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Physiological characteristics and yield of 'Pérola' pineapple in the semi-arid region[1]

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Key words:
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ABSTRACT

The objective of this study was to evaluate the physiological characteristics and yield of 'Pérola' pineapple subjected to irrigation with saline water in the semi-arid region of Bahia. The experiment was conducted in randomized blocks with five treatments, represented by irrigation depths: 100% ETc, using water with electrical conductivity (ECw) of 0.75 dS m^{-1}, and 50, 75, 100 and 125% ETc, using water with ECw of 3.6 dS m^{-1}. The experiment used a drip irrigation system and pressure-compensating emitters with a discharge of 8 L h^{-1}. In the physiographic conditions of Guanambi-BA, pineapple has limitations of the physiological characteristics of chlorophyll fluorescence and chlorophyll index, under irrigation with both saline water and better-quality water. The irrigation depth corresponding to 100% ETc using water with ECw levels of 0.75 and 3.6 dS m^{-1} led to the best yields.

Palavras-chave:
salinidade
plantas CAM
manejo da irrigação

Características fisiológicas e produtividade de abacaxizeiro 'Pérola' na região semiárida

RESUMO

Objetivou-se avaliar as características fisiológicas e a produtividade do abacaxizeiro 'Pérola' submetido à irrigação com água salina no semiárido baiano. O experimento foi conduzido em blocos casualizados com cinco tratamentos representados pelas lâminas de irrigação: 100% da ETc com água de condutividade elétrica (CEa) de 0,75 dS m^{-1} e 50, 75, 100 e 125% da ETc com aplicação de água de CEa de 3,6 dS m^{-1}. Utilizou-se o sistema de irrigação por gotejamento, com gotejadores autocompensantes de vazão nominal de 8 L h^{-1}. Nas condições fisiográficas de Guanambi, BA, o abacaxizeiro apresenta limitações das caraterísticas fisiológicas de fluorescência da clorofila e índice de clorofila, tanto sob irrigação com água salina, quanto com água de melhor qualidade. A lâmina de irrigação referente a 100% da ETc com água de CEa de 0,75 e 3,6 dS m^{-1} proporciona as melhores produtividades.

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Introduction

Given the poor spatial and temporal distribution and scarcity of rainfalls in semi-arid regions, the utilization of water with lower chemical quality in irrigation has been a strategy to complement agricultural production (Santos & Brito, 2016).

Particularly in arid and semi-arid environments, salt stress, due to the use of waters with lower chemical quality, associated with high luminosity, can constitute a combination of stress factors and compromise the yield of unadapted crops, notably C_3 species (Freitas et al., 2014).

In this context, pineapple (*Ananas comosus* L. Merril), with physiology characterized by the facultative Crassulacean Acid Metabolism (CAM) photosynthetic process, i.e., it changes from C_3 to CAM (Aragón et al., 2012; Zhang et al., 2014; Couto et al., 2016), can become an alternative crop in the semi-arid region and increase the range of irrigated crops for producers in these regions. The change from C_3 to CAM leads to water saving, due to stomatal closure during the daytime and better water use efficiency under drought conditions (Carr, 2012).

In the semi-arid region, studies on the use of saline water in the pineapple crop are still scarce and the existing ones, including in other regions, have been carried out under induced-salinity conditions (Marinho et al., 1998; Barreiro Neto et al., 2007; Ibrahim, 2013). Therefore, studies on the application of saline water from tubular wells under field conditions in the pineapple crop are pertinent.

Under semi-arid conditions, there is a maladjustment between ambience and ecological optimum for most unadapted crops. Thus, information on physiology and production is relevant for the introduction of pineapple in this region. In this context, this study aimed to determine physiological characteristics of efficiency and maximum quantum yield of photosystem II, chlorophyll index, leaf area index and yield of 'Pérola' pineapple subjected to saline water irrigation the semi-arid region of Bahia.

Material and Methods

The study was carried out from April 2015 to October 2016 in an experimental area of the Agriculture Sector of the Federal Institute of Bahia, Campus of Guanambi, located in the Irrigated Perimeter of Ceraíma, Guanambi, Bahia. Maximum and minimum temperatures, rainfall, relative air humidity, wind speed (mean and gust) and reference evapotranspiration recorded along the experimental period are presented in Figure 1.

