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Biometrics and grain yield of sorghum varieties irrigated with salt water

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ABSTRACT: The objective of this study was to identify sorghum varieties that have growth and grain yield potential under saline conditions. The study was conducted in 2016 at a greenhouse of the Embrapa Semiárido, in Petrolina, state of Pernambuco, Brazil (9° 8' 8.9" S, 40° 18' 33.6" W, and altitude of 373 m). A randomized block experimental design, with a 6 × 5 factorial arrangement, and three replications was used. The treatments consisted of six grain sorghum varieties (1011-IPA, 2502-IPA, 2564-IPA, 2600-IPA, Ponta Negra, and Qualimax), and five salinity levels of the irrigation water ($EC_w = 0, 1.5, 3.0, 6.0, \text{ and } 12.0 \text{ dS m}^{-1}$). Plant height, stem diameter, dry matter yield, width and length of the +3 leaf, total leaf area, water use efficiency, and grain yield were evaluated. The sorghum varieties 2502-IPA and 1011-IPA presented the highest grain yields when using an EC_w of 6.0 dS m^{-1} , followed by Ponta Negra, Qualimax, and 2600-IPA. The 2564-IPA, 2600-IPA, and Qualimax varieties were more sensitive to the salinity effects, with reductions of 50% of the production with EC_w of 3.52, 2.75, and 4.38 dS m^{-1} , respectively.

Key words: salinity, *Sorghum bicolor* L., semi-arid

Biometria e produção de variedades de sorgo granífero irrigado com águas salinas

RESUMO: Objetivou-se com o presente estudo identificar variedades de sorgo granífero com maior potencial de crescimento e produção de grãos sob condições salinas. O estudo foi conduzido em casa de vegetação localizada na sede da Embrapa Semiárido, Petrolina, PE (9° 8' 8,9" S 40° 18' 33,6" O, 373 m de altitude), no ano de 2016. Adotou-se o delineamento experimental em blocos casualizados, com esquema fatorial 6 x 5, com seis variedades de sorgo granífero (1011-IPA, 2502-IPA, 2564-IPA, 2600-IPA, Ponta Negra e Qualimax) irrigadas com água salina com cinco níveis de salinidade ($CEa = 0; 1,5; 3,0; 6,0 \text{ e } 12,0 \text{ dS m}^{-1}$), em três repetições. Foram avaliadas as variáveis altura da planta, diâmetro do colmo, produção de massa seca, largura e comprimento da folha +3, área foliar total, eficiência do uso da água e produção de grãos. As variedades de sorgo 2502-IPA e 1011-IPA apresentaram as maiores produções de grãos quando usando uma CEa de 6.0 dS m^{-1} , seguida por Ponta Negra, Qualimax e 2600-IPA. As variedades 2564-IPA, 2600-IPA e Qualimax foram mais sensíveis aos efeitos da salinidade, com reduções de 50% na produção com CEa de 3,52, 2,75 e $4,38 \text{ dS m}^{-1}$, respectivamente.

Palavras-chave: salinidade, *Sorghum bicolor* L., semiárido



INTRODUCTION

Water is one of the most important components for the life of plants; its availability and quality affects directly metabolic processes of plants. These effects are more pronounced in arid and semi-arid regions, which have low water availability, and the water is often saline. Considering that severe abiotic stress causes great damage to plants, the use of techniques that minimize stress caused by the salinity of the irrigation water is important. Thus, the use of adapted plants to saline environments is essential for the viability of crops.

Sorghum bicolor (L.) Moench presents salt-tolerant accessions (Shakeri et al., 2017), thus, it is an alternative for production systems that use irrigation with salt water. The genetic variability of this crop has allowed the development of several breeding programs. These materials present diverse agronomic characteristics, which are affected by several environmental factors, such as climatic conditions (Albuquerque et al., 2013), soil fertility (Santos et al., 2014), and water availability (Tardin et al., 2013), and salinity (Guimarães et al., 2016).

The tolerance of plants to salinity is associated with the development of mechanisms that contribute to minimize salt stress. These mechanisms have different energy costs for the plants, which affect negatively their growth and, consequently, the grain yield of the crop (Igartua et al., 1995; Hassanein et al., 2010). In this context, the objective of this study was to identify sorghum varieties that have growth and grain yield potential under saline conditions

MATERIAL AND METHODS

The study was conducted in a greenhouse at the Brazilian Agricultural Research Corporation (Embrapa Semiárido), in Petrolina, state of Pernambuco, Brazil (9° 8' 8.9" S 40° 18' 33.6" W). The region presents a tropical semi-arid climate, with average annual precipitation of 400 mm, average relative air humidity of 67.8%, and average air temperature of 26.5 °C (Reddy & Amorim Neto, 1983).

