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Phytomass and production components of colored cotton under salt stress in different phenological stages[1]

Fitomassa e componentes de produção do algodoeiro colorido sob estresse salino em diferentes fases fenológicas

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HIGHLIGHTS:

Saline stress during the flowering phase reduces the accumulation of phytomasses in the 'BRS Topázio' and 'BRS Safira' genotypes.
The cotton lint mass of the cotton is reduced under irrigation with water of 9.0 dS m^{-1} in the fruiting phase.
It is possible to irrigate cotton with water of high salinity in the vegetative and flowering phases without losses in the total seed mass.

ABSTRACT: Scarcity of good quality water is a limiting factor for irrigated agriculture, especially in semi-arid regions, which induces the use of waters with high salt concentration in crop irrigation. In view of the above, the objective of this study was to evaluate the phytomass accumulation and production components of colored cotton genotypes during the different development stages, under conditions of high salinity, with plants grown in lysimeters under greenhouse conditions, at the Center for Technology and Natural Resources of the Federal University of Campina Grande, Paraíba, Brazil. Three cotton genotypes ('BRS Rubi', 'BRS Topázio' and 'BRS Safira') irrigated with salinized water (9 dS m^{-1}) during the three stages of crop development (vegetative, flowering and fruiting) were evaluated. The experiment was conducted in a randomized block design with three repetitions and three plants per plot, in drainage lysimeters filled with 24.5 kg of an Oxisol, with sandy loam texture. Irrigation with salinized water during the vegetative stage promoted greater phytomass accumulation in the genotypes of naturally colored cotton. In the initial stages of the cotton development, irrigation with saline water can be used with the lowest losses in production components, which are negatively affected when saline water is applied in the fruiting stage. Among the genotypes, 'BRS Topázio' is the most tolerant to irrigation water salinity in terms of seed cotton weight and lint cotton weight, regardless of the development stage.

Key words: *Gossypium hirsutum* L., salinity, toleranc

RESUMO: A escassez de água de boa qualidade é um fator limitante para a agricultura irrigada, principalmente nas regiões semiáridas, o que induz à utilização de águas com elevados teores de sais na irrigação das culturas. Diante do exposto, objetivou-se, com esta pesquisa, avaliar o acúmulo de fitomassa e os componentes de produção de genótipos de algodoeiro colorido durante os diferentes estádios de desenvolvimento da planta, em condições de alta salinidade, sendo as plantas conduzidas em lisímetros sob condições de casa de vegetação, no Centro de Tecnologia e Recursos Naturais pertencente à Universidade Federal de Campina Grande, Paraíba, PB. Foram avaliados três genótipos de algodoeiro ('BRS Rubi'; 'BRS Topázio' e 'BRS Safira') irrigados com água salinizada (9 dS m^{-1}), durante as três fases de desenvolvimento da cultura (vegetativa, floração e frutificação). O experimento foi desenvolvido no delineamento de blocos casualizados com três repetições e três plantas por parcela, conduzidas em lisímetros de drenagem preenchidos com 24,5 kg de um Oxisol, com textura franco-arenosa. A irrigação com água salinizada durante a fase vegetativa promoveu maior acúmulo de fitomassa nos genótipos de algodoeiro naturalmente colorido. Nas fases iniciais do desenvolvimento do algodoeiro a irrigação com água salina pode ser utilizada no cultivo do algodoeiro com as menores perdas nos componentes de produção, sendo estes afetados negativamente quando aplicada água salina na fase de frutificação. Dentre os genótipos, o 'BRS Topázio' é o mais tolerante à salinidade da água de irrigação, quanto à massa de algodão em caroço e massa de algodão em pluma, independente do estádio de desenvolvimento.

Palavras-chave: *Gossypium hirsutum* L., salinidade, tolerância

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Introduction

The proportion of agricultural land negatively affected by high salinity is increasing worldwide due to natural causes and agricultural practices (Munns & Gilliham, 2015). High concentrations of salts affect almost all aspects of plant physiology and biochemistry and significantly reduce yield due to osmotic stress and imbalance of cellular ions, resulting in ionic toxicity and production of reactive oxygen species (Hanin et al., 2016; Taïbi et al., 2016).

Cotton production has stood out as one of the most important agricultural activities for Brazilian agribusiness, because of its adaptation to semi-arid environments due to its tolerance to salt stress of up to 5.1 dS m^{-1} for irrigation water (Oliveira et al., 2013). Despite this tolerance, several researchers have reported negative effects of salinity on naturally colored cotton plants (Lima et al., 2017; Silva et al., 2017).

In this context, the identification of genotypes with salinity tolerance and development of management strategies are very important to reduce the impacts of salinity and increase yield on agricultural land, through the identification of phenological stages in which the crop is more tolerant or sensitive to salinity, considering the release of new genetic materials. They are also important for the adoption of agronomic strategies suitable for agricultural production under conditions where only waters with higher salt concentration are available (Subbarao & Johansen, 1999).

