stress have been tested, including vegetal mulch, a conservationist practice that increases the water storage in the soil and the yield of the crops (Vereecken et al., 2014; Carvalho et al., 2018). Lessa et al. (2019), evaluating the use of plant mulch in sorghum plants irrigated with saline waters, also found a positive effect of this practice. Similarly, Barbosa et al. (2021) also found that the use of mulch minimized the impact of salts on leaf growth and gas exchange, especially in cowpea plants.

In this way, this study aimed to evaluate the yield of the maize crop submitted to different irrigation water salinity in the presence and absence of mulch.

Material and Methods

The experiment was carried out in an experimental farm belonging to The University for International Integration of the Afro-Brazilian Lusophony (UNILAB), Redenção, Ceará, Brazil.

The climate of the region is AW-type, characterized as rainy tropical, very warm, with predominant rains in the summer and autumn seasons (Alvares et al., 2013).

Figure 1 shows the meteorological data during the period in which the experiment was conducted (July to November 2019).

The soil in the experimental area is classified as Ultisol with a soil bulk density of 1.4 kg dm^{-3}, belonging to the sandy-loam texture. The chemical attributes are shown in Table 1.

The fertilization of the plants was obtained according to Coelho (2006), being 160 kg ha^{-1} of N, 70 kg ha^{-1} of P_2O_5, and 120 kg ha^{-1} of K_2O, respectively. However, the source used was organic through cattle biofertilizer as fertilization in the sowing furrow and goat manure as topdressing fertilization.
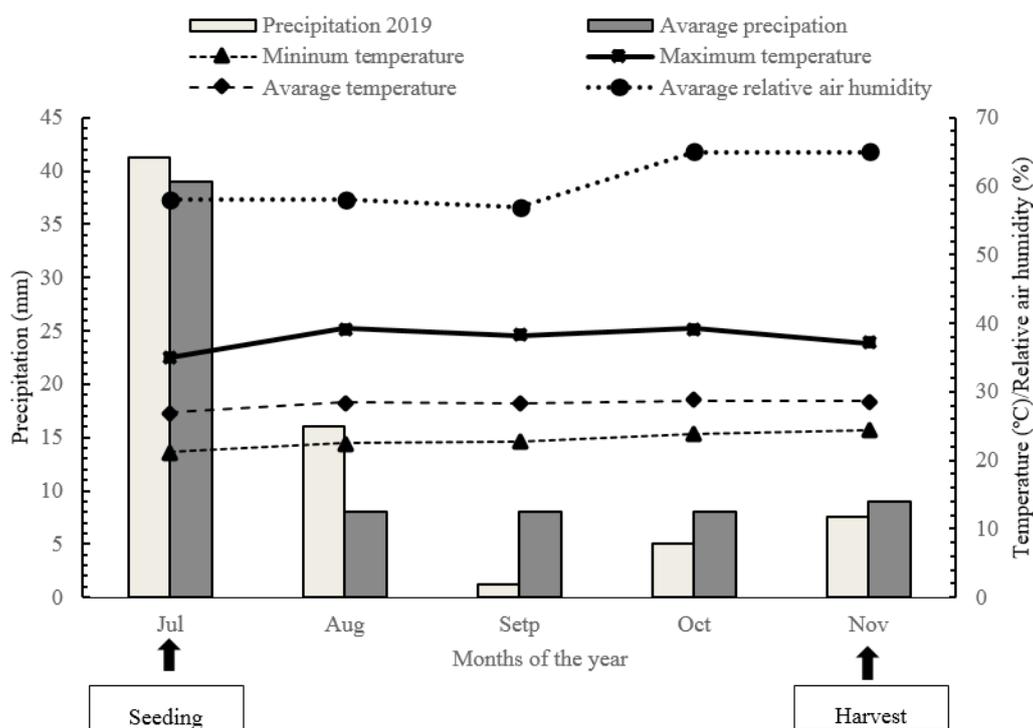
Figure 1. Mean values of temperature, relative air humidity and precipitation during the experiment