A randomized block experimental design, with a 6 × 5 factorial arrangement and three replications was used. The treatments consisted of six grain sorghum varieties (1011-IPA, 2502-IPA, 2564-IPA, 2600-IPA, Ponta Negra, and Qualimax), and five salinity levels of the irrigation water ($EC_w = 0, 1.5, 3.0, 6.0, \text{ and } 12.0 \text{ dS m}^{-1}$).

Sorghum seeds were planted in 20 dm³ plastic pots filled with a 3 cm layer of gravel at the bottom, and 15 kg of soil collected from the 0-20 cm layer of a sandy loam textured soil classified by the Embrapa as latosolic Dystrophic Yellow Argissolo, which presented the following characteristics: electrical conductivity of 0.23 dS m⁻¹, pH of 5.7; 0.7 cmol_c dm⁻³ of Mg; 1.0 cmol_c dm⁻³ of Ca; 1.6 cmol_c dm⁻³ of H + Al, 0.33 cmol_c dm⁻³ of K, 0.07 cmol_c dm⁻³ of Na, 84.7% of sand, 13.5% of silt, and 1.8% of clay. Five seeds were planted per pot, with 2 cm depth. The plants were thinned, leaving only one plant per pot when the plants reached an average height of 15 cm (approximately 12 days after sowing) and, then, the irrigations with the respective salt concentrations started.

Soil fertilization consisted of (mg dm⁻³): N (160), P (400), K (210), Ca (150), Mg (50), S (180), B (0.81), Cu (1.33), Mo (0.15), Mn (3.66), Zn (4.0), and Fe (0.1); using the sources (NH₄)₂SO₄, KH₂SO₄, NaH₂PO₄·H₂O, Ca(NO₃)₂, MgSO₄, CaCl₂·2H₂O, H₃BO₃, CuSO₄·5H₂O, (NH₄)₆Mo₇O₂₄·4H₂O, MnSO₄·H₂O, ZnSO₄·H₂O, FeSO₄·7H₂O, and NaEDTA. Soil fertilization started after thinning and was divided into three equal portions with 25-day intervals.

Irrigation water was salinized using the NaCl, CaCl₂·2H₂O, and MgSO₄·7H₂O salts to obtain a 7:2:1 equivalent ratio for Na:Ca:Mg (Aquino et al., 2007).

Weighing lysimeters were installed in all pots of a block for the irrigation management. The lysimeters were equipped with load cells (TSD model, AEPH, 50 kg capacity) installed under a metal base with a device for collecting excess drained water. The load cells were connected to two multiplexers (AM16/32B) coupled to a datalogger (CR1000), which performed readings every 15 s. The lysimeters were calibrated based on known weights, simulating amounts of water retained in the soil between the permanent wilting point and maximum water retention capacity of the soil.

Irrigations were carried out every two days, using a water depth corresponding to water consumption of the plant, plus a 15% leaching fraction to maintain a balanced salt concentration in the soil.

Harvesting was performed when the central grains of the panicle had a dry appearance. The plants were cut at a height of 10 cm from the ground and the following biometric parameters were evaluated: plant height, stem diameter, number of leaves, and length and width of the +3 leaf. The plants were separated in stems, leaves, panicles, grains, and roots to determine their fresh weights; then, they were taken to a forced-air circulation oven at 60 °C until constant weight to determine their dry weight. The fresh weight of the grains was used to calculate the grain yield per plant.

Leaf area (LA) was estimated using the widths and lengths of the +3 leaf, and number of leaves (NL), according to the model proposed by Mondo et al. (2009) for plants with linear leaf blades. Water use efficiency (WUE) was calculated by the ratio between total dry weight (shoot + root) and plant water consumption.

The data were subjected to analysis of variance (ANOVA) using the Sisvar 5.0 program. The effects of the salinity levels were compared through polynomial regression models of first and second degrees when significant at 0.01 or 0.05 probability level. The Scott Knott test at 0.05 probability level was used for grouping the varieties.

RESULTS AND DISCUSSION

No significant interaction between sorghum varieties and water salinity (electrical conductivity - EC_w) was found for the variables plant height (PH), stem diameter (SD), length and width of the +3 leaf (LW+3), total leaf area (TLA), and root dry weight (RDW). However, significant interactions were found for shoot dry weight (SDW), water use efficiency (WUE), and grain yield.