Thus, the objective was to evaluate the phytomass accumulation and production components of naturally colored cotton genotypes, subjected to irrigation management strategies, varying the stages of development in which the plants were irrigated with saline water.

Material and Methods

The study was carried out under conditions of protected environment (greenhouse), at the Center for Technology and Natural Resources (CTRN) of the Federal University of Campina Grande (UFCG), located in the municipality of Campina Grande, Paraíba, Brazil, at the geographic coordinates 07° 15' 18" S, 35° 52' 28" W and average altitude of 550 m.

The statistical design adopted was randomized blocks in a factorial scheme 3 x 3, corresponding to three cotton genotypes (G1 - 'BRS Rubi'; G2 - 'BRS Topázio'; G3 - 'BRS Safira') and three management strategies, referring to the application of salinized water, varying according to the phenological stages of the plants: vegetative (A) - period between the emergence of the first true leaf and anthesis of the 1st flower; flowering (B) - from anthesis of the 1st flower to opening of the 1st boll; yield formation (C) - from opening of the 1st boll to final harvest of the bolls, resulting in nine treatments, with three repetitions and three plants per plot.

The cotton genotypes were irrigated with low-salinity water (0.8 dS m^{-1} - index 1) and high-salinity water (9.0 dS m^{-1} - index 2), applied under different management strategies: T1 - $A_2B_1C_1$ - plants under salt stress in the vegetative stage (index 2 in stage A) and low-salinity water in the other stages; T2 - $A_1B_2C_1$ - plants subjected to salt stress only in the flowering stage (index 2 in stage B) and T3 - $A_1B_1C_2$ - irrigation with water of high electrical conductivity during the yield formation stage (index 2 in stage C).

Plants were grown in plastic pots with capacity of 20 L (35 cm high, 31 cm upper diameter, 20 cm lower diameter), having a fine-mesh screen at the base and connected to a container through a hose to collect the drained water. Above the screen, the pots received a 3-cm-thick layer of crushed stone and 24.5 kg of an Oxisol, sandy loam textural classification, whose values of physical-hydraulic and chemical attributes, determined in the laboratory, prior to sowing of both experiments, are presented in Table 1.

Prior to sowing, 500 g of organic matter (earthworm humus) per pot were incorporated into the soil material, in order to improve its structure and moisture retention. In order to meet the nutritional needs of the plants, a uniform fertilization based on N, P and K was performed according to the recommendation of fertilization for pot experiments contained in Novais et al. (1991), applying 100, 300 and 150 mg kg^{-1} of soil of N, P and K, respectively, in the forms of ammonium sulfate, single superphosphate and potassium chloride; the complete recommendation of phosphorus and only 1/3 of nitrogen and potassium were applied as basal, while the remaining two thirds were applied as topdressing, via irrigation water, at 45 and 65 days after sowing (DAS). The pots were arranged in single rows spaced by 1.0 and 0.6 m between plants in the row. To improve plant nutrition and supply possible micronutrient deficiencies, foliar fertilization was performed at the beginning of flowering, at 45 DAS, with a commercial product containing: N - 15%; P_2O_5 - 15%; K_2O - 15%; Ca - 1%; Mg - 1.4%; S - 2.7%; Zn - 0.5%; B - 0.05%; Fe - 0.5%; Mn - 0.05%; Cu - 0.5% and Mo - 0.02%.

Sowing was performed using seeds of the three cotton genotypes provided by Embrapa Cotton, five seeds per pot, planted at 3 cm deep and distributed equidistantly. After germination, thinning was carried out, leaving the most vigorous seedling per pot. Soil moisture was maintained at the level equivalent to that of maximum retention capacity in all experimental units, using low-salinity water (0.8 dS m^{-1}), until the emergence of the first true leaf, when the treatments began to be applied.

Irrigations were carried out daily, at 5:00 p.m., applying in each pot the volume of water corresponding to the plant requirement. The volume applied in each irrigation event was estimated by means of water balance, and the volume of water to be applied to the plants was determined by Eq. 1:

Table 1. Physical-hydraulic and chemical attributes of the soil material used in the experiments

Density (kg dm^{-3})	Total porosity (%)	Moisture (kPa)		Available water (%)	Sorption complex						
		33.42	1519.5		Ca^{2+}	Mg^{2+}	Na^+	K^+	$H^+ + Al^{3+}$	pH_{sp}	CE_{se} (dS m^{-1})
					($cmol_c$ kg^{-1})						
1.67	38.59	11.48	2.41	9.07	2.37	3.09	0.37	0.18	5.81	5.24	0.20

Ca^{2+} and Mg^{2+} extracted with 1 mol L^{-1} KCl at pH 7.0; Na^+ and K^+ extracted with 1 mol L^{-1} NH_4OAc at pH 7.0; Al^{3+}+H^+ extracted with 0.5 M CaOAc at pH 7.0; P - Mehlich 1 extractant; pH_{sp} - pH of saturation paste; ECse - Electrical conductivity of saturation extract

$$VI = \frac{(Va - Vd)}{(1 - LF)} \quad (1)$$

where:

VI - volume of water to be used in the next irrigation event (mL);

Va - volume applied in the previous irrigation event (mL);

Vd - volume drained (mL); and,

LF - leaching fraction of 0.2.