Table 1. Soil chemical characterization before the application of treatments

OM	N	P	K$^+$	Ca^{2+}	Mg^{2+}	Na$^+$	H$^+$ + Al^{3+}	Al	SB	CEC	V	ECse	pH
(g kg^{-1})		(mg kg^1)				(cmol$_c$ kg^{-1})					(%)	(dS m^{-1})	
11.9	0.75	16	0.14	4.5	1.9	0.23	1.98	0.2	6.8	8.8	77	0.19	6.6

OM - Organic matter determined according to the Walkley-Black method; N - Determinado através da titulação após destilação a vapor usando o método Kjeldahl, de acordo com Tedesco et al. (1995); P and K were extracted with Mehlich-; Ca^{2+}, Mg^{2+}, Na$^+$ and Al^{3+} were extracted by KCl 1 M, CEC - The soil CEC is the sum of the concentration of H$^+$ + Al^{3+}, K$^+$, Ca^{2+} and Mg^{2+} cátions; V - Base saturation was calculated by dividing the sum of the bases (K$^+$, Ca^{2+}, and Mg^{2+}) by the CEC and multiplying by 100%; Soil pH was determined in a 0.01 mol L^{-1} CaCl$_2$ suspension at a soil:solution ratio of 1:2.5 and ECse - Electrical conductivity of the soil saturation extract at 25 °C

The Criolo maize variety was sown manually on July 4, 2019, at a spacing of 1.0 x 0.3 m. Ten days after sowing (DAS), 100% germination was observed; later, thinning was carried out, leaving only one plant per hole.

The experiment was conducted in a randomized block design arranged in a 2 x 2 factorial scheme. The first factor was the salinity of the irrigation water (1.0 and 4.0 dS m^{-1}) and the second, with and without mulch, with five replicates and four plants per experimental unit.

Vegetal mulch from spontaneous plants was used to cover the soil (8 cm layer) at the beginning of the reproductive phase of corn (R1 - this phenological stage begins when the styles-stigmas are visible, out of the ears), this stage is defined by the beginning of the silking and pollination.

The amount of water applied was calculated based on the crop coefficient (Kc) (Doorenbos & Kassam, 1994) and reference evapotranspiration (ET$_0$) determined by the evaporation pan method, installed near to the experimental area, with an irrigation frequency of two days.

The electrical conductivities in the irrigation water were obtained by the addition of the salts, NaCl, CaCl$_2$.2H$_2$O, and MgCl$_2$.6H$_2$O, in the equivalent proportion of 7:2:1, in the public supply water (0.5 dS m^{-1}), following the relationship between ECw and its concentration (mmol$_c$ L^{-1} = EC x 10), according to Rhoades et al. (2000). For irrigation, drippers were used with a flow rate of 8 L h^{-1}, spaced at 0.30 m, and distribution uniformity coefficient (CUD) around 92%, monitored through tensiometers, set at 20 cm in each experimental unit.

The irrigation time was determined from Eq. 1.

$$T_i = \frac{ET_c \ E_p}{E_a \ q} 60 \qquad (1)$$

where:

T_i - irrigation time (min);
ET_c - evapotranspiration of the crop (mm);
E_p - spacing between drippers;
E_a - water application efficiency (0.9); and,
q - flow rate (L h^{-1}).

For the cover applied before and during the differentiation of treatments, a leaching fraction of 0.15 was added (Ayers & Westcot, 1999).

At the end of the maize crop cycle (110 DAS), five plants were harvested from each plot (central rows) and identified. Then, they were put to dry for 15 days in a protected environment until reaching constant mass.

After drying, the following variables were evaluated: ear+husk mass - EHM, ear mass - EM, cob mass - CM, straw mass - SM (measured with a precision scale, expressed in grams); ear diameter - ED, ear length - EL (measured with the aid of a digital caliper, expressed in millimeters), and grain yield - GRY.

The data were submitted to analysis of variance. After verifying significance, the Tukey test was used to compare the means (p ≤ 0.05). The ASSISTAT 7.7 BETA software (Silva & Azevedo, 2016) was used in the statistical analysis.

