

Naturally colored cotton irrigated with saline water at different growth stages

Algodón de color natural regado con agua salina en diferentes etapas de crecimiento

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ABSTRACT

This study aimed to evaluate the growth, production, and nutrition of naturally colored cotton (cultivar BRS Verde) irrigated with saline water in different growth stages. The trial was conducted with a randomized block design in which the treatments consisted of three irrigation water salinity levels applied throughout the crop cycle or alternately in three growth stages. The lowest-salinity water was drawn from the Arenito Açu aquifer in the state of Rio Grande do Norte, Brazil; the highest-salinity water was prepared to obtain salinity similar to the water drawn from the Calcário Jandaíra aquifer, and an intermediate salinity was obtained from the mixture of equal volumes of the lowest and highest-salinity waters. The application of the lowest-salinity water is recommended in all growth stages due to the increases of about 19% in cotton growth and 40% in yield compared to the application of intermediate or highest-salinity water. The application of the lowest-salinity water in the vegetative stage and the intermediate-salinity water in the following stages is an alternative to using good quality water throughout the cycle, despite the decreases of about 7% in growth and 16% in yield. The nutrition of cotton plants irrigated with saline water throughout the cycle or in some growth stages was marked by an increase of up to 86% in the cotton leaf sodium content, a decrease in the leaf potassium content of up to 21% and increases between 24% and 188% in leaf micronutrient content when the highest-salinity water replaced that with the lowest salinity.

Key words: *Gossypium hirsutum* L., salinity, water quality, lint yield.

RESUMEN

Este estudio tuvo como objetivo evaluar el crecimiento, producción y nutrición de algodón de color natural (cultivar BRS Verde) regado con agua salina en diferentes etapas de crecimiento. El ensayo se realizó en un diseño de bloques al azar en el que los tratamientos consistieron en tres niveles de salinidad del agua de riego aplicados a lo largo del ciclo del cultivo o alternativamente en tres etapas de crecimiento. El agua de menor salinidad se extrajo del acuífero Arenito Açu en el estado de Rio Grande do Norte, Brasil; el agua de mayor salinidad se preparó para obtener una salinidad similar a la del agua extraída del acuífero Calcário Jandaíra, y la salinidad intermedia se obtuvo de la mezcla de volúmenes iguales de las aguas de menor y mayor salinidad. Se recomienda la aplicación de agua de menor salinidad en todas las etapas de crecimiento debido a los incrementos de aproximadamente 19% en el crecimiento del algodón y 40% en el rendimiento comparado con la aplicación de agua de intermedia o mayor salinidad. La aplicación de agua de menor salinidad en la etapa vegetativa y de agua de salinidad intermedia en las siguientes etapas es una alternativa al uso de agua de buena calidad durante todo el ciclo, a pesar de las disminuciones de alrededor de 7% en el crecimiento y 16% en el rendimiento. La nutrición de las plantas de algodón regadas con agua salina durante todo el ciclo o en algunas etapas de crecimiento estuvo marcada por un aumento de hasta un 86% en el contenido de sodio de la hoja de algodón, una disminución del contenido de potasio de la hoja de hasta un 21% y aumentos entre un 24 y 188% en el contenido de micronutrientes de las hojas cuando el agua de mayor salinidad reemplazó a la de menor salinidad.

Palabras clave: *Gossypium hirsutum* L., salinidad, calidad del agua, rendimiento de pluma.

Introduction

Herbaceous cotton (*Gossypium hirsutum* L.) is one of the main commercial crops in Brazil. Lint cotton production in the 2016-2017 and 2017-2018 crop seasons amounted to 1.53 and 2.01 million metric t, respectively. The lint

cotton yield in the Brazilian northeastern region ranged between 1600 and 1800 kg ha⁻¹ in 2017-2018, similar to the nationwide yield. Global lint cotton production in the 2017-2018 growing season was around 27 million t, while India, China, and the United States were the largest producers (CONAB, 2018).

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The most widely planted cotton cultivar in the northeastern region of Brazil is CNPA 7H. The cultivar BRS Verde, launched in 2002, differs only by a gene that promotes the green color of the fiber, inherited from the North American cultivar Arkansas Green (Carvalho *et al.*, 2011). BRS Verde was developed by the National Center for Cotton Research of EMBRAPA and has a low height and a cycle of 130 to 140 d.

Growing naturally colored cotton is important for generating employment and income for small farmers in the region. The use of naturally colored fibers dispenses with the need for dyes in the final phase of the thread or fabric manufacturing. This reduces the environmental impact of the dyeing process and allows the production of organic fabrics as well as the elimination of allergy risks to sufferers. Therefore, an interest in using clothing made from naturally colored cotton is growing worldwide. The sale price of naturally colored cotton fiber can be twice that of white fiber (Carvalho *et al.*, 2011; 2014).

The semiarid region of northeastern Brazil has a strong potential for irrigated agriculture, but many of its water sources are of inferior quality due to high levels of salts. These waters can be used only in situations of high demand and after previous studies, since they can cause soil salinity problems in the medium and long term, compromising agricultural productivity and the environment (Holanda *et al.*, 2010). Therefore, it is necessary to manage soil and water rationally in terms of water quality and water savings.