The water used in the irrigation of the treatment of lowest salinity (0.8 dS m^{-1}) was obtained by diluting water from the public supply system of Campina Grande with rainwater; the level corresponding to 9 dS m^{-1} (High ECw) was prepared in such a way to have an equivalent proportion of 7:2:1, for Na:Ca:Mg, respectively, from the salts NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$, considering the relationship between ECw and salt concentration (10*$mmol_c$ L^{-1} = 1 dS m^{-1} of ECw), extracted from Rhoades et al. (1992). After preparation, the waters were stored in 80-L plastic containers, properly protected to avoid evaporation, entry of rainwater and contamination with materials that could compromise their quality.

At the end of the crop cycle (113 DAS), the plants were harvested, separated into leaves, stems and bracts, placed in paper bags and dried in an air circulation oven, maintained at 65 °C, until reaching constant weight; subsequently, the material was weighed on a scale with precision of 0.1 mg, to obtain the dry phytomass of leaves (LDP), stem (StDP) and bracts, whose sum resulted in the shoot dry phytomass (ShDP). In the same period, the following variables were quantified: seed cotton weight (SCW), lint cotton weight (LCW), 100-seed weight (100SW) and total seed weight (TSW) analyzed according to the methodology of Embrapa Cotton. The bolls were harvested per plant as they reached the harvest point.

The data obtained were subjected to analysis of variance. In the cases of significance, Tukey test ($p \leq 0.05$) was performed for management strategies and cotton genotypes (Ferreira, 2011).

Results and Discussion

According to the analysis of variance contained in Table 2, there were differences between the saline water use management strategies ($p \leq 0.01$) for all variables evaluated. On the other hand, the cotton genotypes analyzed were significantly different in terms of stem dry phytomass, shoot dry phytomass, seed cotton weight and lint cotton weight. In addition, effect of the interaction (Management strategies x Genotypes) was observed at 113 DAS ($p \leq 0.01$) on leaf dry phytomass, stem dry phytomass and shoot dry phytomass, evidence of the difference between genotypes within each management strategy.

In the analysis of the genotype factor within the management strategies studied for leaf dry phytomass - LDP (Figure 1), it was verified that the genotype 'BRS Rubi' was less affected by irrigation with saline water in the phenological stages. The genotypes 'BRS Topázio' and 'BRS Safira', when subjected to salt stress during the vegetative stage, showed increments in phytomass accumulation when irrigation with high-salinity water occurred in the vegetative stage (T1 - $A_2B_1C_1$), with LDP of 28.94 and 31.11 g $plant^{-1}$, respectively. Thus, when cotton plants are irrigated with water of high salinity (9 dS m^{-1}), during the vegetative stage, premature senescence of leaves and reductions in growth occur initially and, soon after the end of salinity application in the flowering and yield formation stages, the plants had to compensate for vegetative growth through the development of new leaves for photosynthesis and consequent growth and development (Silva et al., 2008).