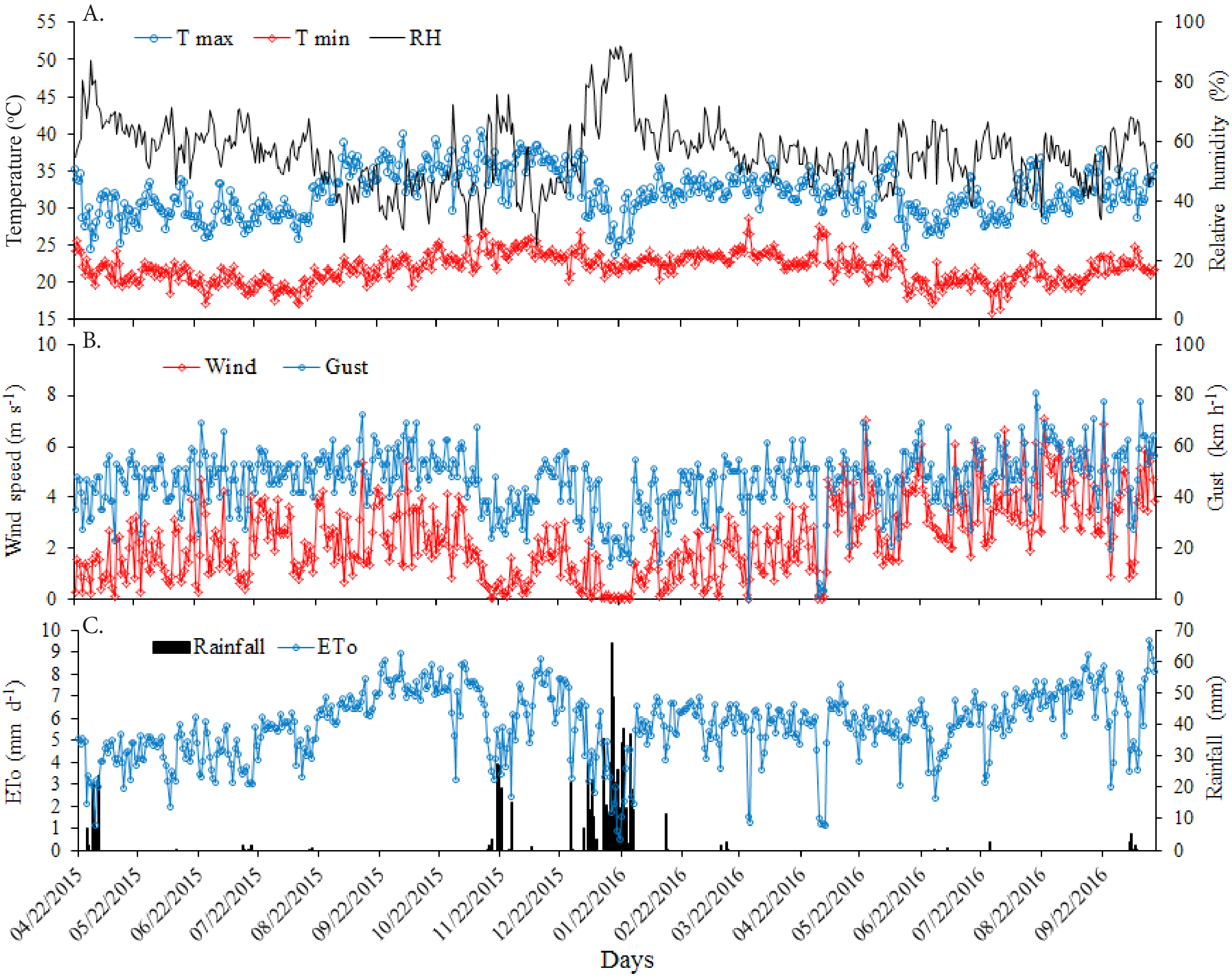

Figure 1. Temperature (maximum-Tmax and minimum-Tmin) and relative air humidity (RH) (A), mean and gust wind speed (B), rainfall and reference evapotranspiration (ETo) (C) during the experimental period

