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Scientific Article

Agronomic performance of sorghum crop under salt stress in soil with plant mulch

Desempenho agronômico da cultura do sorgo sob estresse salino em solo com cobertura morta vegetal

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ABSTRACT - Excess salts in irrigation water affect the production potential of agricultural crops; however, the use of plant mulch can mitigate salt stress. In this context, the objective was to evaluate the yield of sorghum crop under salt stress and different strategies for using plant mulch. The experiment was conducted under field conditions from July to October 2021, in the municipality of Redenção, Ceará, in the Baturité Massif region, Brazil. The experimental design used was randomized blocks, in a 5 x 2 factorial scheme, referring to the mulching strategies (MS1: with mulch throughout the cycle; MS2: without mulch throughout the cycle; MS3: with mulch during stage 1 = germination until panicle initiation; MS4: with mulch during stage 2 = panicle initiation until flowering; MS5: with mulch during stage 3 = flowering until physiological maturity) and two levels of electrical conductivity of water - ECw (0.8 dS m^{-1} and 6.0 dS m^{-1}), with 4 repetitions. Using plant mulch throughout the cycle and the control treatment are more efficient for panicle weight. Using plant mulch throughout the cycle under irrigation mitigates salt stress and promotes greater yield in sorghum. From the beginning of panicle appearance until flowering, irrigation with water of lower salinity led to higher yield.

Keywords: *Sorghum bicolor* L. Salinity. Soil protection.

RESUMO - O excesso de sais na água de irrigação afeta o potencial produtivo das culturas agrícolas, no entanto, o uso de cobertura morta vegetal pode mitigar o estresse salino. Neste sentido, objetivou-se avaliar a produtividade da cultura do sorgo sob estresse salino em diferentes estratégias de uso de cobertura morta vegetal. O experimento foi conduzido em condições de campo no período de julho a outubro de 2021, no município de Redenção, Ceará, na região do Maciço de Baturité. O delineamento experimental utilizado foi em blocos ao acaso, em esquema fatorial 5x2, referentes às estratégias com uso de cobertura morta vegetal: EC1: com cobertura durante todo o ciclo; EC2: sem cobertura durante todo o ciclo; EC3: com cobertura durante a fase 1 = germinação até a iniciação da panícula); EC4: com cobertura durante a fase 2= iniciação da panícula até o florescimento; EC5: com cobertura durante a fase 3= floração até a maturação fisiológica; e dois níveis de condutividade elétrica da água - CEa (0,8 dS m^{-1} e 6,0 dS m^{-1}), com 4 repetições. O uso de cobertura durante todo o ciclo e o tratamento controle são mais eficientes para a massa da panícula. O uso da cobertura morta vegetal durante todo o ciclo sob irrigação atenua o estresse salino e promove maior produtividade. No início do aparecimento da panícula até o florescimento, a irrigação com água de menor salinidade evidenciou maior produtividade.

Palavras-chave: *Sorghum bicolor* L. Salinidade. Proteção do solo.

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INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is a grass with probable origins in Africa. It is a plant of tropical region and of C4 metabolism, being used in animal diet as an energy feed (VENKATESWARAN; ELANGOVAN, SIVARAJ, 2019), as its nutritional value is similar to that of maize (BELL et al., 2018). It is adapted to regions with greater scarcity and irregular distribution of rainfall (SALVADOR et al., 2021).

However, the increase in population density drives the use of good quality water resources in irrigated agriculture, which is an indispensable practice in regions with high climatic variability, such as the semi-arid region of Brazil. However, the vast majority of available water sources have a high salt content, which can have consequences on soil-water-plant relationships, affecting physiological activities and the production potential of crops (ZHAO et al., 2022; SOUSA et al., 2023).

Salt stress, caused by the toxic effects of salts absorbed by plants, mainly Na^+ and Cl^-, can lead to problems such as nutritional imbalance, ion toxicity, water deficit and lower yield, inhibiting plant development. In addition, sorghum plants under salt stress conditions reduce their capacity for nutrient absorption and assimilation (SÁ et al., 2018; SOUSA et al., 2022).

However, some strategies have been used to mitigate the effects of salinity, including mulching. This conservational practice acts in the soil as an insulating agent, preventing sudden temperature fluctuations, and can contribute to increasing the interval between irrigations by retaining water in the soil and keeping it moist for longer, thus avoiding a greater increase in the concentration of salts in the root zone of plants (CARVALHO; RIBEIRO; GOMES, 2018; GADELHA et al., 2021). Goes et al. (2021), when evaluating salt stress in maize crop in soil with mulch applied up to 65 days after sowing, found a mitigating effect of this practice on agronomic performance.