The water used for irrigation in the western region of the state of Rio Grande do Norte comes from shallow wells located in the geological formation called “Calcário Jandaíra”, where water quality and cost of extraction are low. In the region, water is also extracted from deep wells, located in the “Arenito Açú” formation that does not contain excess salts but has high extraction costs (Medeiros *et al.*, 2007). Excess salts in irrigation water cause plant stress and can impair physiological and biochemical functions, causing disturbances in water relations, changes in the absorption and utilization of essential nutrients (Braz *et al.*, 2019), stunted plant growth, and yield reduction.

Salinity poses a great risk to cotton productivity, especially in arid or semiarid regions. Although cotton is considered tolerant, salinity can impair its growth due to osmotic effects, nutritional imbalance, and toxicity of Na and Cl⁻ for the plant’s metabolism. Other effects are the alteration in the extensibility of the cell wall and salt accumulation in the apoplast. In general, moderate salinity does not impair

the photosynthesis or transpiration of cotton plants but increasing salinity can decrease the nitrogen leaf content. Benefits to photosynthesis due to a small increase in salinity are attributed to the osmotic adjustment exerted by Na and Cl⁻. Variations in the balance between Na and K levels in cotton leaves are evident effects of salt stress, but Na retention in roots is a probable mechanism of cotton salt tolerance (Ahmad *et al.*, 2002).

In general, cotton biomass production is affected by increased salinity, but this response differs between different genotypes. The sensitivity of the crop is higher during germination and early development, especially in the 6-leaf stage of the seedling, but tolerance increases in the following growth stages. Among the reported effects of increased salinity are a reduction in vegetative growth, although roots may grow more at moderate salinity; a reduction in seed cotton yield, especially if irrigated with saline water in the early stages; a reduction in the number of bolls, although the weight of the seeds is less affected by salinity; a decrease in cotton fiber quality, and a decrease in the oil content that may tend to rise with small increases in irrigation water salinity and then to decrease with greater salinity increases (Ahmad *et al.*, 2002).

In this context, this study was carried out to evaluate the growth, production, and nutrition of naturally colored cotton (cultivar BRS Verde) irrigated with water with different salt levels in different growth stages.

Materials and methods

The research was carried out from October 2011 to February 2012 at the experimental farm of the Federal Rural University of the Semi-arid Region, located in Mossoró, RN, Brazil (5°03’37” S, 37°23’50” W), at an altitude of 18 m a.s.l. The climate of the region is semiarid, megathermal, and with water deficits during most of the year. The average annual rainfall is 674 mm, of which about 550 mm occurs between February and May. The mean annual relative humidity is 68.9%, while the mean annual temperature is 27.7°C (Vanomark *et al.*, 2018). The soil of the experimental area is a typic hapludult (Soil Survey Staff, 2014).

The experiment was carried out according to a completely randomized block design with five replicates. The description of treatments is shown in Table 1. Each plot consisted of four rows of 7 m in length, each containing 47 plants. The useful area for evaluations included the two central rows of the plot, discarding a plant at each end.

TABLE 1. Description of treatments combining three levels of water salinity applied in three cotton growth stages.

Treatments	Cotton growth stages		
	Vegetative (0-30 DAS)	Reproductive (31-90 DAS)	Maturation (91 DAS - harvest)
	Water salinity (dS m ⁻¹)		
T1	0.55	0.55	0.55
T2	2.16	2.16	2.16
T3	3.53	3.53	3.53
T4	0.55	2.16	2.16
T5	0.55	2.16	3.53
T6	0.55	3.53	3.53

DAS - days after sowing.

The lowest-salinity water (S1 - 0.55 dS m⁻¹) was drawn from a well from the Arenito Açu aquifer, at an average depth of 1000 m. The highest-salinity water (S3 - 3.53 dS m⁻¹) was prepared from water S1 to which 3.975 kg of NaCl and 3.966 L of CaCl₂.2H₂O were added per 1000 L of water to represent the salinity of water from the Calcário Jandaíra aquifer according to Medeiros (1992). The intermediate-salinity water (S2 - 2.16 dS m⁻¹) was obtained by mixing equal volumes of waters S1 and S3.

The naturally colored cotton cultivar BRS Verde was sown with a spacing of 0.15 m between plants and 0.9 m between rows, resulting in a population of 74,000 plants ha⁻¹. Of the total amount of fertilizers, 20% of the urea and 50% of the KCl were applied at planting. The remaining KCl was applied via fertigation at 15 d after emergence (DAE), while the rest of the urea was applied at 15 and 40 DAE, also by fertigation.

The crop was irrigated twice a day with a drip irrigation system whose tubes, with self-compensating emitters, had an average flow of 1.8 L h⁻¹ and a 95% distribution coefficient. The water depth was determined by the Penman-Monteith method using reference evapotranspiration and crop coefficients of 0.70 for the germination stage, 0.85 for the vegetative stage, 1.00 for the reproductive stage, and 0.95 for the maturation stage (Bezerra *et al.*, 2010). The climatological normal for the years 1981 to 2010 (INMET, 2018) showed daily potential evapotranspiration of around 7.2 mm for October and November, 7.6 mm for December and January, and 7.1 mm for February.