Results and Discussion

According to the analysis of variance (Table 2), there was interaction between the electrical conductivity of the irrigation water (A) and mulch (VM) for grain yield (GRY) at p ≤ 0.01. There was isolated effect for both factors at p ≤ 0.01 for ear+husk mass (EHM), ear diameter (ED), and ear length (EL), and at p ≤ 0.05 for ear mass (EM). There was no significant effect on the cob (CM) and straw (SM) mass.

In Figure 2A, it is possible to observe that the ear mass with husk was superior in plants irrigated with low-salinity water (1421 g). However, when the plants were irrigated with high-salinity water (1194.3 g), there was a decrease of 15.95%. This result reflects the impacts caused by the soluble salts present in the irrigation water, which affect the absorption of essential nutrients such as potassium (important in the quality of the ear and consequently in the straw). Rodrigues et al. (2020) evaluated the salt stress in the maize crop under field conditions; in the same edaphoclimatic conditions of their study, they observed a reduction in the ear+husk mass at 110 days after sowing.

The highest values of ear+husk mass were registered in the treatments with vegetal mulch (1437.1 g) concerning the treatments without mulch (1179.3 g), obtaining a reduction of 17.93% (Figure 2B). It is noteworthy that mulch is essential to control soil moisture, thus reducing water evaporation and contributing to water savings (Luís et al., 2020). Reinforcing this information about this conservationist practice, Borges et al. (2014) registered the same trend when cultivating maize crops.

There was an increase in the values of ear mass in the treatments irrigated with low-salinity water (1116.7 g) in comparison with the treatments irrigated with high-salinity water (698.3 g), showing a reduction of 39.88% (Figure 3A). Probably it is because of the lower concentration of salts in the soil (ECse = 0.52 dS m^{-1}), so the water absorption of the plant is

Table 2. Summary of the analysis of variance for unhusked ear mass (UEM), husked ear mass (HEM), cob mass (CM), straw mass (SM), husked ear diameter (ED), husked ear length (EL) and yield (Y) maize culture in function of salinity and soil mulch

SV	DF	Mean square						
		UEM	HEM	CM	SM	ED	EL	Y
Saline waters (SW)	1	0.00259*	0.0087**	0.0044^{ns}	0.0015^{ns}	25.0693**	3.8281**	1.8159^{ns}
Soil mulch (SM)	1	0.00332*	0.0046**	0.0008^{ns}	0.0000^{ns}	59.8868**	3.2670**	11.6180**
SW x SM	1	0.00037^{ns}	0.0006^{ns}	0.000^{ns}	0.002^{ns}	0.59801^{ns}	0.0086^{ns}	15.7084**
Residue	16	0.00045	0.0002	0.0020	0.0006	1.5037	0.3629	88416
Total	19	-	-	-	-	-	-	-
CV (%)	-	16.24	18.42	27.41	34.16	4.13	6.23	21.48