In view of the above, the objective of this study was to evaluate the agronomic performance of sorghum under salt stress and different mulching strategies.

MATERIAL AND METHODS

The experiment was conducted under field conditions, from July to October 2021, in the experimental area belonging to the University of International Integration of Afro-Brazilian Lusophony (UNILAB), Liberdade Campus, municipality of Redenção, in the Baturité Massif, state of Ceará, Brazil. The climate of the region is BSh' type, as very high temperatures and rainfall prevail in the summer and autumn seasons (ALVARES et al., 2013). Means of temperatures, relative humidity and precipitation during the experimental period are presented in Figure 1 according to data obtained from Funceme (2021).

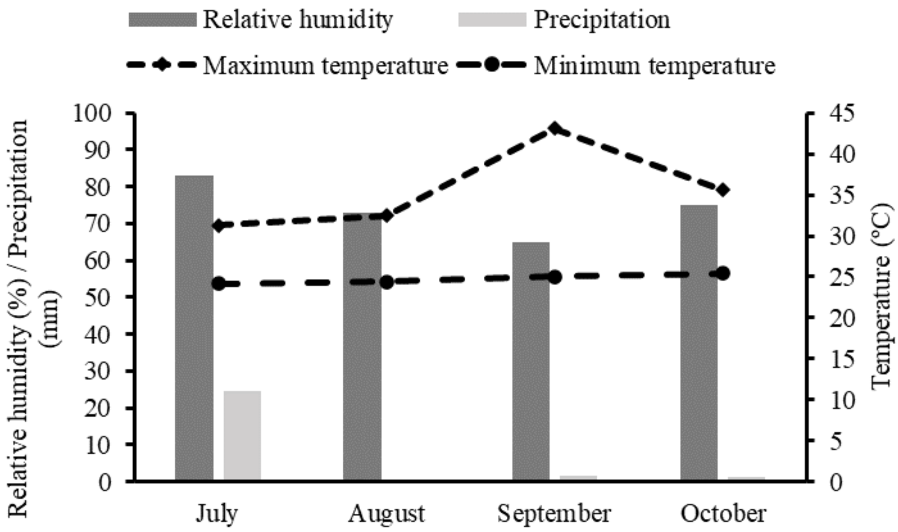

Figure 1. Precipitation, relative humidity and minimum and maximum temperatures during the months of conducting the experiment.

Samples were collected at 0-20 cm depth in the experimental area and sent to the Soil and Water Laboratory of the Department of Soil Sciences of the Federal University of Ceará (UFC) to determine the chemical attributes of the soil prior to application of the treatments, as presented in Table 1, following the methodology described by Teixeira et al. (2017).

Table 1. Chemical characterization of the soil.

OM	N	Ca^{2+}	K^+	Mg^{2+}	Na^+	$H^+ + Al^{3+}$	Al^{3+}	SB	CEC	V	P	pH	ECse
($g\ kg^{-1}$)					($cmol_c\ kg^{-1}$)					(%)	($mg\ kg^{-1}$)	(H_2O)	($dS\ m^{-1}$)
8.4	0.53	2.5	0.29	2.2	0.15	1.32	0.05	5.14	6.46	97	26	6.5	0.21

OM - Organic matter; SB - sum of bases; CEC - cation exchange capacity; V - base saturation; ECse - electrical conductivity of soil saturation extract.

The experimental design was randomized blocks, in a 5x2 factorial scheme, referring to the mulching strategies, namely: MS1 - with mulch throughout the cycle; MS2 - without mulch throughout the cycle; MS3: with mulch during growth stage 1, from emergence to panicle initiation; MS4: with mulch during growth stage 2, from panicle initiation to flowering; MS5: with mulch during growth stage 3, from flowering to physiological maturity, and two levels of electrical conductivity of irrigation water (W1 – 0.8 dS m^{-1} and W2 – 6.0 dS m^{-1}), with four replications.

The experimental area was 105.6 m^2, with a total of 40 plots, 2 m long and 40 plants, 24 plants per experimental unit per treatment within a usable area of 1.2 m.