At 100 DAE, the following crop growth characteristics were determined in each plot: plant height (PH), stem diameter (SD), and number of leaves (NL). The number of bolls and lint yield were determined in one row in the useful area of each plot. The first sampling was carried out when 60% of the bolls in the experimental area were open.

The evaluation of the nutritional status of the plants included the determination of macronutrients (Ca, Mg, P, K, N, and Na) and micronutrients (Mn, Zn, Fe, and Cu). For this, the fifth leaf below the apex was collected from 20 plants per plot at 65 DAE, as recommended by Malavolta *et al.* (1997).

The data were subjected to an analysis of variance to verify differences among treatments using the t-test ($P < 0.01$ or 0.05). The means of the variables that showed a significant effect of the treatments were compared using the Tukey test ($P < 0.01$ or 0.05). We used the SISVAR software for all analyses (Ferreira, 2014).

Results and discussion

The application of water with different salinities in different growth stages had a significant effect ($P < 0.01$) on plant height and stem diameter of BRS Verde cotton (Fig. 1), with coefficients of variation (CV) of 8.9% and 9.4%, respectively. The effects observed on the number of leaves (CV = 27.0%), lint yield (CV = 37.5%), and number of bolls (CV = 41.6%) were not statistically significant according to the t-test.

There was a decrease in plant height (Fig. 1A) and stem diameter (Fig. 1B) when the saline waters (T2 - 2.16 dS m⁻¹ and T3 - 3.53 dS m⁻¹) were applied throughout the crop cycle instead of the lowest-salinity water (T1 - 0.55 dS m⁻¹). However, a significant difference was only observed among the treatments that applied the lowest-salinity water (T1) at all growth stages and the treatments that applied the highest-salinity water (T3) or the intermediate-salinity water (T2) at all stages. Treatments T2 and T3, which did not differ in plant height and stem diameter, showed the lowest mean values.

Growth impairment of BRS Verde cotton due to water salinity was reported by Sousa Júnior *et al.* (2005), who observed a decrease of 3.23% in stem diameter and 5.68% in plant height per unit increment of the electrical conductivity of water (ECw) from 2.0 to 9.5 dS m⁻¹. The decrease in plant height of cotton cultivar BR 1 subjected to increased irrigation water salinity levels was attributed by Graciano *et al.* (2011) to the reduction in the osmotic potential of the soil solution. This reduction can be due to the high concentration of sodium (as observed in Fig. 3B), hindering the absorption of water and nutrients by the plants. The effect of sodium on the height of cotton plants can also be attributed to a cationic imbalance, such as the reduction in the K/(Ca + Mg) ratio (Queiroz & Büll, 2001).

A reduction in stem diameter was also observed in *Jatropha* plants subjected to an increase in EC_w from 0.6 to 3.0 dS m⁻¹ (Nery *et al.*, 2009). Castor bean plants (Cavalcanti *et al.*, 2005) showed a reduction in this variable of 1.45% for each unit increase in EC_w at 80 DAE. However, Costa *et al.* (2013) found no difference in the diameter of the castor bean stem when they applied water with EC_w of up to 3.66 dS m⁻¹, according to the growth stage. The effects of the different salinity levels are due to management conditions, soil and climate characteristics, plant species, genotypes of the same species, and plant growth stages (Suassuna *et al.*, 2017).

Cotton plants irrigated with the lowest-salinity water throughout the cycle (T1) showed greater height and stem diameter than when irrigated with waters whose salinity varied according to the growth stage. On the other hand, irrigation with different salinity waters in different growth stages (T4, T5, and T6) showed better results than the use of saline waters (T2 and T3) throughout the cycle. This may be due to the fact that cotton tolerance to salinity increases as growth stages progress (Khorsandi & Anagholi, 2009).

The number of leaves (Fig. 1C) showed a response to salinity different from plant height and stem diameter. Although not statistically different, a greater number of leaves was observed when irrigation water salinity was different according to the growth stage (T4, T5, and T6) than when water salinity was the same in all stages (T1, T2, and T3). The highest mean (61 leaves) was obtained when the lowest-salinity water was applied in the vegetative stage, and the intermediate-salinity water was applied in the other stages (T4). This treatment had 16% more leaves than T1, which used the lowest-salinity water in all stages. This indicates that if the plants grow well while receiving the lowest-salinity water in the vegetative stage, it would be advantageous to apply moderate-salinity water in the other stages (T4), or even to apply moderate salinity water in the reproductive stage and the highest-salinity water in the maturation stage (T5). According to Khorsandi and Anagholi (2009), to compensate for the delay in development after saline stress, cotton plants restart the vegetative growth and emit new leaves, which reactivate the photosynthesis and start a new cycle to produce flowers and bolls.

