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Yield of cotton cultivars under different irrigation depths in the Brazilian semi-arid region

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Key words:
Gossypium hirsutum
evapotranspiration
water deficit

ABSTRACT

The objective of this study was to evaluate the effect of irrigation depths on seed cotton yield and water-use efficiency of cotton cultivars in the Brazilian semi-arid region. Field experiment was conducted during two consecutive years in the Apodi region, RN, using sprinkler irrigation. The experiment consisted of factorial combination in split-plots, composed of four irrigation depths (130; 100; 70 and 40% ETc and four cotton cultivars - FiberMax 993, BRS 286, BRS 336 and BRS 335), in randomized block design with 4 replicates. Data were evaluated by mean test (Tukey) and regression analysis. Considering the irrigation depths of 40% ETc, cotton yield was 48% lower compared to the higher irrigation depth (130% ETc). The higher water-use efficiency (0.69 kg m^{-3}) was obtained with 70% ETc irrigation depth. The highest seed cotton yield was achieved with the higher water depth for all evaluated cultivars. Yield response factor (Ky) was equal to 0.632, 0.711, 0.784 and 0.858, for FiberMax 993, BRS 286, BRS 335 and BRS 336 cultivars, respectively. FiberMax 993 and BRS 286 cultivars presented the best performance, showing that they are more suitable for irrigated farming in the semi-arid region.

Palavras-chave:
Gossypium hirsutum
evapotranspiração
déficit hídrico

Produtividade de cultivares de algodoeiro herbáceo sob diferentes lâminas de irrigação no semiárido brasileiro

RESUMO

O objetivo deste trabalho foi avaliar o efeito de lâminas de irrigação sobre o rendimento e eficiência no uso da água de cultivares de algodoeiro no semiárido brasileiro. Foi conduzido um experimento de campo por dois anos consecutivos, na região de Apodi, RN, com irrigação por aspersão. O experimento consistiu de uma combinação fatorial em parcelas subdivididas, sendo quatro lâminas de irrigação (130; 100; 70 e 40%ETc) e quatro cultivares de algodoeiro (FiberMax 993, BRS 286, BRS 336 e BRS 335), em delineamento de blocos casualizados, com quatro repetições. Os dados foram avaliados através de teste de médias (Tukey) e análise de regressão. A produtividade com a menor lâmina aplicada (40% ETc) foi 48% menor se comparada a maior lâmina (130% ETc). A maior eficiência no uso da água foi encontrada com a lâmina de 70% ETc (0,69 kg m^{-3}) e a maior produtividade de algodão em caroço foi alcançada com a lâmina de irrigação igual a 130%ETc para todas as cultivares avaliadas. O fator de resposta do rendimento (Ky) foi igual a 0,632; 0,711; 0,784 e 0,858 para as cultivares FiberMarx 993, BRS 286, BRS 335 e BRS 336, respectivamente. As cultivares FiberMax 993 e BRS 286, no geral, apresentaram os melhores resultados, demonstrando serem mais indicadas para o cultivo irrigado na região semiárida.

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INTRODUCTION

Irrigation is the most important factor in the agricultural production of semi-arid regions, especially in the dry period of the year (Dagdalen et al., 2006), and it is one of the practices that ensure high levels of crop productivity (Aujila et al., 2005; Dagdelen et al., 2009). The cultivation of irrigated cotton in the Brazilian semi-arid region is important for the regional development and for employment growth, since it allows the production of different products that can be used for diverse purposes, generating income through its fiber (textile industry), seeds (biodiesel, cooking oil, etc.) and cotton seed cake (animal feeding), stimulating activities of different economy sectors.

The adoption of irrigation in the semi-arid region is essential, due to the occurrence of water deficiency during the crop cycle caused by low rainfall rates and poor temporal distribution of precipitations. One of the problems found in the semi-arid region is that the water sources for irrigation are scarce and in many regions have been decreasing over time due to other uses, especially urbanization and industrialization, which compete with agriculture for the water use.