The growth variables presented different results (Table 1). Plants of the Qualimax variety had higher heights, regardless

Table 1. Plant height (PH), stem diameter (SD), length and width of the +3 leaf (LW+3), total leaf area (TLA), and root dry weight (RDW) of sorghum plants irrigated with salt water

Variety	PH (cm)	SD (mm)	LW + 3 (cm)		TLA (cm ²)	RDW (g)
			Width	Length		
1011-IPA	98.33 c	12.65 b	6.38 b	74.07 b	2531.34 b	47.79 a
2502-IPA	109.40 c	15.69 a	7.31 a	75.80 b	3568.56 a	32.13 b
2564-IPA	108.90 c	15.38 a	7.73 a	72.93 b	3855.85 a	40.73 a
2600-IPA	107.27 c	10.85 c	6.50 b	68.67 b	2315.23 b	24.72 b
Ponta Negra	126.33 b	16.32 a	6.92 b	83.00 a	3824.90 a	54.26 a
Qualimax	136.63 a	14.83 a	6.89 b	71.87 b	2751.54 b	39.34 a

Means followed by the same letter in the columns do not differ by the Scott Knott test at 0.05 probability level

of the salinity level of the irrigation water, followed by Ponta Negra and the other varieties, which presented no statistical differences among them. The 2502-IPA, 2564-IPA, Ponta Negra, and Qualimax varieties presented the largest stem diameters, with averages between 14.83 and 16.32 mm.

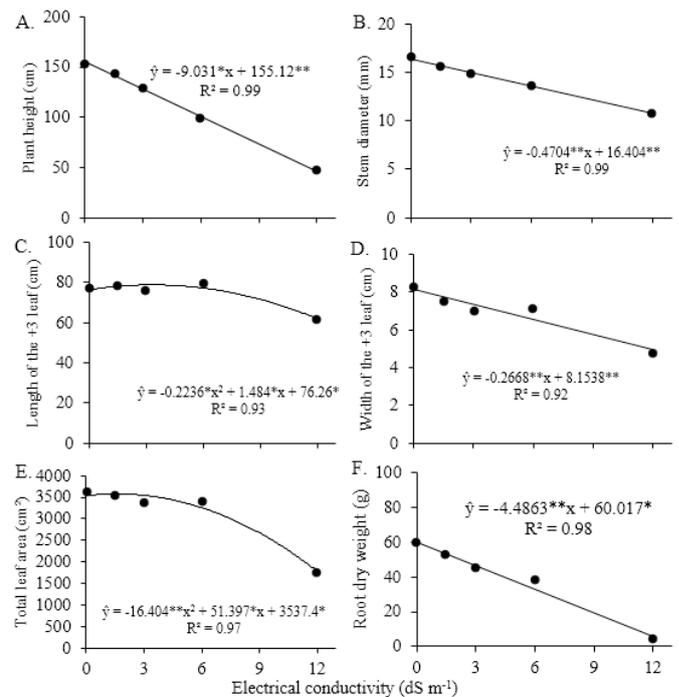
Plant size is an important characteristic for the selection of sorghum cultivars. Cultivars that present lower plant height are associated with higher stem resistance, presenting less susceptibility to lodging and breaking (Silva et al., 2009). Thus, the varieties 2502-IPA and 2564-IPA present greater grain yield potential due to their lower heights and larger stem diameters; and the varieties 1011-IPA and Ponta Negra have intermediate potentials; 1011-IPA due to its smaller height, and intermediate stem diameter, and Ponta Negra due to its intermediate height, and greater stem diameter.

The factors evaluated had no significant effect on the number of leaves of the plants, which presented a mean of nine leaves (CV = 17.19%). The varieties 2502-IPA and 2564-IPA had significantly longer leaves, and Ponta Negra had broader leaves. This resulted in a higher total leaf area (TLA) for these varieties (Table 1), since TLA is calculated according to leaf biometric characteristics (length and width). This characteristic is desirable, since the photosynthetic process depends on the interception of light energy and its conversion into chemical energy, which is a process that occurs directly in the leaf (Taiz & Zeiger, 2013).

The Ponta Negra, 1011-IPA, Qualimax, and 2564-IPA had higher root dry weights than the other varieties (Table 1). The differences between the growth variables of these varieties, regardless of the salinity levels studied, showed morphological characteristics that may favor their adaptability to saline stress conditions, since in many cases, is the root sensitivity to stress that limits the productivity (Steppuhn & Raney, 2005).