The cotton production parameters of lint yield (Fig. 2A) and number of bolls (Fig. 2B) did not show a significant effect of treatments, even after data transformation of the number of bolls, which did not adjust to the normal distribution, according to the Shapiro-Wilk test. These results were explained by Ribeiro-Oliveira *et al.* (2018) in

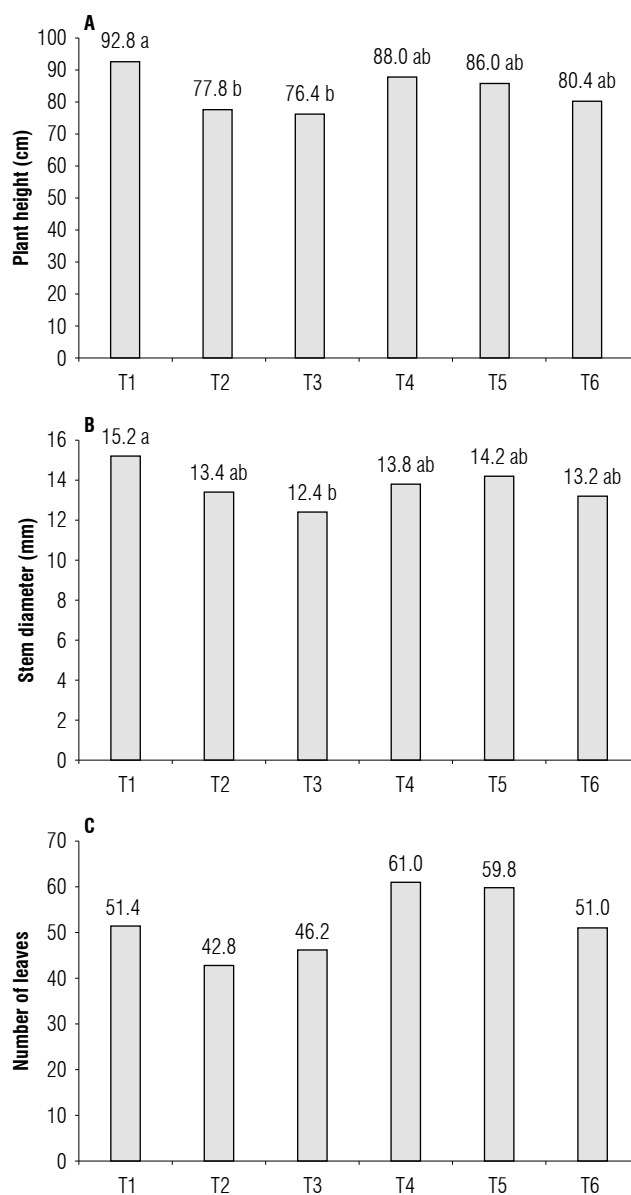


FIGURE 1. A) Comparison of means of plant height, B) stem diameter, and C) number of leaves at 100 d after emergence of naturally colored cotton subjected to three irrigation water salinity levels in different growth stages. T1 (S1 (0.55 dS m⁻¹) water in the three stages); T2 (S2 (2.16 dS m⁻¹) water in the three stages); T3 (S3 (3.53 dS m⁻¹) water in the three stages); T4 (S1 in the vegetative stage (V), and S2 in the reproductive (R) and maturation (M) stages); T5 (S1 in V, S2 in R, and S3 in M), and T6 (S1 in V, and S3 in R and M).

a study on data transformation. The behavior of data on the number of bolls was similar to that of lint yield, stem diameter, and plant height when water of the same salinity was applied throughout the cotton cycle (T1, T2, and T3). When irrigated with the lowest-salinity water in all growth stages (T1), lint yield and number of bolls were 40% higher than in T3, in which the highest-salinity water was used at all stages.

According to Ahmad *et al.* (2002), long-term irrigation with saline water caused a decrease in the number of bolls per plant and seed cotton yield. The reduction in the number of bolls was due to the reduction of fruiting sites and a greater fall of bolls. In this regard, Jácome *et al.* (2003) tested several cotton genotypes irrigated with increasing levels of water salinity and observed a significant reduction in the number of bolls per plant of BRS Verde and of the lint yield of CNPA 7H. Similarly, Sousa Júnior *et al.* (2005) observed a linear decrease in the number of bolls of BRS Verde cotton when the EC_w of irrigation water increased from 2.0 to 9.5 dS m⁻¹.

However, the second-largest yield was observed when the lowest-salinity water was applied in the vegetative stage, the intermediate-salinity water was applied in the reproductive stage, and the highest-salinity water was applied in the maturation stage (T5). The treatment T5 had a 13% lower lint yield and 11% lower number of bolls than T1. According to Khorsandi and Anagholi (2009), the application of saline water in the vegetative stage is more harmful to cotton plants, since they do not recover when suffering moderate to severe damages, while plants are less affected in the reproduction and maturation stages.

Although there were no statistical differences, the lowest values of the production variables were observed in the T6 treatment, in which the highest-salinity water was applied in the reproductive and maturation stages after the application of the lowest-salinity water in the vegetative stage. Given the existence of two water sources with different salinities in the region, and that the farmers in the area face problems of availability of good quality water and soil salinization, the results obtained in T5 indicate

that the application of good quality water in the vegetative stage and the mixture of the water from the two sources in the reproductive and maturation stages should be better studied as an alternative to improve cotton growth and production. This is in agreement with Khorsandi and Anagholi (2009) and Soares *et al.* (2018). These authors recommend the application of good quality water until full crop establishment, followed by the application of intermediate-salinity water in the reproductive stage. The highest-salinity water is not so harmful in the maturation stage because plants have already formed their reproductive organs, guaranteeing the production of bolls and because the plants are more tolerant of salinity during the growth of bolls than during the vegetative and reproductive stages.