Fertilization was carried out according to the recommendation of Fernandes et al. (1993), with 60 kg ha^{-1} of N, 70 kg ha^{-1} of P_2O_5 and 80 kg ha^{-1} of K_2O, using the fertilizer sources urea (45% N), single superphosphate (18% P_2O_5) and potassium chloride (62% K_2O), respectively. N and K were applied as basal and as top-dressing at 21 days after sowing (DAS), while P was entirely applied as basal.

Sowing was carried out manually with grain sorghum seeds of the 'Al Precioso' variety, whose main characteristics are high rusticity, earliness, drought tolerance and, despite being used for grain production, it can also be used for silage production. Sorghum seeds were distributed in linear meter with a spacing of 0.8 x 0.05 m.

Thinning was carried out at 10 DAS, leaving 15 plants per experimental plot, and in this same period the treatments with brackish water began to be differentiated. The material used as mulch came from spontaneous plants dried naturally and was arranged to form a 10-cm-high layer, in an area of 0.5 m^2 in each treatment.

The water with lower salinity (0.8 dS m^{-1}) came from the Ceará Water and Sewage Company (CAGECE), which supplies the experimental site. On the other hand, the brackish water with electrical conductivity of 6.0 dS m^{-1} was prepared using the soluble salts NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$ in the proportion of 7:2:1 referring to Na^+, Ca^{2+} and Mg^{2+}, respectively (MEDEIROS, 1992), according to the relationship between ECw and their molar concentration ($mmol_c$ L^{-1} = EC × 10).

Irrigation was applied by a drip system, using emitters with flow rate of 8.0 L h^{-1} and spaced 0.30 m apart. The volume of water applied was calculated based on the crop coefficient according to the development stages, with values of 0.4, 0.8, 1.15, 0.8 and 0.55 for the initial, development, flowering, final and harvest stages, respectively (DOORENBOS; KASSAM, 1994).

Reference evapotranspiration (ETo) was estimated by the class A pan method, with an irrigation interval of 2 days. The distribution uniformity coefficient (DUC) was 92%.

Irrigation time was estimated using Equation 1:

$$Ti = \frac{ETc \ x \ Ep \ x \ 60}{Ea \ x \ q} \quad (1)$$

Where:
Ti - irrigation time (min);
ETc - crop evapotranspiration (mm);
Ep - spacing between drippers;
Ea - application efficiency (0.9); and
q - flow rate (L h^{-1}).

A leaching fraction of 0.15 was added to the applied depth (AYERS; WESTCOT, 1999).

At 90 DAS, 5 plants were collected from the usable area of each treatment to evaluate the effect of salinity on sorghum crop under the different mulching strategies, and the following variables were analyzed: panicle weight (PW) and thousand-grain weight (TGW), measured with an analytical scale and expressed in grams, panicle length (PL), measured with a digital caliper in cm, number of grains per panicle (NGP) and yield (YLD), expressed in kg ha^{-1}.

To assess normality, the data obtained were subjected to the Kolmogorov-Smirnov test ($p \leq 0.05$). After checking normality, the data were subjected to analysis of variance, and when significant by the F test, they were subjected to Tukey test ($p \leq 0.05$), using the Assistat 7.7 Beta software (SILVA; AZEVEDO, 2016).

RESULTS AND DISCUSSION

According to the analysis of variance (Table 2), there was no significant effect for the thousand-grain weight (TGW), but there was an individual effect of mulch strategies for panicle weight (PW), panicle length (PL) and number of grains per panicle (NGP) at 1% probability level. For the yield variable, there was an interaction between the studied factors (mulching strategies and electrical conductivity of irrigation water) at 5% probability level.

Table 2. Summary of analysis of variance (ANOVA) for panicle weight (PW), panicle length (PL), thousand-grain weight (TGW), number of grains per panicle (NGP) and yield (YLD) of sorghum under mulching strategies and salt stress.

		Mean Square				
SV	DF	PW	PL	TGW	NGP	YLD
EC	4	269.02**	7.66670**	0.14200^{ns}	303272.27355**	2963792.57637**
ECw	1	27.46^{ns}	0.26244^{ns}	0.07500^{ns}	89279.82144^{ns}	25392.07529*
EC x ECw	4	27.46^{ns}	2.10043^{ns}	0.07500^{ns}	47506.72873^{ns}	218882.53936*
Residual	27	2137.756	152.023	0.16033	42586.04769	71743.84962
CV%	-	18.72	6.5	19.34	17.28	10.19

SV: Source of variation, DF: Degrees of freedom, CV (%): Coefficient of variation, EC: Mulching strategies, ECw: Electrical conductivity of irrigation water *Significant by the F test at 5% probability level; ** Significant by F test at 1% probability level; ns = not significant.