SV - Source of variation; DF - Degrees of freedom; CV - Coefficient of variation; ns - Not significant, **; *Significant at p ≤ 0.01 and p ≤ 0.05 by F test, respectively
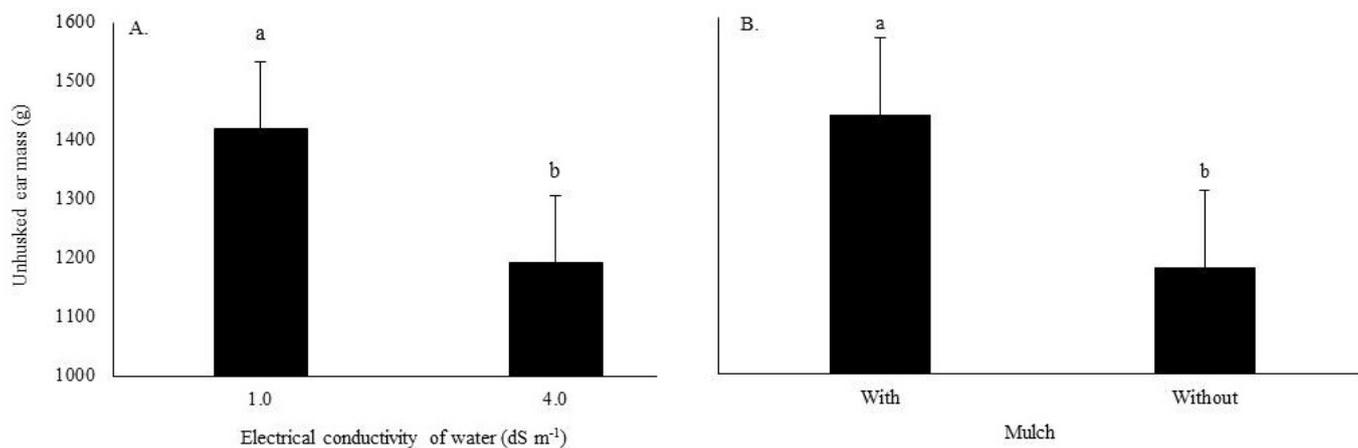
Columns followed by same lowercase letter, do not differ from each other by the Tukey test (p ≤ 0.05)
Figure 2. Unhusked ear mass as a function of electrical conductivity of water (A) and mulch (B)
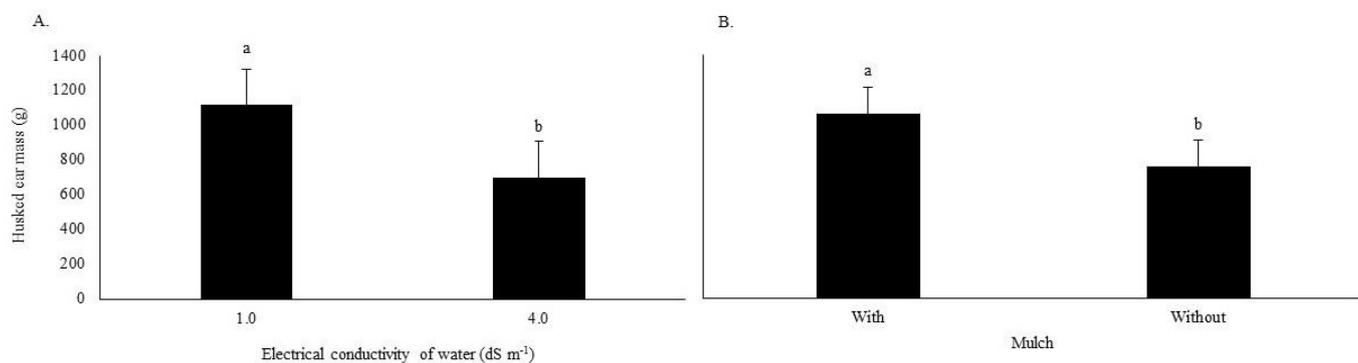
Columns followed by same lowercase letter, do not differ from each other by the Tukey test (p ≤ 0.05)
Figure 3. Husked ear mass as a function of electrical conductivity of water (A) and mulch (B)

not as impaired as plants that undergo intense salt stress, where there is a reduction in osmotic potential (Taiz et al., 2017).

Likewise, Rodrigues et al. (2020) pointed out a reduction of 33.18% between the extreme salinity values in the maize plants grown under field conditions. Carvalho et al. (2012) also registered a reduction in the ear mass when irrigated with high-salinity water (3.3 dS m^{-1}) compared with low-salinity water (1.2 dS m^{-1}).

In the presence of the mulch, the plants express the greater value of ear mas (1060 g) concerning the treatment without mulch (755 g), obtaining a reduction of 28.77% (Figure 3B). This result may be related to the positive effect of vegetal mulch

in protecting the soil and maintaining its moisture, improving the profitability and quality. Borges et al. (2014), analyzing the corn grain yield with the adoption of mulch, showed a trend similar to that of the present study for this variable.