The treatments had a significant effect on the leaf contents of sodium ($P < 0.01$ - Fig. 3B), potassium ($P < 0.01$ - Fig. 3C), phosphorus ($P < 0.05$ - Fig. 3D), magnesium ($P < 0.05$ - Fig. 3E), and calcium ($P < 0.05$ - Fig. 3F). These variables showed CV values of 15.8%, 10.9%, 20.3%, 11.6%, and 15.3%, respectively. No significant effect was observed on leaf nitrogen content (CV = 16.2%) (Fig. 3A), which is the most limiting nutrient to plant growth. No treatment achieved a leaf nitrogen content of 32 g kg⁻¹, which is the appropriate level according to Dechen *et al.* (2007). This occurred in the treatments receiving saline water since the effect of salinity reduces nitrogen absorption, mainly in the form of NO₃⁻, and restricts its load in the xylem (Miller *et al.*, 2007).

The sodium content of leaves (Fig. 3B) increased when replacing good quality irrigation water (T1) with saline water in all growth stages (T2 and T3). The accumulation of sodium in plant shoots in response to the increase in salt concentration in the soil solution is an important

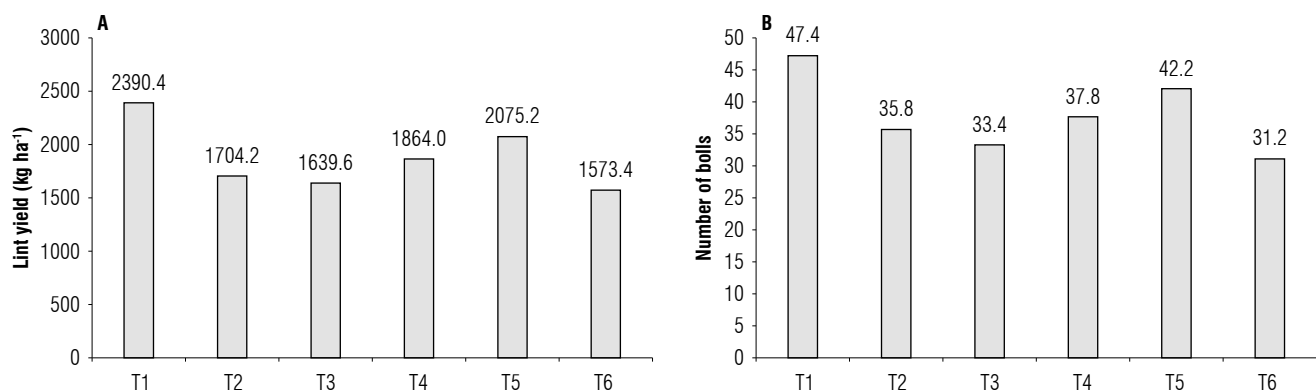


FIGURE 2. Comparison of means for A) lint yield, and B) number of bolls of colored cotton subjected to three irrigation water salinity levels in different growth stages. T1 (S1 (0.55 dS m⁻¹) water during the three stages); T2 (S2 (2.16 dS m⁻¹) water during the three stages); T3 (S3 (3.53 dS m⁻¹) water during the three stages); T4 (S1 in the vegetative stage (V), and S2 in the reproductive (R) and maturation (M) stages); T5 (S1 in V, S2 in R, and S3 in M), and T6 (S1 in V, and S3 in R and M).

mechanism of plant tolerance to salinity (Queiroz & Büll, 2001). The highest leaf sodium content was observed when the highest-salinity water was applied in all stages (T3), similar to T6, which received the lowest-salinity water in the vegetative stage and the highest-salinity water in the reproductive and maturation stages. When comparing this treatment with treatments that received the lowest-salinity water only in the vegetative stage (T4, T5, and T6), there was no difference in the sodium leaf content when the highest-salinity water (T5) or the intermediate-salinity water (T4)

was applied during the reproductive period. Additionally, the leaf contents of sodium of these treatments were similar to those of treatments T1 and T2.

The potassium leaf content (Fig. 3C) declined when the lowest-salinity irrigation water (0.55 dS m^{-1}) was replaced by saline water (2.16 and 3.53 dS m^{-1}) in all growth stages. However, when applying waters of different salinities in different growth stages, the T4 treatment (which used the lowest-salinity water in the vegetative stage and