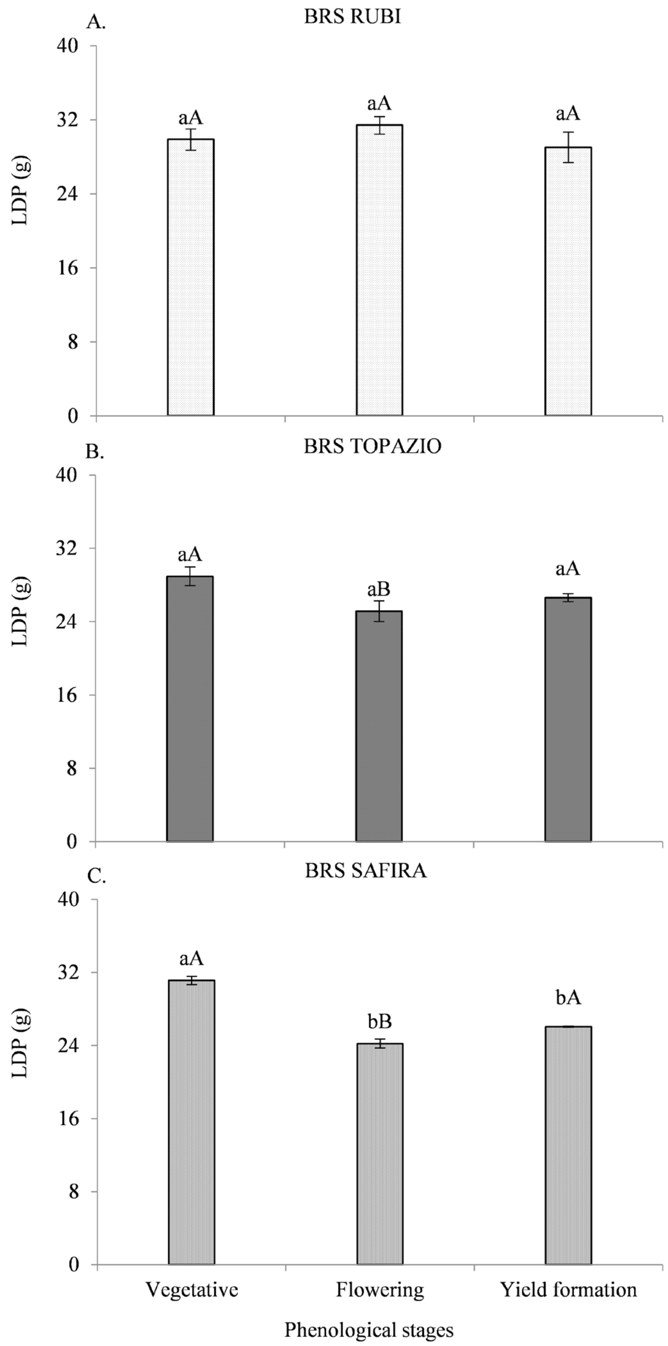
In the comparison of means related to stem dry phytomass - StDP (Figure 2), obtained in the colored cotton genotypes irrigated with waters of low salinity (0.8 dS m^{-1}) and high salinity (9.0 dS m^{-1}), it was found that 'BRS Topázio' and 'BRS Safira' when irrigated with salinized water in the flowering stage, according to strategy T2- $A_1B_2C_1$, showed reductions in StDP of 12.06 and 32.57%, respectively, when compared to plants irrigated with salinized water in the vegetative stage. However, among genotypes, StDP was higher in 'BRS Safira', with a mean of 24.85 g $plant^{-1}$ (Figure 2). The results obtained in this study agree with those reported by Lima et al. (2014), who evaluated the formation of phytomass and yield of castor bean cv. 'BRS Energia' irrigated with water of different salinity levels in different phenological stages and under two nitrogen doses, and observed an increase in StDP of 14.57% in plants irrigated with saline water in the vegetative stage.

Based on the mean values shown in Figure 3, it was found that the genotypes 'BRS Topázio' and 'BRS Safira' subjected to salt stress during flowering ($A_1B_2C_1$) had reductions shoot phytomass accumulation (ShDP) of 17.59 and 23.40% in comparison to plants under salt stress only in the vegetative

Table 2. Summary of the analyses of variance for leaf dry phytomass (LDP), stem dry phytomass (StDP), shoot dry phytomass (ShDP), seed cotton weight (SCW), lint cotton weight (LCW), 100-seed weight (100SW) and total seed weight (TSW) as a function of different salinity management strategies and cotton genotypes at 113 days after sowing – DAS