The low-salinity water resulted in a higher ear diameter (30.84 mm) when compared to the high-salinity water (28.6 mm), with a reduction of 7.26% (Figure 4A). It should be noted that salinity affects water absorption, physiological processes, and the yield aspects of crops (Lacerda et al., 2011; Sousa et al., 2016).

Contrary to these findings, Costa et al. (2015) reported that maize yield was not affected by salt stress.
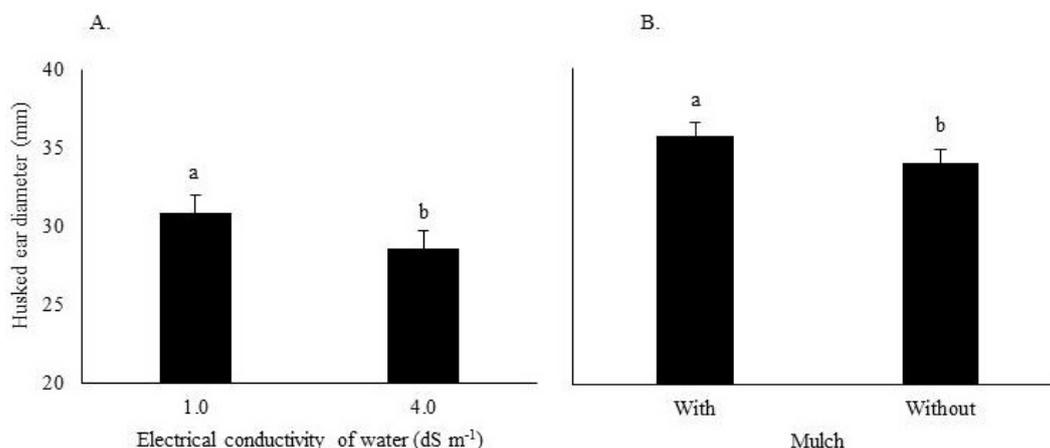
Columns followed by same lowercase letter, do not differ from each other by the Tukey test (p ≤ 0.05)
Figure 4. Husked ear diameter as a function of electrical conductivity of water (A) and mulch (B)

Likewise, Rodrigues et al. (2020) evaluated corn plants under field conditions with salt stress; they did not observe negative interference from the salinity of the irrigation water on the ear diameter.

The presence of mulch increased the ear diameter (31.45 mm) concerning the absence (27.99 mm), registering a reduction of 11% (Figure 4B). The soil protection minimizes the loss of water by evaporation, favoring the increase in the ear diameter. In a study conducted by Borges et al. (2014), they found a positive influence of mulch on the ear diameter.

According to Figure 5A, the high-salinity water negatively affected the ear length, obtaining lower mean values (9.18 cm) than the low-salinity water (10.05 cm), with a reduction of 8.56%. This effect can be explained by the fact that salinity inhibits plant growth due to osmotic, toxic effects affecting absorption of essential nutrients and, consequently, yield components (Braz et al., 2019; Rodrigues et al., 2020).

These same authors did not observe a negative effect of salt stress on the ear length. Figure 5B shows that the treatments with soil cover obtained higher values of ear length (10.02 cm) concerning the absence (9.21 cm), being reduced by 8.08%. Favorato et al. (2016) studied the crop of green maize in the no-tillage system and obtained results similar to the present study. On the other hand, Borges et al. (2014) found no significant effect of mulch on ear length.

Figure 6 shows interaction between irrigation water salinity and soil cover. Irrigation with low-salinity water in the presence of mulch provides the highest grain yield (2766.67 kg ha^{-1}), statistically superior to treatment with high-salinity water (2.400 kg ha^{-1}). Likewise, low-salinity water in the absence of mulch (2.100 kg ha^{-1}) was also statistically superior to high-salinity water (1.253.33 kg ha^{-1}). This low grain yield is possibly associated with the studied variety (Criola) and salt stress; however, it is above the average grain yield of Ceará (1.232 kg ha^{-1}) and below the national average (5.543 kg ha^{-1}) (CONAB, 2021).