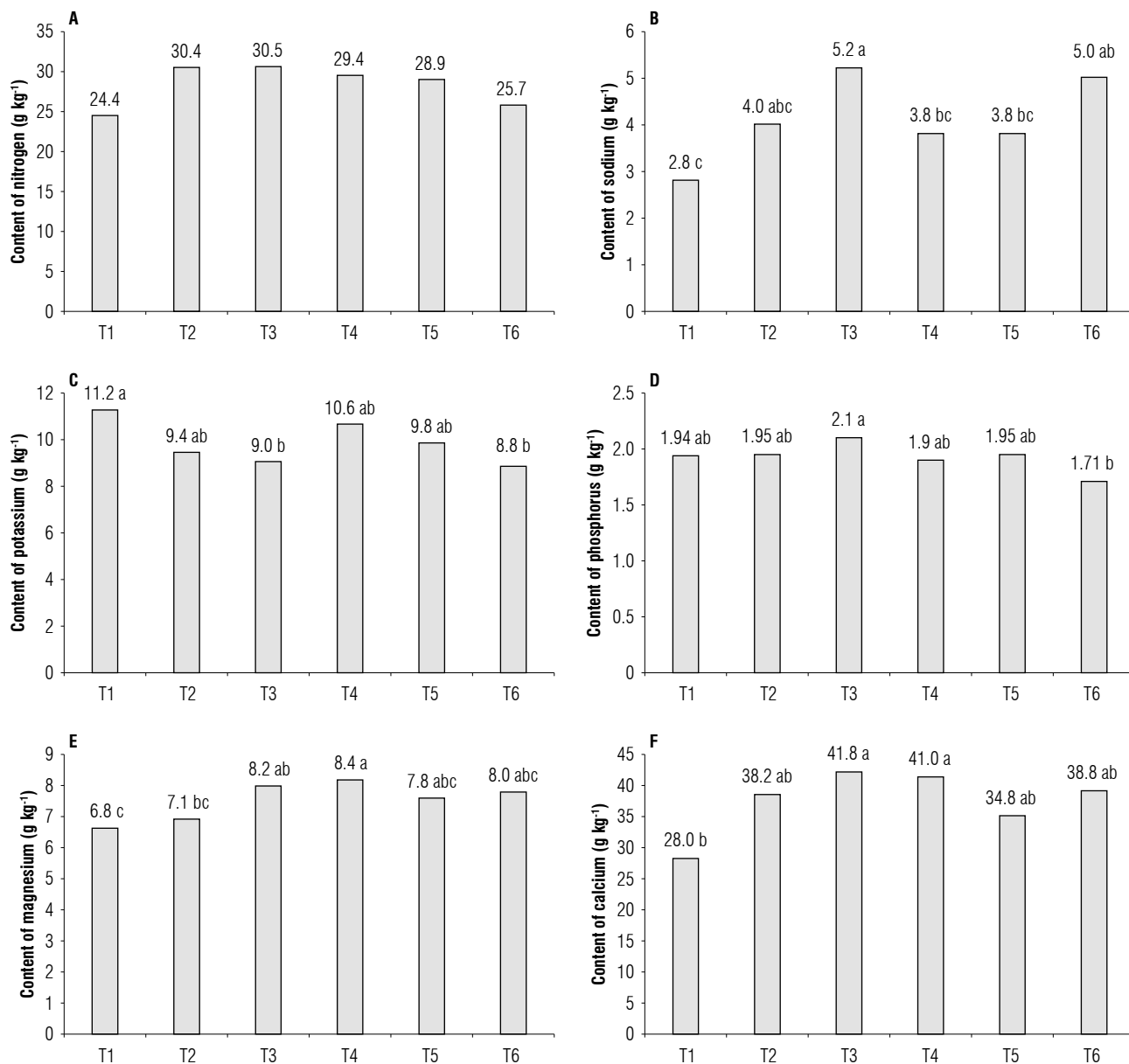


FIGURE 3. Comparison of means for the leaf contents of A) nitrogen, B) sodium, C) potassium, D) phosphorus, E) magnesium, and F) calcium of colored cotton subjected to three irrigation water salinity levels in different growth stages. T1 (S1 (0.55 dS m^{-1}) water in the three stages); T2 (S2 (2.16 dS m^{-1}) water in the three stages); T3 (S3 (3.53 dS m^{-1}) water in the three stages); T4 (S1 in the vegetative (V), and S2 in the reproductive (R) and maturation (M) stages); T5 (S1 in V, S2 in R, and S3 in M), and T6 (S1 in V, and S3 in R and M).

intermediate-salinity water in the other stages), showed slightly lower results than T1 and higher results than saline water treatments (T2, T3, T5, and T6). Despite this, T1 and T4 differed significantly only from the treatments that applied the highest-salinity water (T3 and T6).

According to Queiroz and Büll (2001), the increase in soil sodium content reduces the absorption of potassium by cotton plants, as occurred in the treatments that used saline water in this study. Inhibition of potassium uptake due to high sodium concentration in the soil solution is one of the main disturbances caused by salinity. This inhibition may explain why the potassium leaf content was lower than 14 to 16 g kg⁻¹ in all treatments, which is considered the appropriate content by Dechen *et al.* (2007).