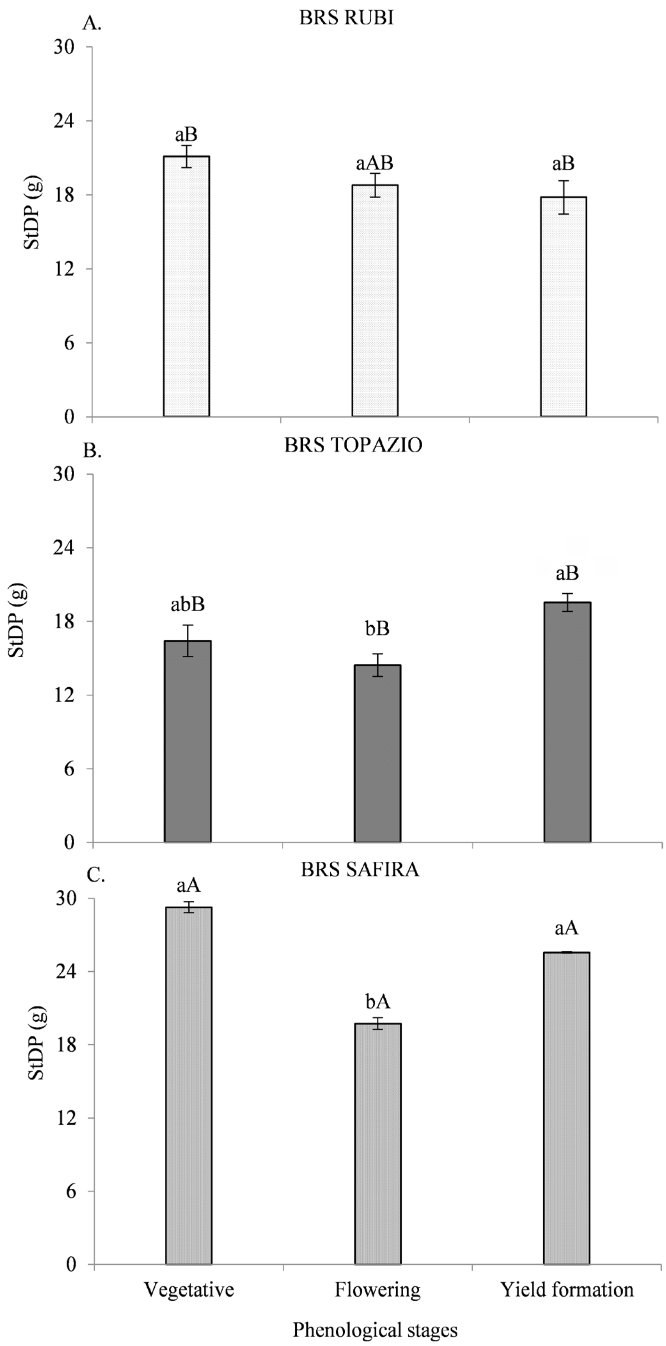
Variables	Mean square					CV (%)	Overall mean
	Management strategies (MS)	Genotypes (G)	Interaction (MS x G)	Blocks	Residue		
LDP	23.776**	26.6688**	15.037*	4.771ns	3.197	6.39	27.966
StDP	51.412**	155.509**	22.216*	22.519ns	5.735	11.32	20.260
ShDP	826.271**	326.840**	133.262**	31.781ns	26.588	6.89	74.785
SCW	19564.028**	3444.965**	110.916ns	135.139ns	334.414	9.76	187.384
LCW	3176.759**	2589.196**	12.342ns	30.529ns	47.618	9.69	71.230
100SW	2.117**	0.523ns	0.107ns	0.918ns	0.197	4.75	9.358
TSW	4766.722**	198.019ns	148.917ns	37.225ns	195.569	13.70	102.046

ns, *, ** Not significant and significant at $p \leq 0.05$ and at $p \leq 0.01$ by F test, respectively; CV – Coefficient of variation



In each phenological stage, means with the same lowercase letter indicate no significant difference between salinity management strategies and between genotypes, and means with the same uppercase letter do not differ by Tukey test at p ≤ 0.05. Vertical bars represent the standard error (n=3)

Figure 1. Leaf dry phytomass (LDP) of three cotton genotypes in three stages of application of irrigation water of 9 dS m^{-1}, at 113 days after sowing – DAS