For panicle weight, the highest means were found in strategies MS1 (mulch throughout the cycle) and MS2 (without mulch during the entire cycle), with 26.8 and 33.3 g, respectively (Figure 2). The MS1 strategy led to a reduction of 6.5 g compared to the control (MS2), which corresponded to a difference of 19.52%. This result reveals that, despite the positive effect of mulching, the crop adapted well to the absence of soil protection, i.e., the planting density of the present study promoted soil shading and may have contributed to mitigating water loss by evaporation and consequently to higher performance in panicle weight.

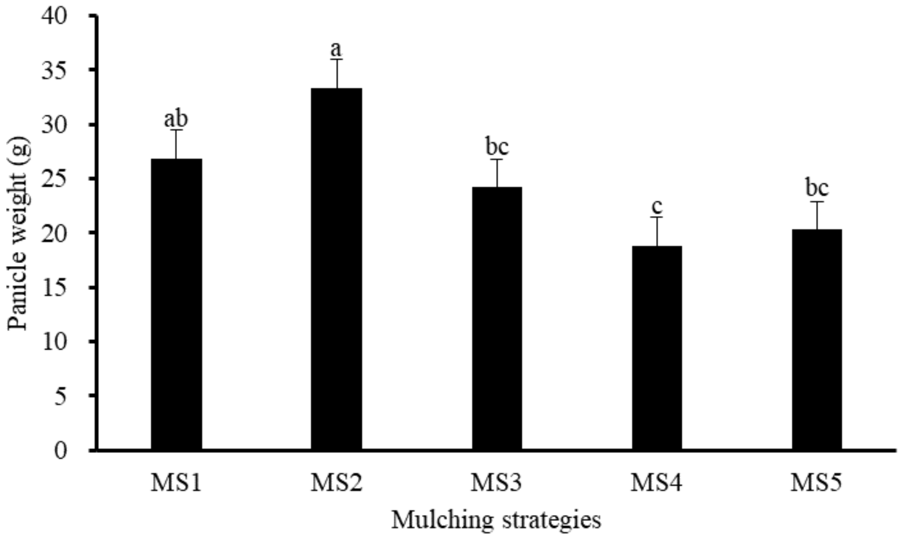

Figure 2. Panicle weight of sorghum plants under mulching strategies. Means followed by the same lowercase letter did not differ from each other by Tukey test (p<0.05); Vertical bars represent standard error n=8.

The positive effect of mulch has been reported in several studies. For Goes et al. (2023), the use of mulch as soil protection is capable of reducing water evaporation during irrigation. In a study carried out with maize crop, Goes et al. (2021) also observed no differences between strategies with and without mulch during the entire crop cycle for ear mass. Similarly, Favarato et al. (2016) used soil cover in maize crop and observed no differences for weight of marketable ears between treatments with and without soil cover.

On the other hand, Costa et al. (2021) observed an increase in ear mass when maize crop was subjected to the presence of mulch compared to the treatment without plant protection in the soil.

Treatments MS1, MS2, MS3 and MS4 did not differ from each other for panicle length, but were superior to MS5 (Figure 3). This result reveals that the mulch may have contributed with its physical functions of water storage in the soil, but in the flowering stage it may have contributed with greater nitrogen immobilization and consequently shorter panicle length (MAIA JÚNIOR et al., 2020).