In this way, knowing the response of the cotton plants to different amounts of water, in environments such as the semi-arid, is very important for economic comparisons between the agricultural options for the region. Irrigation with deficit causes water stress on the plant, which may affect the growth and development of the crop, while irrigation in excess becomes costly for the producer and also is an environmental damage (in many cases, the excess of water does not result in higher productivity).

Yazar et al. (2002) state that with the water stress during the growing season of the cotton plant, final productivity can be affected, since it depends on the production and control of boll weevils, and both can be affected with water stress. Regarding the excess of water, several studies such as Wanjura et al. (2002) and Karam et al. (2006) show that the productivity of the cotton plant can be reduced due to water excess.

Considering that farmers who grow cotton with irrigation do not vary the amount of water applied over the years, and often do not use the recommended irrigation depth, the data obtained in field does not reflect reality (with useful information). Thus, the conduction of studies with appropriate observations to estimate the cotton productivity according to different irrigation depths is necessary.

Concerning the cotton cultivars available in the market, most of them is indicated for the Cerrado region, and thus it is necessary to study which of them are more adapted to irrigated cultivation in semi-arid region and if there is no difference between them in relation to resistance to water deficit, since this would be an important feature for the farming in the region. According to Nunes Filho et al. (1998), cotton cultivars may have different leaf morphology, foliar height and area, showing greater or lesser ability to osmoregulation under intense water stress in the soil.

Considering that the determination of irrigation and cultivating depths - those that are the best for the climate and soil conditions of the semi-arid - permits an increase in the productivity of the cotton plant, with higher efficiency for irrigation water use. Therefore, the aim of this research was to assess the effect of irrigation depths on the productivity of the cotton seed, water-use efficiency and yield response factor of upland cotton cultivars in the Brazilian semi-arid region.

MATERIAL AND METHODS

The experiment was conducted on the Experimental Farm of Agricultural Research Company of Rio Grande do Norte (EMPARN), located in Apodi, RN, West Potiguar mesoregion and Chapada do Apodi micro-region, whose geographical coordinates are 5° 37’ 19”S latitude and 37° 49' 06” W longitude, with an altitude ranging between 128 and 132 m. The region’s climate is characterized as hot tropical and semi-arid, with a predominance of type BSw´h´, according to Köppen climate classification, with the rainy season starting in the fall. The soil of the experimental area was classified as eutrophic Cambisols, sandy clay texture, with 49% of sand, 45% of clay and 6% of silt. The fertilization was carried out according to the technical recommendations for the culture, based on the analysis of soil fertility (Table 1).

Table 1. Chemical characteristics of soil in the experimental area of Apodi, RN, at the depth of 0-40 cm

Year	pH	OM*	P	Na^+	K^+	Ca^{2+}	Mg^{2+}	H + Al	CEC*	SB
	water	($g\ kg^{-1}$)					($cmol_c\ dm^{-3}$)			
2012	5.7	3.00	20.1	0.8	0.72	4.7	2.3	1.73	10.25	8.52
2013	6.20	3.92	23.69	0.83	0.69	5.00	2.40	2.47	11.40	8.92

* OM - Organic matter, CEC - Cation exchange capacity, SB - Sum of bases

The experimental design was adopted in randomized blocks, with factorial scheme 4 x 4, with split-plots design and four repetitions. Also, the experiment was performed in two cultivation cycles (2012 and 2013). The treatments were composed of four irrigation depths on the plots (40, 70, 100 and 130%ETc) and four cultivars of upland cotton (BRS 286, BRS 335, BRS 336 and FiberMax 993) in subplots. Each experimental plot was formed by six rows (0.84 m between them), 7.5 m in length, totaling an area of 37.8 m^2, and the useful area considered was the 4 central rows, excluded 1.25 m from each end.