Although the crop was not fertilized with phosphorus, its content in cotton leaves (Fig. 3D) was greater than the range of 2.0 to 2.5 g kg⁻¹ considered adequate by Malavolta (2004). However, T6, which received the highest-salinity water in the reproductive and maturation stages, showed significantly lower leaf phosphorus contents than T3. When the irrigation water salinity was the same in all crop stages, the leaf phosphorus content increased from T1 (0.55 dS m⁻¹) to T2 (2.16 dS m⁻¹) and to T3 (3.53 dS m⁻¹) which was the treatment with the highest phosphorus content. However, a reduction in phosphorus content of plant tissue was expected due to the ionic force effect, which reduces phosphate activity in the soil solution. Additionally, the high adsorption of phosphate, whose solubility decreases when NaCl increases in the soil, may contribute to the lower content of this macronutrient (Sharpley *et al.*, 1992). According to Zoz *et al.* (2009), an increase in phosphorus availability to plants may occur if the salt accumulation causes an increase in pH and a reduction in phosphorus adsorption in the soil.

In the treatments that received the lowest-salinity water only in the vegetative stage, the leaf phosphorus content was similar to that in the treatments that received the intermediate-salinity water in the reproductive and maturation stages (T4), the intermediate-salinity water in the reproductive stage, and the highest-salinity water in the maturation stage (T5). These treatments showed a higher leaf phosphorus content than T6 that received the highest-salinity water in the reproductive and maturation stages. Considering that treatments T6 and T3 received the highest-salinity water from the beginning of the reproductive stage, the higher leaf P content of T3 may be due to increased soil pH or to plant adaption to stress before the reproductive stage. According to Grattan and Grieve (1998),

the effect of salinity on plant phosphorus content depends on the genotype, phenological stage, phosphorus content in the substrate, type of salts, and salinity level.

The contents of magnesium in the leaf tissue of all treatments (Fig. 3E) were higher than the range of 4.0 to 5.0 g kg⁻¹ considered adequate by Malavolta (2004). Our results showed a significant increase as the lowest-salinity irrigation water (T1 - 0.55 dS m⁻¹) was replaced by saline waters (T2 - 2.16 dS m⁻¹ and T3 - 3.53 dS m⁻¹). This increase might be due to the magnesium contained in saline waters.

The leaf contents of magnesium observed in treatments T4, T5, and T6 that received saline waters in some stages of their growth were similar to that observed in T3 that received the highest-salinity water in all stages. However, Queiroz and Büll (2001), who studied higher levels of water salinity, observed a reduction in the absorption of calcium and magnesium in five cotton cultivars due to the increased salinity of the irrigation water. According to these authors, the increase in the concentration of sodium in the soil solution promotes a reduction in the absorption of calcium and magnesium due to the effect of competitive inhibition between these cations during absorption.

Calcium contents in the cotton plant tissue (Fig. 3F) were also above the range considered adequate by Malavolta (2004), which is between 30 and 40 g kg⁻¹. Only T1 that received the lowest-salinity water in all growth stages had a slightly lower calcium content than that considered adequate. This observation illustrates the trend of an increase in leaf calcium contents when saline water (2.16 or 3.53 dS m⁻¹) was applied in all stages or in the reproductive and maturation stages. One aspect that must be taken into account is that in the preparation of saline water used in this study, the high levels of calcium in the water of the Calcário Jandaíra aquifer were reproduced.

The treatments irrigated with waters of different salinities in different growth stages of BRS Verde cotton had a significant effect on the leaf contents of zinc ($P < 0.01$), copper, and manganese ($P < 0.05$), but not on the iron content (Fig. 4). These variables showed CV values of 30.5, 7.2, 20.0, and 24.6%, respectively.

The zinc content in cotton leaves was generally above the range considered adequate, which is from 10 to 15 mg kg⁻¹ (Malavolta *et al.*, 1997; Galvão, 2002), while the iron and copper contents were within the appropriate ranges, which are from 50 to 250 mg kg⁻¹ for iron (Malavolta *et al.*, 1997; Galvão, 2002) and from 5 to 15 mg kg⁻¹ for copper