The increase in salinity level in the irrigation water affected significantly almost all variables analyzed (Figure 1). Plant height decreased about 9 cm (5.82%) (Figure 1A), stem diameter decreased approximately 0.5 mm (2.87%) (Figure 1B), width of the +3 leaf decreased 0.26 cm (3.27%) (Figure 1D), and root dry weight decreased 4.48 g (7.47%) (Figure 1F) per unit increase in salinity level (EC_w).

Several studies also found significant reductions in biometric parameters of plants with increasing salinity levels. Tabatabaei & Anaghali (2012) evaluated the initial growth of sorghum varieties under saline conditions and found reductions of more than 50% in plants grown under salinity levels higher than 10 dS m⁻¹. Guimarães et al. (2016) evaluated



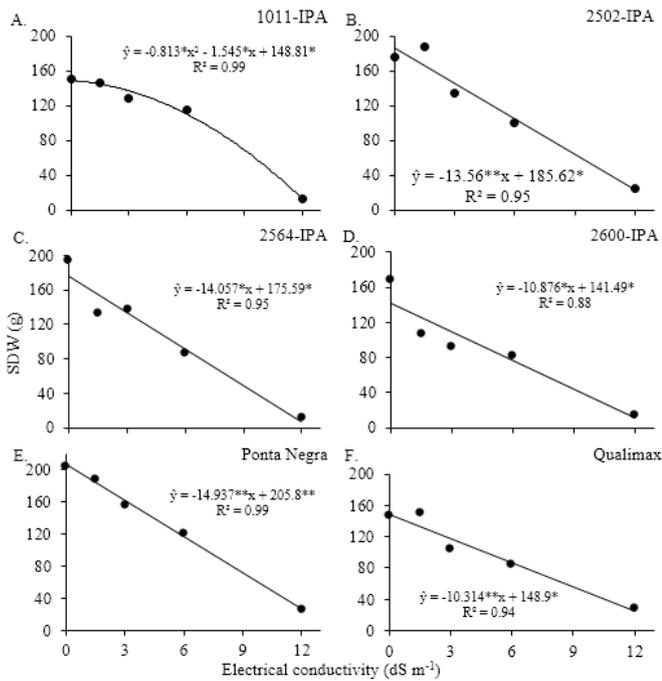
** and * Significant regression coefficient at 0.01 and 0.05 probability, respectively

Figure 1. Plant height (A), stem diameter (B), length (C) and width (D) of the +3 leaf, total leaf area (E), and root dry weight (F) of sorghum varieties subjected to different salinity levels of the irrigation water

forage sorghum varieties under irrigation with saline effluent and found significant reductions in plant height and in stem diameter with increasing soil salinity.

The length of the +3 leaf, and total leaf area fitted to the quadratic model, with reductions when water salinity exceeded 3.32, and 1.56 dS m⁻¹, respectively. These reductions were more pronounced when the EC_w reached levels above 6.0 dS m⁻¹ (Figures 1C and E). Reductions in leaf area is an important adaptive mechanism of plants grown under excessive salt or water stress; they reduce transpiration and, consequently, decrease Na⁺, and Cl⁻ ions in the xylem, promoting water conservation in plant tissues (Taiz & Zeiger, 2013).

The sorghum varieties had different shoot dry weight (SDW). The 2502-IPA, 2564-IPA, 2600-IPA, Ponta Negra, and Qualimax varieties presented linear reductions with increasing salinity level, whereas the 1011-IPA variety fitted to a quadratic model. The 2564-IPA, 2600-IPA, and Ponta Negra presented reductions in SDW of 50% at low salinity levels 6.25, 6.50, and 6.89 dS m⁻¹, respectively compared to the 1011-IPA, 2502-IPA, and Qualimax which presented reductions in SDW of 50% at higher levels 8.67, 6.84, and 7.21 dS m⁻¹, respectively (Figure 2).