The cultivation was held in no-tillage system, and it was conducted with a planting machine of 4 rows, and no thinning was necessary.

The agronomic and irrigation data are presented in Table 2.

Irrigations were performed with a conventional sprinkler system with fixed spacing between sprinklers of 12 x 15 m, depth of 10 mm h^{-1} and Christiansen uniformity coefficient (CUC) of 85%, and irrigations carried out every 4 days.

For the calculation of the replacement depth, the following equation was used:

$$L_{irrig} = \frac{ETc}{f} \tag{1}$$

Table 2. Agronomic data and parameters of irrigation during the cultivation cycle of the cotton plant

Variables	2012	2013
Planting date	07/30/2012	08/19/2013
Row spacing	0.84 m (between rows)	
Planting density	8-12 plants m^{-1}	
Planting fertilization	150 kg ha^{-1} of P_2O_5 and 30 kg ha^{-1} of N in the form of MAP*	
Top dressing fertilization	150 kg N ha^{-1} in the form of Urea	
Beginning of irrigation treatments	08/19/2012 (17 DAE)	09/08/2013 (15 DAE)
Last irrigation	11/07/2012 (97 DAE)	11/24/2013 (92 DAE)
Harvest date	12/04/2012	12/11/2013
Duration of the cycle	124 days	109 days
Total precipitation during the growing cycle	0.0 mm	29.0 mm

* MAP - Monoammonium phosphate; DAE - Days after emergency

where:

L_{irrig} - gross irrigation depth, mm;
ETc - crop evapotranspiration, mm; and
f - application efficiency, decimal.

The crop evapotranspiration (ETc) is given by Eq. 2:

$$\mathrm{ETc} = \mathrm{ETo} \times \mathrm{Kc} \tag{2}$$

where:

ETo - reference evapotranspiration based on the methodology of Penman-Monteith (Allen et al., 1998); and

Kc - crop coefficient for the cotton, estimated by the expression obtained by Bezerra et al. (2010), depending on the number of days after the emergency

$$\mathrm{Kc} = -0{,}00006 \cdot \mathrm{DAE}^2 + 0{,}011 \cdot \mathrm{DAE} + 0{,}5703 \tag{3}$$

where:

DAE - days after emergence.

The required phytosanitary treatments were performed to show the first symptoms of pests and diseases, as well as control of hogweeds.

The assessed agronomic variables of plants from the useful area of the experiment were for each repetition and treatment: productivity of cotton seed, plant height, number of bolls per square meter and the boll's average weight.

To determine the relationship between productivity and water consumption by the culture, and to assess the response of the cultivars to water deficit, the water-use efficiency (WUE) was calculated and also a non-dimensional parameter that relates the relative reduction of the yield with the relative reduction in the irrigation depth, according to FAO 33 (Doorenbos & Kassam, 1979), and according to Eqs. 4 and 5, respectively:

$$\mathrm{WUE} = \frac{\mathrm{Y}}{\mathrm{L}} \tag{4}$$

$$1 - \frac{\mathrm{Y_a}}{\mathrm{Y_m}} = \mathrm{K_y}\left(1 - \frac{\mathrm{L_a}}{\mathrm{L_m}}\right) \tag{5}$$

where:

WUE - water-use efficiency, kg m^{-3};
Y - yield, kg ha^{-1};
L - irrigation depth, m^3 ha^{-1};
Ya - yield of a given irrigation depth, kg ha^{-1};
YM - maximum yield, kg ha^{-1};
Ya/Ym - relative yield, non-dimensional;
1 - (Ya/Ym) - relative decrease in yield, non-dimensional;
La - applied irrigation depth that generates Ya yield, mm;
Lm - maximum irrigation depth applied, mm;
La/Lm - irrigation depth, non-dimensional;
1 - (La/Lm) - relative decrease in the irrigation depth, non-dimensional; and
Ky - yield response factor defined as the decrease in yield as function of irrigation depth, non-dimensional).