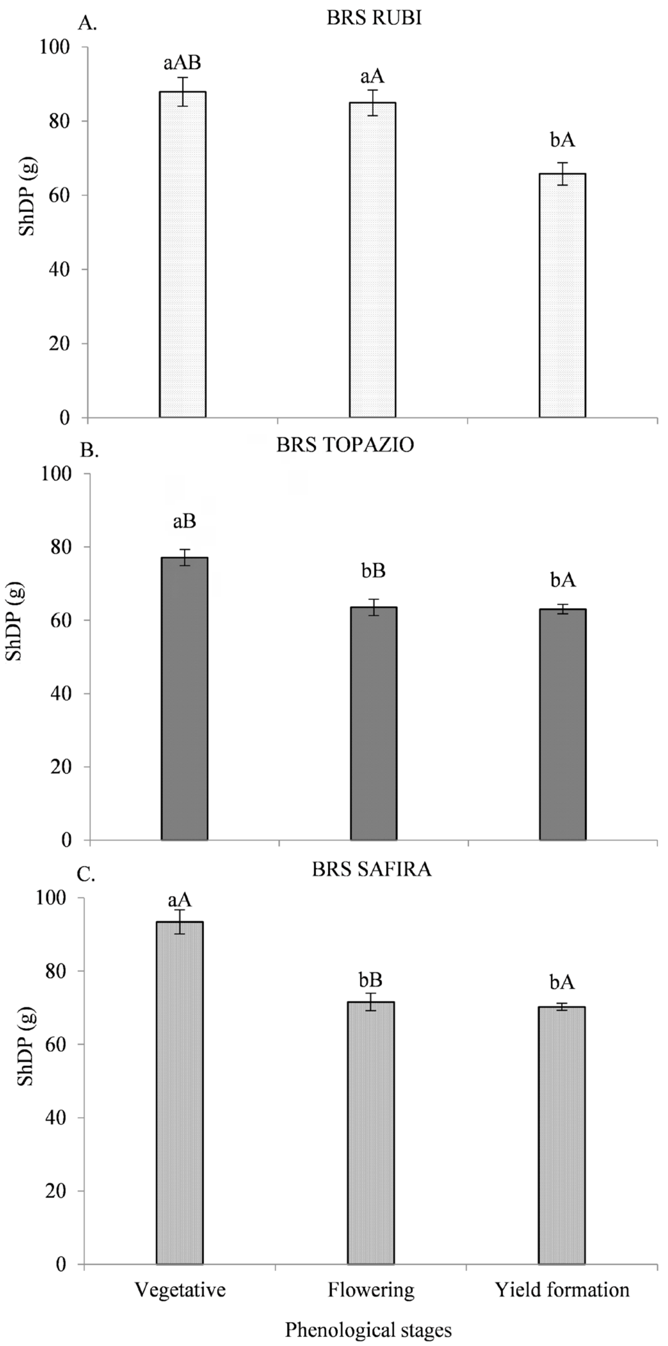


In each phenological stage, means with the same lowercase letter indicate no significant difference between salinity management strategies and between genotypes, and means with the same uppercase letter do not differ by Tukey test at p ≤ 0.05. Vertical bars represent the standard error (n=3)

Figure 2. Stem dry phytomass (StDP) of three cotton genotypes in three stages of application of irrigation water of 9 dS m^{-1}, at 113 days after sowing – DAS

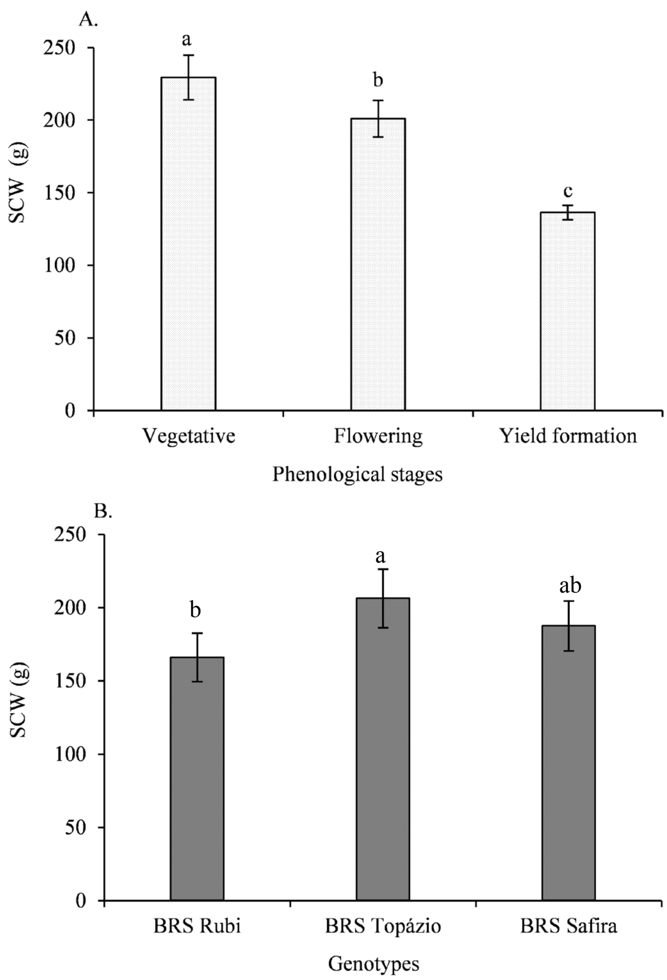
stage ($A_2B_1C_1$), respectively. As the results obtained for LDP and StDP, when the plants were irrigated with salinized water (9 dS m^{-1}) during the flowering stage, which may be associated with a reduction in ShDP (Figure 2). Also regarding phytomass accumulation, there is a tendency for the flowering stage (T2 - $A_1B_2C_1$) to be the most sensitive to salt stress. These results only reinforce that there are differences in the salinity effects between plant species, between genotypes of the same species and between stages of development of the same genotype (Brito et al., 2018). Therefore, phytomass production was a good criterion for evaluating the degree of stress and the ability of the cotton genotypes to overcome salt stress when applied in the vegetative stage.

According to the results of the means comparison test of the saline water application management strategies for seed cotton weight - SCW (Figure 4A), it was observed that the treatment T1 - $A_2B_1C_1$ was statistically superior to the others with a value of around 229.37 g $plant^{-1}$, and the lowest production was obtained with saline water irrigation in the fruiting stage, with a reduction of 40.51% when compared to the vegetative stage. Oliveira et al. (2012), evaluating the effect of different salinity levels of irrigation water (0.5; 2.0; 3.5; 5.0 and 6.5 dS



In each phenological stage, means with the same lowercase letter indicate no significant difference between salinity management strategies and between genotypes, and means with the same uppercase letter do not differ by Tukey $p \leq 0.05$. Vertical bars represent the standard error (n=3)