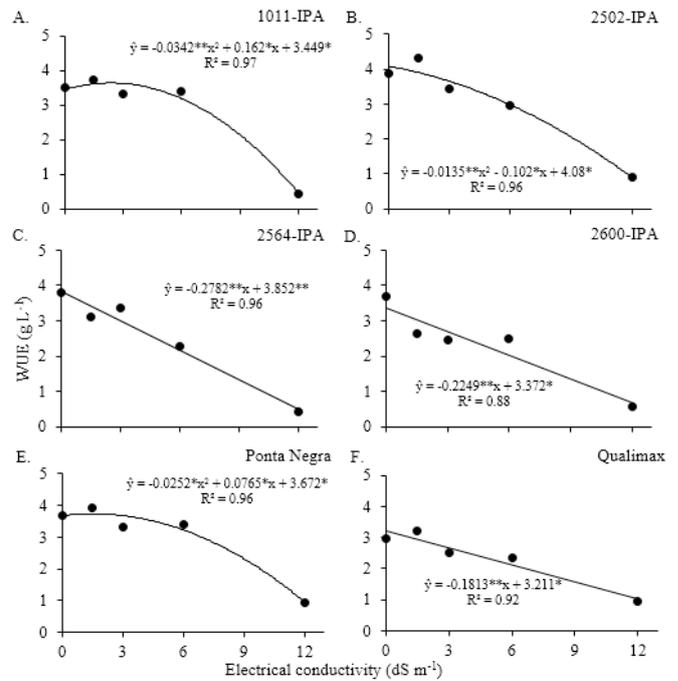
** and * Significant regression coefficient at 0.01 and 0.05 probability, respectively
Figure 2. Shoot dry weight (SDW) of sorghum varieties subjected to different salinity levels of the irrigation water

The reductions in plant growth caused by saline stress (Figures 1 and 2) may be associated with the toxic effect of excess salts in the root environment, leading to nutritional imbalance, and affecting important physiological processes of plant growth, and development (Willadino & Camara, 2010). Moreover, water uptake by roots reduce due to the decreased water potential in these soils (Tigabu et al., 2013).

Reductions in the growth of sorghum plants are found in several studies in different saline conditions. Sun et al. (2014) found reductions of up to 52% in the production of sorghum varieties when irrigated with salt water of up to 10 dS m⁻¹. Niu et al. (2012), evaluating sorghum genotypes (SS304, NK7829, Sordan79, and KS585) irrigated with salt water with 8 dS m⁻¹, found that salinity affects specifically each genotype, with reductions of up to 79% in the SDW of the genotype KS585. Shakeri & Emam (2017) evaluated biomass production of 36 sorghum cultivars irrigated with salt water and found reductions of up to 66% when using irrigation water with EC_w of up to 12 dS m⁻¹.

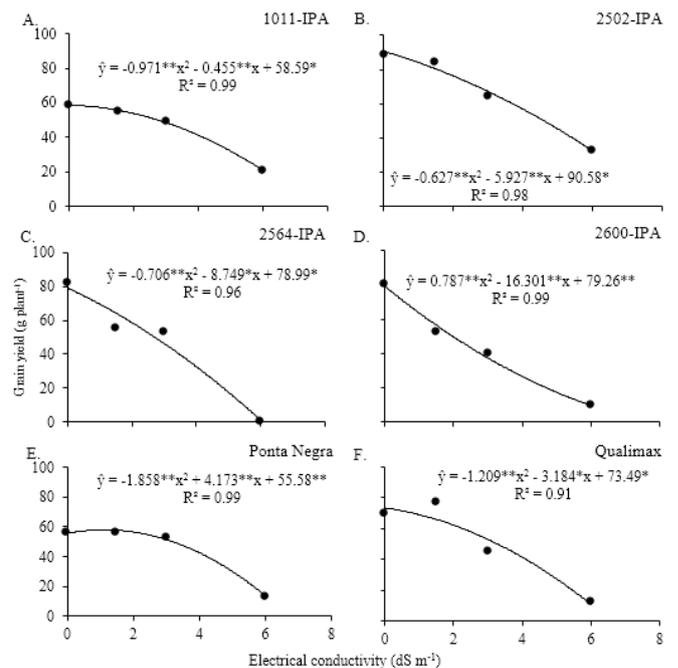
All these studies concluded that the genotypes or cultivars of *Sorghum bicolor* L. have specific responses to salinity levels, regarding the effects on plant growth and production.

Considering that water use efficiency (WUE) is the ratio between accumulated dry biomass (grams) and water consumption (liters), a significant reduction was observed with increasing salinity levels for all cultivars. WUE reduction of 50% was found with the EC_w of 9.85 (1011-IPA), 9.00 (2502-IPA), 6.92 (2564-IPA), 7.50 (2600-IPA), 10.25 (Ponta Negra), and 8.86 (Qualimax) dS m⁻¹ (Figure 3). These reductions indicate problems in water use by the plants for producing biomass with increasing salinity, and different effects for the production and water consumption of the plants, since the plants consumed more and produced less (Santos Júnior et al., 2013).