The data of the variables evaluated were submitted to analysis of variance with the F-test at 0.01 and 0.05 probability. The analysis was performed every year and with the grouped data (joint analysis). For the statistical analysis the Sisvar software 5.3 (Ferreira, 2010) was used. When verified a significant effect in the analysis of variance, the data obtained in different treatments of qualitative nature (cultivars) were compared - through the Tukey's test - and those of quantitative nature (irrigation depths) were submitted to a regression study, at 0.01 and 0.05 level of probability. The purpose was to adjust equations with biological meanings, through the selection of mathematical models that showed improved levels of significance and a higher value for the determination coefficient (R^2).

RESULTS AND DISCUSSION

The amount of water applied ranged from 311 to 1,013 mm in 2012, and from 408 to 1,179 mm in 2013, and these differences were due to climatic variations that occurred in the region and the rainfall of 29 mm in 2013. On the average of the two years of study, 1179 (130% ETc); 906 (100% ETc); 635 (70% ETc) and 360 (40% ETc) mm depths were applied for treatments of 130; 100; 70 and 40% ETc, respectively.

As there was no significant interaction between treatments and the years, data from the experiments (in the period of two years) were grouped together for the statistical analyses. Similarly, there was no significant interaction between the irrigation depths and cotton cultivars and thus each factor was analyzed separately.

It was observed that all the analyzed variables were affected by the irrigation depths and the cultivars upland cotton, a result proven by the F-test at 0.01 and 0.05 probability (Table 3).

The yield with the lowest depth applied (40% ETc) was 48% lower than the highest depth (130% ETc). Regarding the yield components, plant growth in height was 37% lower if compared to the highest irrigation depth (40 and 130% ETc). For the average number of bolls m^{-2} there was a decrease of 54% with the implementation of the lower irrigation depth (40% ETc) in relation to the highest depth (130%), while the average weight of bolls was 15% lower. For the water-use efficiency (WUE) the irrigation depth with 130% ETc, despite having presented the highest productivity, had the lowest WUE (0.48 kg m^{-3})

Table 3. Yield, water-use efficiency, plant height, boll weight and number of bolls m^{-2} according to irrigation depths and cultivars of upland cotton grown in Apodi (grouped data)

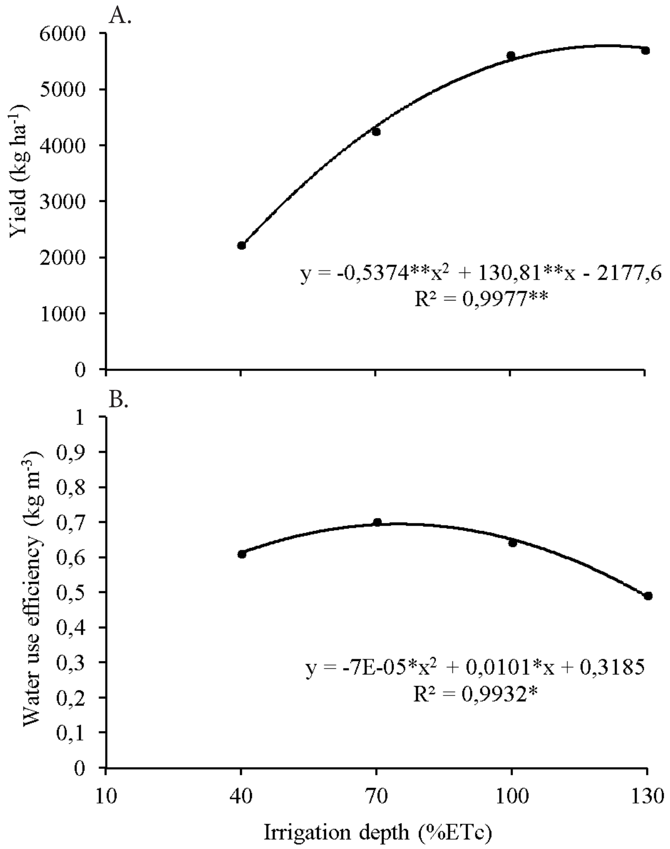
	Yield (kg ha^{-1})	Water-use efficiency (kg m^{-3})	Height (cm)	Boll weight (g)	Number of bolls m^{2}
Irrigation depth (% ETc)					
40	2,225.00	0.61	61.80	5.14	43.30
70	4,254.00	0.69	78.80	5.77	69.30
100	5,620.00	0.64	91.60	6.01	87.50
130	5,732.00	0.48	98.00	6.02	94.10
F-test	**	**	**	**	**
Cultivars					
BRS 286	4,634.00 ab	0.63 ab	86.00 a	5.84 a	78.20 ab
BRS 335	4,294.00 b	0.57 ab	81.20 ab	5.66 ab	71.40 bc
BRS 336	3,959.00 b	0.54 b	77.20 b	5.91 a	63.80 c
Fibermax 993	4,875.00 a	0.70 a	86.00 a	5.52 b	80.70 a
F-test	**	*	**	**	**