Pineapple was cultivated in typic dystrophic Red Yellow Latosol, with weak A horizon, on flat to gently undulating relief. Its chemical characteristics (Tedesco et al., 1995) and texture analysis (EMBRAPA, 1997) in the layer of 0-20 cm before installing the experiment were: pH (in water) = 5.7; P (Mehlich extractor) = 23.5 mg dm^{-3}; K (Mehlich extractor) = 108 mg dm^{-3}; Na = 0.1 $cmol_c$ dm^{-3}; Ca = 1.4 $cmol_c$ dm^{-3}; Mg = 0.6 $cmol_c$ dm^{-3}; Al = 0 $cmol_c$ dm^{-3}; H+Al = 1.7 $cmol_c$ dm^{-3}; SB = 2.4 $cmol_c$ dm^{-3}; t = 2.4 $cmol_c$ dm^{-3}; T = 4.1 $cmol_c$ dm^{-3}; V = 58%; B = 0.3 mg dm^{-3}; Cu = 0.4 mg dm^{-3}; Fe = 16.0 mg dm^{-3}; Mn = 32.5 mg dm^{-3}; Zn = 2.1 mg dm^{-3}; EC = 0.7 dS m^{-1}; Sand = 68 dag kg^{-1}; Silt = 11 dag kg^{-1} and Clay = 21 dag kg^{-1}.

'Pérola' pineapple seedlings (slips) were planted in April 2015 in single row, at spacing of 0.25 m between plants and 1.2 m between rows, with a population of 33,300 plants ha^{-1}. Soil correction and basal and top-dressing fertilizations were performed according to the soil analysis (Souza et al., 2007). During the experiment, cultivation and phytosanitary practices established for the crop were employed and there was low incidence of pests and diseases.

One month after planting, plants received foliar application of urea, zinc sulfate and potassium chloride (KCl). After that, every two months, urea (5 g $plant^{-1}$) and KCl (2.5 g $plant^{-1}$) were applied through broadcast.

Irrigation was applied using a drip system, with pressure-compensating emitters with nominal flow rate of 8 L h^{-1}, spaced by 0.75 m, forming a continuous wet strip along plant rows. Until the fourth month after planting, irrigations were daily applied in the same way in all plots, in order to maintain an uniform soil water content and favor the initial growth of the seedlings and establishment of the crop. Subsequently, irrigation depths started to be applied, and irrigation time was calculated based on crop evapotranspiration (ETc) (Santos et al., 2015), obtained by the reference evapotranspiration (ETo) daily determined through the Penman-Monteith method, using data from a weather station installed approximately 200 m away from the experiment, and crop coefficient (Kc), equal to 0.8 in the initial stage of crop establishment and to 1.0 during the vegetative stage and after flower induction (reproductive stage), according to Santana et al. (2013).

The experiment was conducted in randomized blocks with five treatments, represented by the following irrigation depths: 100% ETc, using water with electrical conductivity (ECw) of 0.75 dS m^{-1} and C2S1 classification, and 50, 75, 100 and 125% ETc, using water from a tubular well with ECw of 3.6 dS m^{-1}. Treatments had four replicates and the experimental unit consisted of four 8-m-long rows. Evaluations were made in plants from the central 4 m of the two central rows, totaling 26 evaluated plants in the plot.

The water from tubular well has pH of 6.4, 11.90 $mmol_c$ L^{-1} of calcium, 9.54 $mmol_c$ L^{-1} of magnesium, 0.48 $mmol_c$ L^{-1} of potassium, 30.40 $mmol_c$ L^{-1} of sodium, 0 $mmol_c$ L^{-1} of carbonate, 4.10 $mmol_c$ L^{-1} of bicarbonate and 34.80 $mmol_c$ L^{-1} of chloride (EMBRAPA, 1997); classified as C4S1 according to Ayers & Westcot (1985).

Pineapple flowering was artificially induced 13 months after planting, by applying ETHREL (240 g L^{-1} of Ethephon), a synthetic growth regulator, precursor of the synthesis of ethylene, using a 20-L backpack sprayer. The backpack sprayer received 40 mL of ETHREL + 400 g of urea (2%) to apply an estimated volume of 50 mL of the mixture inside the leaf rosette.