Figure 3. Shoot dry phytomass (ShDP) of three cotton genotypes in three stages of application of irrigation water of 9 dS m^{-1}, at 113 days after sowing – DAS



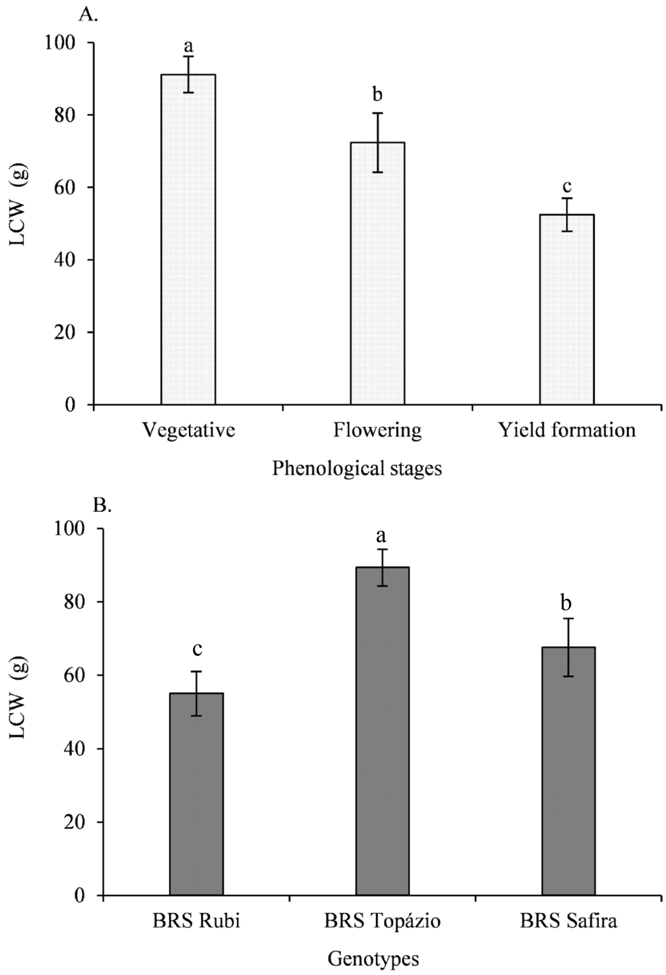
Different letters indicate significant difference between phenological stage and cotton genotypes by Tukey test at $p \leq 0.05$. Vertical bars represent the standard error (n=3)

Figure 4. Seed cotton weight (SCW) of three cotton genotypes and three stages of application of irrigation water of 9 dS m^{-1}

m^{-1}) in seeds treated and not treated with growth regulator on the production of seed cotton, observed deleterious effect from 3.5 dS m^{-1}, with losses in seed cotton production between salinity levels of 3.5 and 6.5 dS m^{-1}, on the order of 52.23%, regardless of the application of the growth regulator.

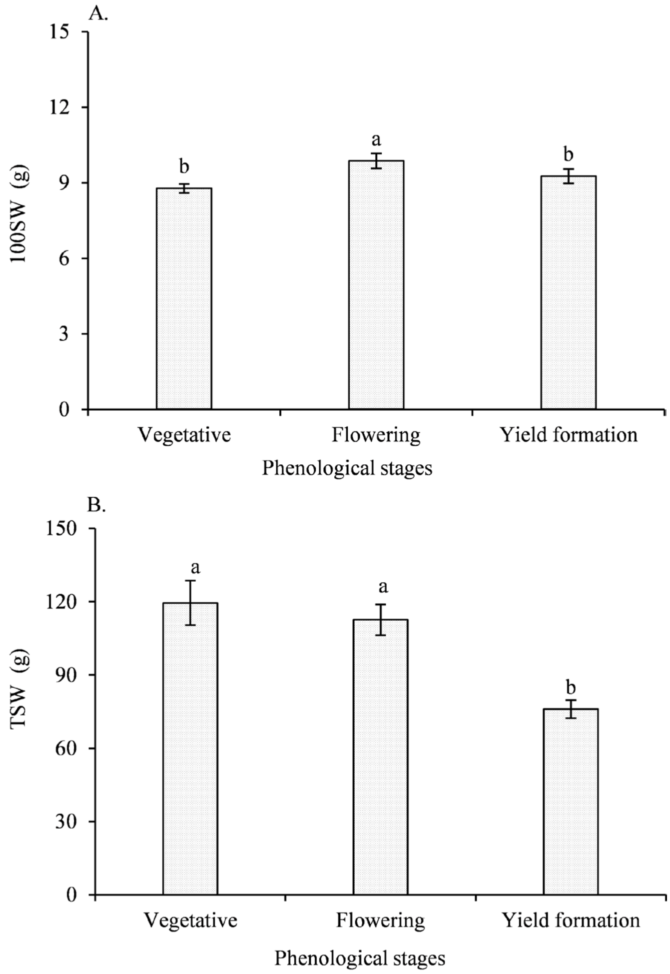
For SCW as a function of different cotton genotypes (Figure 4B), it was observed that 'BRS Topázio' showed higher accumulation of SCW (187.36 g $plant^{-1}$), which was 16.78 and 11.22% higher than the values of 155.91 and 166.34 g $plant^{-1}$ obtained in 'BRS Rubi' and 'BRS Safira', respectively. These results differ from those reported by Ferraz (2012), who evaluated the behavior of herbaceous cotton genotypes under foliar application of silicon and found lower values of SCW for 'BRS Rubi', 'BRS Topázio' and 'BRS Safira', equal to 116.6, 131.7 and 98.5 g $plant^{-1}$, respectively. These differences in SCW can be explained by the different genetic constitutions of the genotypes evaluated, and growth differences between cotton genotypes were also reported by Soares et al. (2018).