** and * Significant at 0.01 and 0.05 probability, respectively; ns - not significant. Mean followed by the same letters in the column do not differ at 0.05 probability by the Tukey's test

(Table 3). Regarding the cultivars, with the exception of the average weight of bolls, it was observed that the best results for the other features assessed were obtained with the FiberMax 993 cultivar. The highest average bolls weight was obtained by cultivar BRS 336.

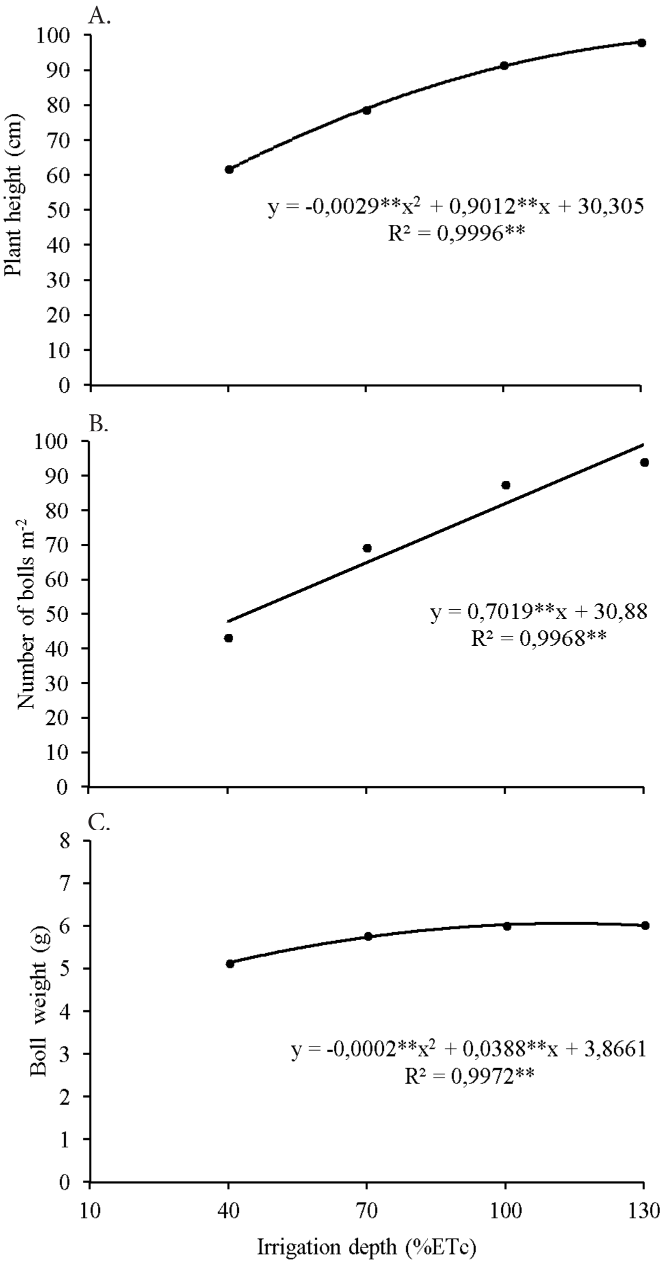
The irrigation deficit generated the decrease in the height growth, cotton seed production for the average number of bolls m^{-2} and an average bolls weight. On the other hand, it was responsible for the increase of the water-use efficiency (Figures 1 and 2).