From August 2015 to September 2016, monthly readings of the following physiological characteristics were taken: quantum efficiency (Fv/Fm), maximum quantum yield of photosystem II (PSII) (Y_{PSII}), chlorophyll index and leaf area index (LAI).

Fv/Fm and Y_{PSII} were determined based on the readings of chlorophyll *a* fluorescence, taken with a modulated-light fluorometer (OPTI-Sciences - Model OS1-FL) in the morning (8 h) and afternoon (14 h). The clips to measure chlorophyll *a* fluorescence were placed in the middle third of the pineapple "D" leaf, and the measurement was taken after 5 min of adaptation to the dark, by emitting a 0.3-s pulse of saturating light at 0.6 kHz frequency, to obtain the value of Fv/Fm. In addition, readings were taken on pineapple leaves adapted to the light, in which saturating pulses were applied to determine Y_{PSII}.

Contents of chlorophyll a, b, total (a + b) in the pineapple crop were evaluated always in the "D" leaf, using a chlorophyll meter (CLOROFILOG® - Model CFL 1030). LAI readings were taken using a ceptometer (AccuPAR - Model Lp-80), which directly estimates LAI based on the measurements of incident radiation and radiation transmitted through the canopy.

A completely randomized design (CRD) with four replicates was used only for the variables Fv/Fm and Y_{PSII}, because readings were taken only in the central blocks. Hence, a 5 x 13 x 2 factorial scheme was adopted, arranged in CRD. Treatments consisted of five irrigation depths, 13 periods (months) and two times of evaluation (8 and 14 h).

Pineapple fruits were harvested 17 months after planting and 5 months after flower induction. After harvest, the following variables were measured: fruit fresh weight with and without crown, crown weight, by direct weighing on precision scale; fruit length with and without crown, using a millimeter ruler, and fruit diameter, using a digital caliper. Yield was estimated (kg ha^{-1}) based on weight and number of fruits harvested in the evaluated area of each plot.

Physiological data of Fv/Fm, Y_{PSII}, chlorophyll index and LAI were subjected to analysis of variance and a follow-up analysis was made for the interactions according to their significance. Means of these variables were compared by F and Tukey tests ($p < 0.05$) for the reading times and irrigation depths, respectively, and grouped by the criterion of Scott-Knott ($p < 0.05$) for the factor evaluation period (months). Pineapple yield characteristics were subjected to analysis of variance and means were compared by Tukey test ($p < 0.05$).

Results and Discussion

Quantum efficiency (Fv/Fm) and quantum yield of photosystem II (Y_{PSII}) in 'Pérola' pineapple plants subjected to different irrigation depths varied along the months (Table 1). The results of chlorophyll a fluorescence variables prove that plants subjected to abiotic stress, such as salinity, high temperatures, low relative humidity, among others, exhibit alterations in the functional state of the thylakoid membranes

Table 1. Quantum efficiency (Fv/Fm) and quantum yield of photosystem II (Y_{PSII}) in 'Pérola' pineapple plants subjected to different irrigation depths with saline water along the months, at 8 and 14 h

Months	Fv/Fm		Y_{PSII}	
	8 h	14 h	8 h	14 h
Aug/15	0.49 Bb	0.63 Aa	0.28 Cb	0.35 Ba
Sep/15	0.50 Bb	0.55 Ca	0.30 Ba	0.28 Ca
Oct/15	0.47 Cb	0.57 Ba	0.25 Cb	0.34 Ba
Nov/15	0.59 Aa	0.55 Cb	0.38 Aa	0.36 Ba
Dec/15	0.49 Ba	0.50 Da	0.32 Ba	0.31 Ca
Feb/16	0.59 Aa	0.59 Ba	0.38 Aa	0.28 Cb
Mar/16	0.51 Bb	0.63 Aa	0.27 Cb	0.47 Aa
Apr/16	0.51 Bb	0.61 Aa	0.27 Cb	0.36 Ba
May/16	0.50 Bb	0.59 Ba	0.28 Cb	0.36 Ba
Jun/16	0.51 Bb	0.58 Ba	0.23 Db	0.37 Ba
Jul/16	0.48 Cb	0.53 Ca	0.22 Db	0.33 Ba
Aug/16	0.45 Cb	0.55 Ca	0.19 Db	0.31 Ca
Sep/16	0.48 Ca	0.50 Da	0.22 Da	0.19 Da
CV (%)	15.6		39.37	