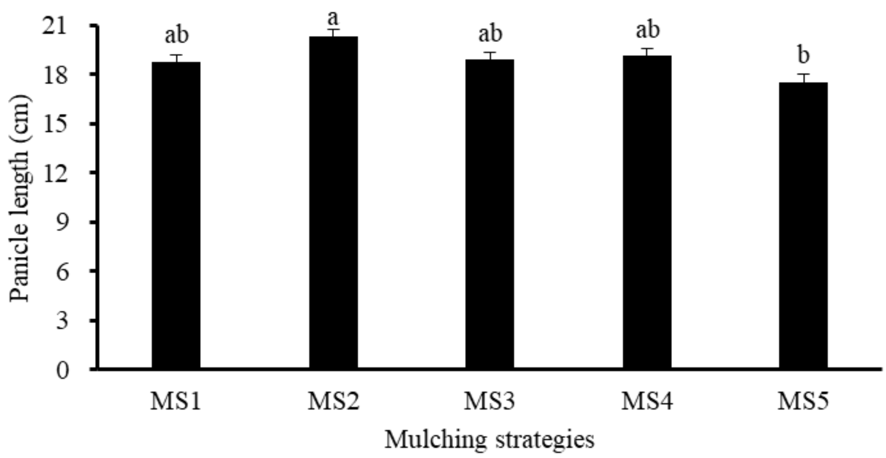

Figure 3. Panicle length of sorghum plants under mulching strategies. Means followed by the same lowercase letter did not differ from each other by Tukey test (p<0.05); Vertical bars represent standard error n=8.

In a study carried out with maize crop, Torres et al. (2020) described that the reduction in ear length may be related to the reduction of photoassimilates available to plants, as there is less translocation of nutrients for the formation of ears, which consequently affects their length.

Contrasting results were found in maize crop by Costa et al. (2021), who reported no better performance in ear length in the treatment subjected to mulch during the entire cycle compared to the treatment in the absence of mulch.

The mulching strategy MS2 led to the highest number of grains per panicle (Figure 4). This response may be related to the choice of using mulch from weeds, which may not have been ideal for the sorghum crop, consequently not contributing to higher number of grains per panicle (WOLSCHICK et al., 2016). These results may vary according to the cover used and may depend on the rates of soil cover and residue decomposition, C/N ratio, and release of allopathic substances (ZIECH et al., 2015).

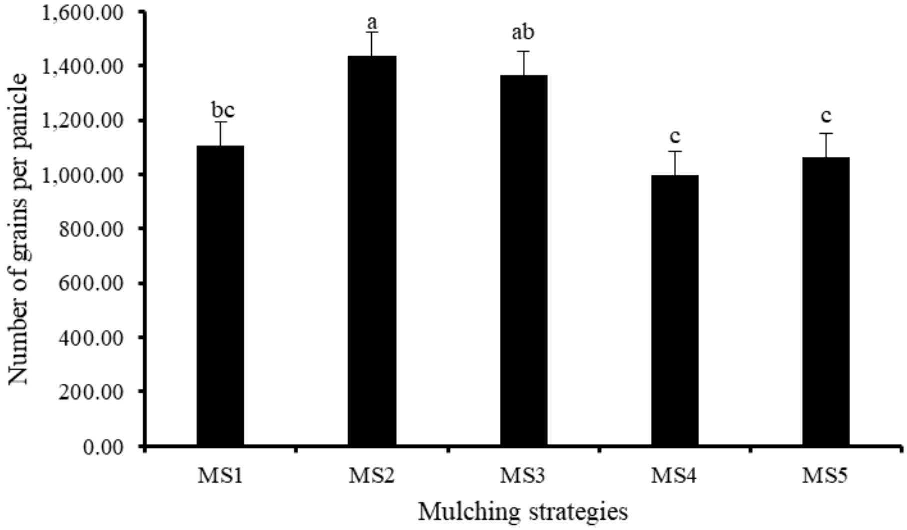

Figure 4. Number of grains per panicle of sorghum plants under mulching strategies. Means followed by the same lowercase letter do not differ from each other by Tukey test ((p<0.05); Vertical bars represent standard error n=8.

The reduction in the number of grains under the MS4 and MS5 strategies may be associated with lower nutrient absorption, as also observed for panicle length. Grain sorghum has a high K requirement and there is greater accumulation of this nutrient by the panicle and grains in these stages. As potassium is an important nutrient for the translocation of photoassimilates, the interference or reduction in the absorption of nutrients by the plant can lead to a lower number of grains per panicle (BORGES et al., 2016).

The highest yield was obtained in the MS2 mulching strategy, but there was no significant difference between the ECw levels. Nonetheless, in numerical terms, the water with higher salinity led to a mean value of 3,466 kg ha^{-1}, and the water with lower salinity led to 3,437 kg ha^{-1} (Figure 5). These mean values of yield are above the average of the Northeast in the 2023 season, 2,454 kg ha^{-1} (CONAB, 2023). This effect may be related to the tolerance of the crop to salt stress, as described by Ayers and Westcot (1999).