The results of this study are similar to those verified by several authors in the literature. Singh et al. (2010) showed that irrigation with depths smaller than 80% ETc causes a



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

Figure 1. Seed cotton yield (A) and water-use efficiency (B) of the cotton plant grown in the Brazilian semi-arid region, according to different irrigation depths (pooled data)



** and * Significant at 0.01 and 0.05 probability, respectively.

Figure 2. Plant height (A), number of bolls m^{-2} (B) and the average boll weight (C) of the cotton plant grown in the Brazilian semi-arid region, according to different irrigation depths (pooled data)

significant reduction of the yield components of the cotton plant. Unlu et al. (2011) also claim - based on their studies - that irrigation deficit causes a significant decline in the plant height and number of bolls m^{-2}. Onder et al. (2009) presented results demonstrating that there was an increase in the number of bolls plant^{-1} with the increase of irrigation depths, and concluded that the best results for the cotton plant are presented when applying irrigation with 100% of the necessary depth. Rajak et al. (2006) state that cotton plants have better growth when irrigation is equivalent to 120% ETc.

Regarding yield, the deficit in the irrigation of the cotton plant resulted in a decline of yield of the seed cotton, described by a polynomial function with high coefficient of determination (R^2 = 0.99), decreasing the depth from 130% to 40% ETc (Figure 1A). Maximum yield of 5,732 kg ha^{-1} was reached with the depth 130% ETc. In irrigation with a deficit of 70% ETc, the yield was reduced to 4,225 kg ha^{-1}, that is, a reduction of 26% in productivity. When a higher deficit was imposed, with irrigation depth of 40% ETc, the yield was 2,225 kg ha^{-1}, corresponding to a reduction of 61% in relation to the maximum yield. The results of this study corroborate those obtained by Dagdelen et al. (2006), who using irrigation with depths ranging from 867 to 257 mm cycle^{-1}, verified a yield reduction from 5,490 to 1,780 kg ha^{-1}. DeTar (2008) also observed a reduction in the yield of the cotton plant due to irrigation deficit. Onder et al. (2009) tested four irrigation depths with deficit in 2 cultivation cycles and demonstrated that irrigation with deficit causes decrease in yield and in the yield components, corroborating the results presented in this study.

Bezerra et al. (2008) also verified an increase in the seed cotton's yield with the increase of irrigation depth, being the highest one found with the depth of 120% ETc. Rajak et al. (2006) found an increase of 33% in the yield when a 120% ETc irrigation depth was used - compared with 80% ETc irrigation -, results that are similar to those obtained by this research.

With the results of this study it is found that in general the cotton plant responds to the application of irrigation depths higher than 100% ETc, both in growth and yield. On the other hand, the irrigation with deficit cause a decrease in yield and yield components, corroborating the results obtained by Singh et al. (2010). The yield increase may be associated with the physiological response to the culture with the highest water availability, since this affects the physiological processes of the plant, and consequently, the growth and development of culture. In addition, according to Cetin & Bilgel et al. (2002), the higher the water availability in the soil the greater the ability of the roots to absorb nutrients and the photosynthetic efficiency of the leaves.

These results demonstrate the importance of conducting local studies to determine crop coefficients (Kc) for the irrigated cotton production in the semi-arid region, since the Kc values used in this work may be undersized.