** and * Significant regression coefficient at 0.01 and 0.05 probability, respectively
Figure 3. Water use efficiency (WUE) of sorghum varieties subjected to different salinity levels of the irrigation water

Plants under treatments with EC_w of 12.0 dS m⁻¹ had no grain yields (Figure 4). The evaluated varieties presented similar results, with more pronounced reductions when the EC_w exceeded 3 dS m⁻¹. The 1011-IPA, 2502-IPA, and Ponta Negra were less sensitive to salinity, with reductions of 50% in grain production with the EC_w of 5.24, 5.01, and 5.08 dS m⁻¹, respectively. The 2564-IPA, 2600-IPA, and Qualimax varieties were more sensitive to the salinity effects, with reductions of 50% of the production with EC_w of 3.52, 2.75, and 4.38 dS m⁻¹, respectively.



** and * Significant regression coefficient at 0.01 and 0.05 probability, respectively
Figure 4. Grain yield of sorghum varieties subjected to different salinity levels of the irrigation water

The reductions in grain yield found for the sorghum varieties is one of the main effects of salinity on plants; similar effects are found for other species of agronomic interest, such as peanut (Correia et al., 2009), melon (Medeiros et al., 2008), and cucumber (Medeiros et al., 2009). According to Rhoades et al. (2000), salinity affects the development and reproduction of plants. Salinity reduces seed development and cause symptoms similar to those of water stress. Soil salinity is usually caused by irrigation with salt water and by the combination of water, soil, and crop managements. It results in increased crop cycle, and reduced grain yield and quality, influencing directly the viability of the crop.

Similar reductions in grain yield are found in other studies with different grain species. Igartua et al. (1995) found reductions of up to 72% in grain yield of 31 sorghum genotypes when using a salinity level (EC_w) of the irrigation water of 12 dS m^{-1} . Hassanein et al. (2010) found reductions of up to 21% in sorghum grain yield when using a salinity level (EC_w) of 5 dS m^{-1} . These results were associated with the effects of salinity on different physiological processes, especially the translocation of water and solutes, cell division, and cell differentiation.

The sorghum varieties 2502-IPA and 1011-IPA presented the highest grain yields when using an EC_w of 6.0 dS m^{-1} , followed by Ponta Negra, Qualimax, and 2600-IPA. The 2564-IPA variety was the most sensitive to the salinity effects, with no grain yield at the salinity level of 6.0 dS m^{-1} (Table 2). The 2502-IPA variety had higher grain yield than the others when using an EC_w of 3.0 dS m^{-1} , followed by 2564-IPA, Ponta Negra, and 1011-IPA.

Table 2. Grain yield (g plant⁻¹) of sorghum varieties irrigated with water with different salinity levels

Variety	EC (dS m^{-1})				
	0	1.5	3.0	6.0	12.0**
1011-IPA	58.94 c	54.79 b	49.18 b	20.79 b	-
2502-IPA	89.10 a	84.24 a	64.19 a	32.94 a	-
2564-IPA	82.24 a	55.63 b	52.88 b	0.00 d	-
2600-IPA	80.59 a	53.03 b	40.10 c	9.34 c	-
Ponta Negra	56.02 c	56.47 b	52.26 b	13.57 c	-
Qualimax	69.34 b	77.08 a	44.74 c	12.24 c	-

Means followed by the same letter in the columns do not differ by the Scott Knott test at 0.05 probability level. **No production

The tested varieties were able to develop, with grain yield within their average for the crop when irrigated with salt water, except the 2564-IPA variety. This indicates that this variety has greater sensitivity to salinity compared to the other materials evaluated. The 1011-IPA, and 2502-IPA showed good results when subjected to the salinity levels, and can be alternative varieties for places that have availability of salt water with EC_w of up to 6 dS m^{-1} , and similar soil and climatic conditions, since above this salinity level, reductions of more than 50% in grain production may occur.

CONCLUSIONS

1. The sorghum varieties 2502-IPA and 1011-IPA presented the highest grain yields when using an EC_w of 6.0 dS m^{-1} , followed by Ponta Negra, Qualimax, and 2600-IPA.
2. The 2564-IPA, 2600-IPA, and Qualimax varieties were more sensitive to the salinity effects, with reductions of 50%

of the production with EC_w of 3.52, 2.75, and 4.38 dS m^{-1} , respectively.

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