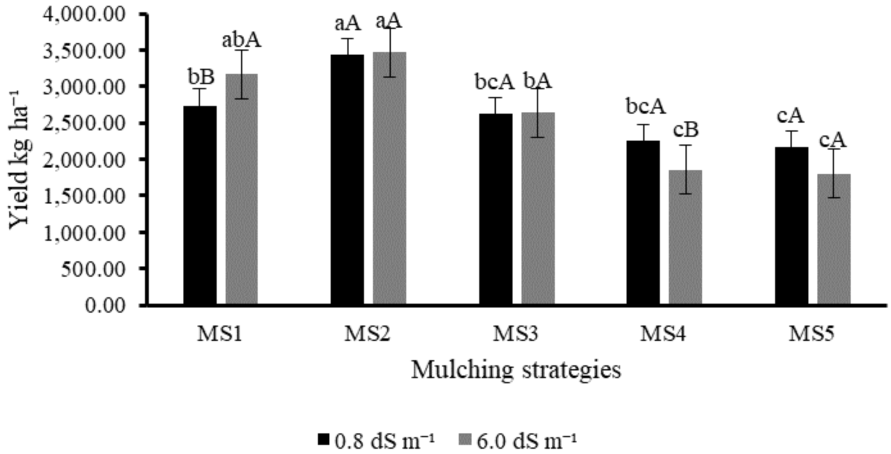

Figure 5. Yield of sorghum plants under mulching strategies and different levels of electrical conductivity of irrigation water. Means followed by the same lowercase letter for the use of mulch and uppercase letters for the levels of electrical conductivity of irrigation water, under the same mulching strategy, do not differ from each other by Tukey test (p<0.05); Vertical bars represent standard error n=8.

On the other hand, under MS1, a difference was observed between the two levels of electrical conductivity; the water with higher salinity promoted higher yield in sorghum crop, with mean value of 3,166 kg ha^{-1}, compared to the water with lower salinity, which led to yield of 2,740 kg ha^{-1}. This result represented an increase in yield on the order of 426 kg ha^{-1} compared to the water with lower salinity, corresponding to 15.55%. The effect of mulching on sorghum yield may be related to the possibility of release of allelopathic substances by the straw used, which caused a reduction in the production potential of the crop (PACHECO et al., 2021).

However, for MS4, the water with lower salinity promoted higher yield, with mean value of 2,258 kg ha^{-1}, while the water with higher salinity led to a mean yield of 1,859 kg ha^{-1}. In this stage, which corresponds to the period from panicle initiation to flowering, the mulch may have reduced the absorption of nutrients such as nitrogen, affecting the production performance of the crop.

Soils without vegetation cover have their surface more exposed to the evaporation of water particles in the soil, as reported by Maia Júnior et al. (2020) in their study; however, lower yield was observed in plants that received mulch compared to the treatment with no mulch throughout the cycle.

The yields observed in MS2, for the two levels of electrical conductivity of irrigation water, and in MS1, for water with higher electrical conductivity, are above the national average in 2023, 3,378 kg ha^{-1} (CONAB, 2023). This result may be related to the greater tolerance of the crop when irrigated with water of higher salinity, as highlighted by Sousa et al. (2018), who described that the sorghum crop is able to retain ions and compartmentalize them in different parts of the plant in order to reduce the deleterious effects of salts, revealing the possibility of using water with a salinity level above the salinity threshold of the crop.

Guimarães et al. (2022) evaluated sorghum crop irrigated with brackish water and obtained a yield below that observed in the present study when compared to MS1, but obtained a higher yield when compared to MS4 under salt stress. Goes et al. (2021), in a study with corn in soil with mulch applied in the reproductive stage, observed higher yield under irrigation with lower salinity water, compared to the treatment with higher salinity water. As in the present study, Sousa et al. (2023) also found a positive effect of mulch on the yield of peanut crop under salt stress.

The strategy of using mulch throughout the cycle was able to minimize the deleterious effects of salinity in the root zone, reducing the effects of salt stress, as this practice tends to increase water storage in the soil (GOES et al., 2021). This result was not observed in the MS4 mulching strategy, indicating that the use of mulch was not able to mitigate the deleterious effects of salts on sorghum crop from panicle initiation to flowering.

CONCLUSIONS

Using mulch throughout the cycle and the control treatment are more efficient for panicle weight.

Using mulch throughout the cycle under irrigation attenuates salt stress and promotes higher yields.

From the beginning of panicle appearance until flowering, irrigation with lower salinity water led to higher yield.

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