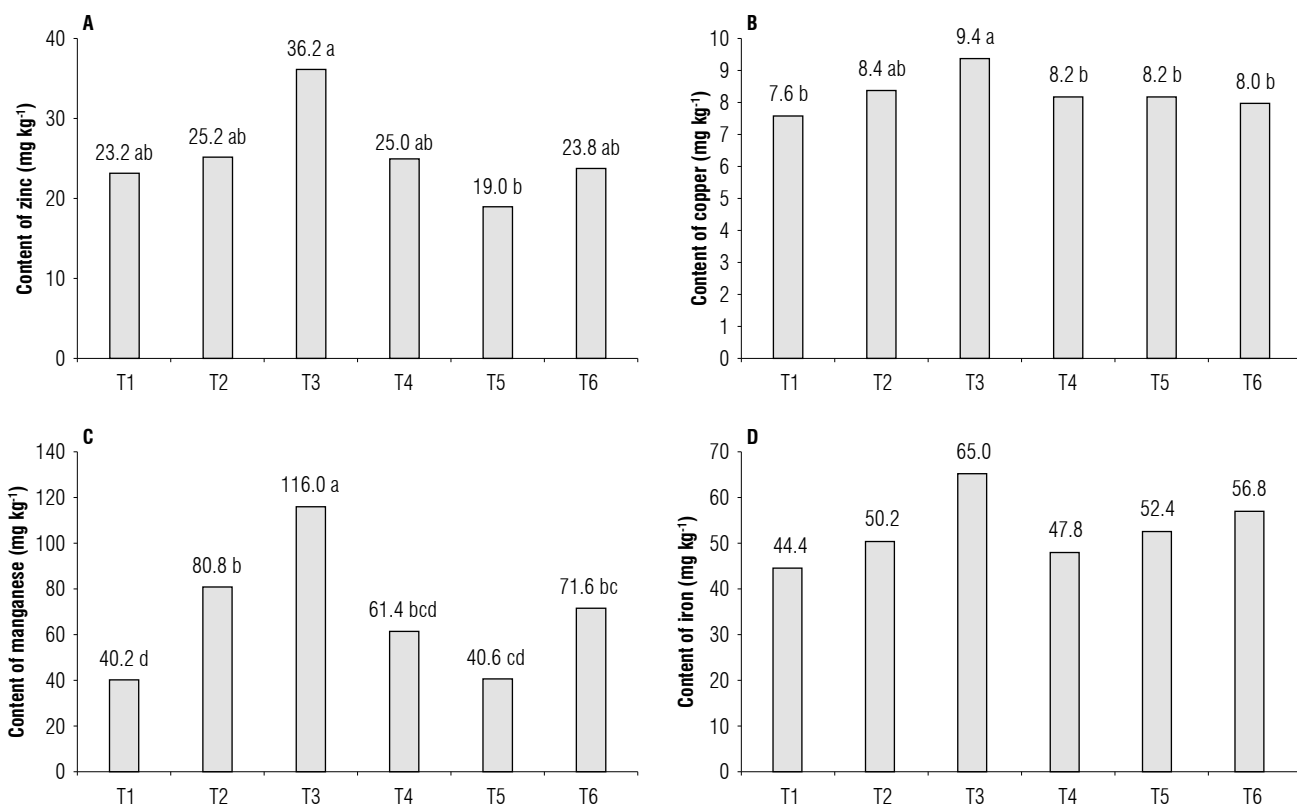


FIGURE 4. Comparison of means for the foliar contents of the micronutrients A) zinc, B) copper, C) manganese, and D) iron of colored cotton subjected to three irrigation water salinity levels in different growth stages: T1 (S1 (0.55 dS m⁻¹) water in the three stages); T2 (S2 (2.16 dS m⁻¹) water in the three stages); T3 (S3 (3.53 dS m⁻¹) water in the three stages); T4 (S1 in the vegetative stage (V), and S2 in the reproductive (R) and maturation (M) stages); T5 (S1 in V, S2 in R, and S3 in M), and T6 (S1 in V, and S3 in R and M).

(Carvalho, 2007). The manganese content is not considered to be toxic to cotton, since Foy *et al.* (1995) observed manganese toxicity only in cotton plants with leaf contents greater than 1500 mg kg⁻¹.

A clear tendency of increase in leaf contents of zinc (Fig. 4A), copper (Fig. 4B), manganese (Fig. 4C), and iron (Fig. 4D) with increased irrigation water salinity was observed when comparing the different salinity applied in all cotton growth stages (T1, T2, and T3). The increases observed between treatments T1 (water of 0.55 dS m⁻¹ in all stages) and T3 (water of 3.53 dS m⁻¹ in all stages) were 24%, 46%, 56%, and 190% for copper, iron, zinc, and manganese, respectively.

According to Hu and Schmidhalter (2001), the ability to metabolize micronutrients efficiently depends on the plant's genotype, but salinity alters micronutrient availability due to an increase in the solubility of these elements. Additionally, changes in soil pH occur that also influence micronutrient solubility. This information is corroborated by Grattan and Grieve (1992), who reported that micronutrient concentration in plant shoots is also influenced by

soil mineralogy, type of plant and tissue, level of salinity, micronutrient concentration in the medium, and environmental conditions. These authors reported increases due to salinity in the shoot contents of zinc, manganese, and iron in diverse crops.

When the cotton was irrigated with the lowest-salinity water in the vegetative stage and with saline waters in the other growth stages (T4, T5, and T6), the micronutrient contents differed little among the treatments. In general, the contents in these treatments were lower than in the T3 treatment, in which the highest-salinity water (3.53 dS m⁻¹) was used in all growth stages.

Conclusions

The recommendation to apply the lowest-salinity water in all growth stages is based on the increase in cotton growth and yield of around 19% and 40%, respectively, compared to the application of the intermediate or highest-salinity water. The application of the lowest-salinity water in the vegetative stage and intermediate-salinity water in the following stages is an alternative to using good quality water

throughout the cycle, despite the decreases of about 7% in growth and 16% in yield. The nutrition of cotton plants irrigated with saline water throughout the cycle or in some growth stages was marked by an increase of up to 86% in the leaf sodium content, a decrease in the leaf potassium content of up to 21% and increases between 24% and 188% in leaf micronutrient content when the highest-salinity water replaced that with the lowest salinity.

Author's contributions

AFM and MTG formulated the research goals and aims and managed the project. AFM, MTG, and KDT developed and designed the methodology. AFM, KDT, and LRC conducted the experiment. AFM, MTG, and MFN carried out the statistical analysis. AFM, MTG, NOM, and NSD wrote the original draft. MFN, NOM, and NSD reviewed the draft and translated it into English.

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