*Means followed by same letters, uppercase in the columns for months, belong to a same cluster by the criterion of Scott-Knott at 0.05 probability level, and lowercase in the row for times, do not differ significantly by F test at 0.05 probability level

of chloroplasts, which cause changes in the characteristics of the fluorescence signals and, consequently, in quantum efficiency (Fv/Fm) and potential quantum yield (Y_{PSII}) (Cha-Um & Kirdmanee, 2011). These fluorescence signals indicate the functioning of the photosystem II (PSII) and, therefore, the efficiency in the use of photochemical radiation in carbon assimilation by plants, because the electrons ejected from the photosynthesizing pigments not used in ATP and NADPH production return to the pigments, re-emitting the absorbed light in the form of fluorescence.

The Fv/Fm values in pineapple are below the range considered as optimal for most crops (Fv/Fm of 0.800 ± 0.5) by Bolhàr-Nordenkampf et al. (1989). Thus, the Fv/Fm ratios indicate that the photosynthetic apparatus of 'Pérola' pineapple plants was altered. In addition, there was a reduction in the chlorophyll indices along the months (Table 2). Such reduction is a defense mechanism for reducing the capture of light energy and, consequently, reducing the flow of electrons to the electron transfer chain (Willadino et al., 2011).

Table 2. Indices of chlorophyll a, b, total (a + b) and chlorophyll a/b ratio in 'Pérola' pineapple plants subjected to different irrigation depths with saline water along the months

Months	Chlorophyll a	Chlorophyll b	Chlorophyll Total	Chlorophyll a/b
Aug/15	34.50 B	22.36 B	56.86 C	1.56 C
Sep/15	36.27 A	24.58 B	60.85 B	1.48 D
Oct/15	32.61 C	20.92 B	53.54 C	1.58 C
Nov/15	38.33 A	27.92 A	66.26 A	1.38 D
Dec/15	33.56 B	19.02 C	52.50 C	1.86 B
Jan/16	34.41 B	19.35 C	53.76 C	1.84 B
Feb/16	37.08 A	23.06 B	60.15 B	1.63 C
Mar/16	35.29 B	21.56 B	56.85 C	1.66 C
Apr/16	33.92 B	19.70 C	53.62 C	1.80 B
May/16	31.51 C	15.92 D	47.40 D	2.05 B
Jun/16	36.29 A	19.73 C	56.02 C	1.89 B
Jul/16	35.48 B	19.37 C	54.85 C	1.85 B
Aug/16	27.12 D	11.60 E	38.73 E	2.51 A
Sep/16	35.27 B	19.11 C	54.38 C	1.94 B
CV (%)	11.56	21.18	14.6	15.45

*Means followed by same uppercase letters, in the columns, belong to a same cluster by the criterion of Scott-Knott at 0.05 probability level

The observed chlorophyll indices indicate that chlorophyll a was present at higher concentrations in pineapple leaves, with proportions ranging from 1.38:1 to 2.51:1 in relation to chlorophyll b (Table 2). However, chlorophyll a/b ratios are much lower for the pineapple crop, which was conducted under field conditions, i.e., exposed to radiation. Chlorophyll a/b ratio close to the 3:1 proportion indicates that these pigments are under normal conditions in the plants, thus having greater action on light energy capture in comparison to chlorophyll b, which is defined as accessory pigment (Taiz & Zeiger, 2013).

The values of chlorophyll a/b ratio are due to the high values of chlorophyll a. Increment in the proportion of chlorophyll b in the pineapple crop can be considered as an important adaptability feature, since chlorophyll b absorbs energy at wavelength different from that of chlorophyll a, and transfer it to the reaction center, thus maximizing the capture of energy that effectively acts in the photochemical reactions (Taiz & Zeiger, 2013).