Melo Filho et al. (2017) reported that soil cover decreases the evaporation of water available to plants, avoiding the increase in salt concentration and promoting depletion of salts in the soil surface and close to the root zone of the plants. It is worth noting that the reduction in grain yield attributed to
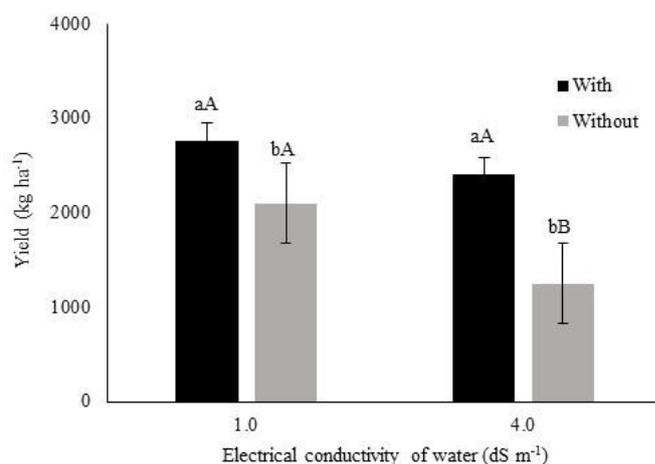
Columns followed by the same lowercase letters at the same electrical conductivity of water or by the same uppercase letters at the same soil condition (with and without mulch) do not differ by the Tukey test (p ≤ 0.05)

Figure 6. Grain yield of maize plants as a function of electrical conductivity of water on soil with and without mulch

salt stress may be associated with the metabolic cost of energy and the attempt to adapt to salinity (Lacerda et al., 2011; Lima et al., 2020).

Corroborating this study, Rodrigues et al. (2020), investigating the maize crop irrigated with saline water, observed a decrease in grain yield. Feng et al. (2017) also registered a similar tendency when they found a reduced grain yield of the maize crop grown with high-salinity water.

Conclusions

1. The irrigation water with higher electrical conductivity negatively affects the ear+husk mass, ear mass, ear diameter, and ear length.

2. The use of vegetation cover on the soil increased the ear+husk mass, ear mass, ear diameter, and ear length.

3. The water with higher salinity (4.0 dS m^{-1}) reduces the productivity of the corn crop but with less intensity in the presence of mulch.

Acknowledgments
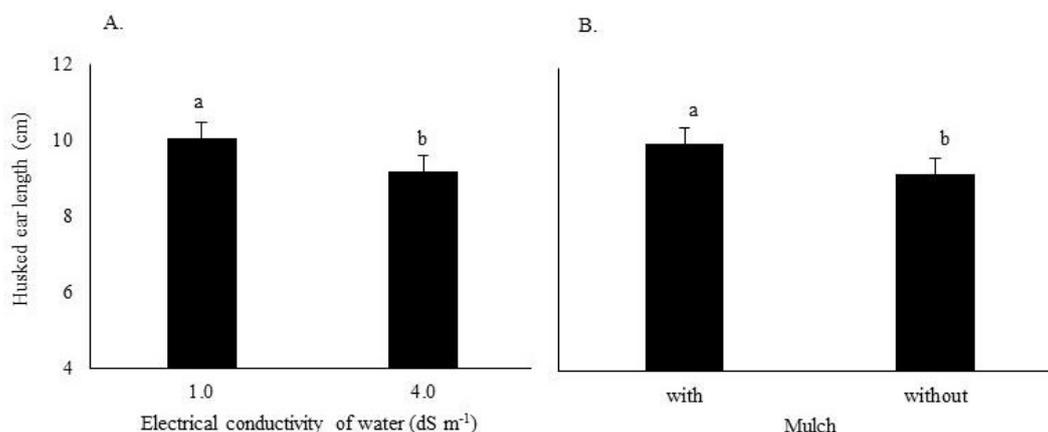
Columns followed by same lowercase letter, do not differ from each other by the Tukey test (p ≤ 0.05)

Figure 5. Husked ear length as a function of electrical conductivity of water (A) and mulch (B)

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