For lint cotton weight (LCW), as observed with SCW, the results of the means comparison test of the saline water application management strategies (Figure 5A) show that the strategy T1 - $A_2B_1C_1$, that is, salt stress in the vegetative stage, was statistically superior to the other treatments with a value of around 91.12 g $plant^{-1}$, and the lowest production was obtained with the T3 strategy (salt stress in the fruiting stage), with reduction of 58.24% when compared to the T1 management. The results obtained in the present study show that the effect of salinity on lint cotton production is related to the application of stress in the fruiting stage. Santos et al. (2016), working with the genotype 'BRS Topázio' irrigated with water of five salinity levels (0; 7; 2.7; 6.7 and 8.7 dS m^{-1}) also observed a reduction in production variables in response to increased salinity. The reduction in cotton production as a result of the increase in ECw can be attributed to the lower absorption of water and nutrients by plants under water stress, resulting in a decrease



Different letters indicate significant difference between phenological stage and cotton genotypes by Tukey test at p ≤ 0.05. Vertical bars represent the standard error (n=3)

Figure 5. Lint cotton weight (LCW) of three cotton genotypes and three stages of application of irrigation water of 9 dS m^{-1}



Different letters indicate significant difference between phenological stage by Tukey test at p ≤ 0.05. Vertical bars represent the standard error (n=3)

Figure 6. 100-seed weight (100SW) and total seed weight (TSW) of cotton genotypes in three stages of application of irrigation water of 9 dS m^{-1}, at 113 days after sowing – DAS

in cotton production, according to the results obtained by Zonta et al. (2016).

Among the genotypes evaluated as a function of the strategies, higher production of lint cotton weight (LCW) was observed in 'BRS Topázio' (89.33 g), which differed from 'BRS Rubi' and 'BRS Safira', with mean values of 55.00 and 67.55 g (Figure 5B). Ferraz (2012), evaluating the behavior of herbaceous cotton genotypes under foliar application of silicon, found similar results in terms of LCW for 'BRS Rubi', 'BRS Topázio' and 'BRS Safira', with values between 50 and 40 g per plant, in treatments without foliar application of silicon.

For 100-seed weight (100SW) as a function of the saline water application management strategies (Figure 6A), it is observed, at 113 DAS, that the management strategies with saline water application in the vegetative and fruiting stages (T1 and T3) resulted in decreases in 100SW of 11.14 and 6.18%, respectively, when compared to plants irrigated with saline water in the flowering stage, which had an average 100SW of 9.87 g. These results are similar to those obtained by Oliveira et al. (2012), who evaluated the effect of salinity on the production of 'Delta Opal' cotton as a function of seed treatment with mepiquat chloride and observed that 100SW ranged from 11.43 to 8.18 g according to irrigation with electrical conductivities of 0.5 and 6.5 dS m^{-1}, respectively.

The results of the means comparison test of the saline water application management strategies for total seed weight (TSW) (Figure 6B) showed a similar trend to that of the physiological attributes, and strategies with saline water irrigation in the vegetative and flowering stages led to higher TSW, with mean values of 117.75 and 112.58 g $plant^{-1}$, respectively. This result is an indication that the exposure of plants to irrigation water salinity during the vegetative and flowering stages has less effect on seed production; that is, after the vegetative growth stage, in which sensitivity to salt stress is more evident, cotton plants become progressively tolerant throughout their cycle (Maas & Grattan, 1999).

Conclusions

1. Irrigation with salinized water (9 dS m^{-1}) during the vegetative stage promoted greater phytomass accumulation in the genotypes of naturally colored cotton.

2. In the early stages of cotton development, irrigation with salinized water can be used with the lowest losses in production components.

3. Among the genotypes, 'BRS Topázio' is the most tolerant to irrigation water salinity, in terms of seed cotton weight and lint cotton weight, regardless of the development stage.

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