Regarding chlorophyll indices, the results in the present study are consistent with those of others reported in the literature, in which chlorophyll levels do not change with the increase in saline stress (Aziz et al., 2011). However, other authors claim that chlorophyll a is strongly influenced by the availability of prevailing environmental factors, such as light, water and mineral nutrients, and when plants are subjected to salt-induced osmotic stress there is a negative effect on the concentrations of these photosynthetic pigments (Willadino et al., 2011).

Pineapple leaf area index (LAI) showed significant interaction ($p < 0.05$), considering the studied factors (irrigation depth and periods) (Table 3). However, there were no significant differences between the irrigation depths from August 2015 to February 2016. After this initial period, in the following months, the highest LAI values occurred with the application of irrigation depth equivalent to 100% ETc and ECw = 0.75 dS m^{-1}. However, in April, May and September 2016, there were no differences between the irrigation depths of 75 and 100% ETc and ECw = 3.6 dS m^{-1}. The highest mean value of LAI was 2 m^2 m^{-2}, observed in June and July 2016.

LAI values between 6 and 8 m^2 m^{-2} are the most common for the pineapple crop. However, LAI values of 12 m^2 m^{-2} have already been found under ideal weather conditions for the pineapple crop on the Coastal Tablelands of Paraíba (Souza et al., 2007). Therefore, under the conditions of the present study, the stress induced by salinity and water deficit was not determinant in the reduction of pineapple LAI, because in the treatment using water with ECw = 0.75 dS m^{-1}, the values did not differ from those relative to saline water. Possibly, meteorological factors, such as wind and high temperatures, besides the quality of the seedlings used, were more important.

For treatments with saline water, the reduction in leaf area and, consequently, in LAI, leads to lower transpiration and, therefore, minimizes the accumulation of salts in the plant and the increase of salt concentration in rhizosphere. Thus, LAI reduction can contribute to better performance of the plant in saline environments (Mendonça et al., 2010).

Table 3. Leaf area index (LAI) in 'Pérola' pineapple plants under different irrigation depths with saline water along the months

Months	Leaf area index (m^2 m^{-2})				
	100% ETc (ECw = 0.75 dS m^{-1})	50% ETc (ECw = 3.6 dS m^{-1})	75% ETc (ECw = 3.6 dS m^{-1})	100% ETc (ECw = 3.6 dS m^{-1})	125% ETc (ECw = 3.6 dS m^{-1})
Aug/15	0.44 Ca	0.52 Ba	0.50 Ba	0.43 Ba	0.50 Aa
Sep/15	0.44 Ca	0.52 Ba	0.50 Ba	0.43 Ba	0.50 Aa
Oct/15	0.54 Ca	0.60 Ba	0.55 Ba	0.58 Ba	0.61 Aa
Jan/15	0.79 Ca	0.67 Ba	0.58 Ba	0.64 Ba	0.55 Aa
Feb/16	1.17 Ba	0.94 Aa	0.97 Aa	0.92 Aa	0.90 Aa
Apr/16	1.10 Ba	0.18 Bb	1.19 Aa	0.83 Aab	1.11 Aa
May/16	1.67 Aa	1.01 Aab	1.01 Aab	1.11 Aab	0.79 Ab
Jun/16	2.00 Aa	1.04 Ab	1.19 Ab	1.21 Ab	0.90 Ab
Jul/16	2.00 Aa	0.97 Ab	1.08 Ab	1.11 Ab	0.92 Ab
Aug/16	1.60 Aa	0.91 Ab	0.95 Ab	1.01 Aab	0.78 Ab
Sep/16	1.76 Aa	1.00 Ab	1.16 Aab	1.07 Aab	0.80 Ab
CV (%)			36.36		

*Means followed by same letters, uppercase in the columns for months, belong to a same cluster by the criterion of Scott-Knott at 0.05 probability level, and lowercase in the rows for irrigation depths, do not differ by Tukey test at 0.05 probability level

Table 4. Yield, fruit weight with crown (FW+C), fruit weight without crown (FW-C), crown weight (CW), fruit length with crown (FL+C), fruit length without crown (FL-C), crown length (CL) and fruit diameter (FD) of pineapple plants under different irrigation depths with saline water

Irrigation depths	Yield (kg ha^{-1})	FW+C	FW-C(g)	CW	FL+C	FL-C	CL	FD
			(g)			(cm)		
100% ETc (ECw = 0.75 dS m^{-1})	14475.5 a	518.41 a	442.00 a	76.80	25.07	10.62 a	14.45	8.02
50% ETc (ECw = 3.6 dS m^{-1})	5157.0 b	189.99 b	137.98 b	52.00	19.80	6.86 ab	12.94	5.82
75% ETc (ECw = 3.6 dS m^{-1})	5947.5 b	225.72 ab	158.00 b	67.29	21.81	7.14 ab	14.66	6.10
100% ETc (ECw = 3.6 dS m^{-1})	6916.5 ab	266.08 ab	200.62 ab	65.46	22.74	7.97 ab	14.78	6.59
125% ETc (ECw = 3.6 dS m^{-1})	2711.0 b	133.28 b	90.55 b	42.73	15.43	4.54 b	10.89	4.35
CV (%)	50.87	52.78	59.31	40.88	31.16	30.45	32.85	28.44

*Means followed by same letters, in the columns, do not differ by Tukey test at 0.05 probability level

However, LAI is directly related to the use of solar energy, which will later be transformed into chemical energy in the biochemical phase of photosynthesis (Francisco et al., 2014) and, therefore, this reduction will decrease photosynthetic activity and consequently the yield.

Yield, fruit weight with crown (FW+C), fruit weight without crown (FW-C) and fruit length without crown (FL-C) were influenced by the different irrigation depths applied in the pineapple crop. For crown weight (CW), fruit length with crown (FL+C), crown length (CL) and fruit diameter (FD), there were no significant effect, therefore the mean values were presented (Table 4).

The irrigation depth of 100% ETc and ECw = 0.75 dS m^{-1} promoted mean yield of 14.4 t ha^{-1}, not differing statistically from the value relative to 100% ETc and ECw = 3.6 dS m^{-1} (6.91 t ha^{-1}), but differing from those relative to 50, 75 and 125% ETc and ECw = 3.6 dS m^{-1}.

These yield results are below those found by other authors for the pineapple crop cultivated in the semi-arid region (Franco et al., 2014; Pegoraro et al., 2014; Maia et al., 2016); in addition, the values are very far from the average in the Bahia state, which is 25,165 kg ha^{-1}.

Besides the stress factors imposed on the crop, it is important to point out that the population was only 33,300 plants ha^{-1}, whereas commercial plantations and even the cited studies used populations ranging from 41,666 to 51,280 plants ha^{-1}, i.e., another factor that contributed to the low yield per hectare in the present study.

In addition, the inhibition of photosystem II, which demonstrates effect of combined stress factors on the plant, results in values below the expected for LAI, and yield reduction was expected, as indeed occurred.

The irrigation depths referring to 100% ETc and ECw = 0.75 dS m^{-1} and 75 and 100% and ECw = 3.6 dS m^{-1} led to the highest FW+C, with values of 518.41, 225.72 and 266.08 g, respectively. For FW-C, the irrigation depths of 100% ETc and ECw = 0.75 dS m^{-1}, and 100% ETc and ECw = 3.6 dS m^{-1}, led to the highest values (442 and 200.62 g, respectively), differing from the irrigation depths of 50, 75 and 125% ETc and ECw = 3.6 dS m^{-1}.

For FL-C, the highest mean value of 10.62 cm was obtained with the application of irrigation depth of 100% ETc and ECw = 0.75 dS m^{-1}, while the lowest value of 4.54 cm was obtained with the irrigation depth of 125% ETc and ECw = 3.6 dS m^{-1}.

Conclusions

1. Under the physiographic conditions of Guanambi-BA, the pineapple crop has limitations of the physiological characteristics of chlorophyll fluorescence and chlorophyll index, under irrigation with both saline water and better-quality water.

2. The irrigation depth of 100% ETc using water with ECw levels of 0.75 and 3.6 dS m^{-1} leads to the best yields.

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