Water-use efficiency (WUE) or water productivity is defined as the ratio between the yield (Ya) and the total amount of the water used during the cycle (La), which is expressed in kg m^{-3} (Geerts & Raes, 2009). As the rains in Apodi were sparse during the cultivation cycles (0 and 29 mm, see Table 1), it is considered only the irrigation water.

Regarding the WUE, one can observe in Figure 1B that it had a behavior described by a parabola, having its maximum value with the depth of 70% ETc and then declining. The depth of 130% ETc, despite having the highest productivity, had the lowest WUE (0.48 kg m^{-3}). For the other irrigation depths, the results were very similar: 0.61, 0.69 and 0.64 kg m^{-3} for depths 40, 70 and 100% ETc, respectively. The increase of the WUE in irrigation depths with deficit can be attributed to several factors, such as the reduction of losses due to evaporation and the increase of reproductive organs in relation to the vegetative organs, that is, an increase of the harvest index (Karam et al., 2009).

Nalayini et al. (2006) found the best results for the WUE with 80% ETc, corroborating the results found in this research, in which the highest WUE was obtained with the depth of 70% ETc. In studies with irrigation deficit, Singh et al. (2010) found similar results to those presented here, with significant differences in the WUE for the different irrigation depths, with values ranging from 0.54 to 0.649 kg m^{-3}, for the 100% ETc and 50% ETc depths, respectively. Dagdelen et al. (2009) observed higher WUE through irrigation deficit, and the depth of 25% of the ETc was 0.98 kg m^{-3}, while for the 70% ETc the WUE was 0.81 kg m^{-3}. Dagdelen et al. (2006) tested irrigation depths between 30 and 100% ETc and found WUE of 0.6 to 0.74 kg m^{-3}, and the highest values found with the lowest irrigation depths were very close to those found in this study.

These results are important because, according to Geerts & Sars (2009), the main advantage of irrigation deficit is to maximize the WUE, which in this case was with irrigation depth of 70% ETc. It must note that, despite a decrease in the yield with irrigation deficit, the quality of the product is often not changed (Hueso & Cuevas, 2006; Zhang et al., 2006). It should be also noted that in areas where water is a limiting factor, as in the semi-arid region, maximizing the WUE is often more economically profitable for the producer than maximizing yield (Geerts & Raes, 2009).

Regarding the cultivars, in Table 3 one can observe that the FiberMax 993 cultivation presented higher yield (4,875 kg ha^{-1}), being statistically equal to the BRS 286 cultivar (4,634 kg ha^{-1}). The lowest yields were found for BRS 335 and BRS 336 cultivars, 4,294 and 3,959 kg ha^{-1}, respectively. The water-use efficiency (Table 3) was also higher for the FiberMax 993 cultivar(0.70 kg m^{-3}), followed by the BRS 286, 335 and 336 cultivars with 0.63, 0.57 and 0.54, respectively. The cultivars FiberMax 993, BRS 286 and BRS 3365 did not differ between each other statistically.

Regarding height and yield components of the plants (Table 3), the results follow the same behavior of yield, and the best results were found for FiberMax 993 cultivar, followed by BRS 286, BRS 335 and BRS 336, with exception of the weight of bolls, for which the FiberMax 993 presented the worst results. However, even with the lowest average weight of boll, its yield is compensated due to the greater number of bolls m^{-2} (Table 3).

It is observed that the FiberMax 993 cultivar had the best results for all features evaluated and, instead, to BRS 336 cultivar showed the worst results. Moreover it is observed that, in spite of presenting the worst results, BRS 336 cultivar had good yield, an average of 3,959 kg ha^{-1}, higher than the national average, which was 3,662 kg ha^{-1} in the 2012/2013 harvest (CONAB, 2014). These results demonstrated that all cultivars evaluated in this research have potential for irrigated cultivation in the semi-arid region with the correct irrigation management and other cultivations practices.

Regarding the yield response factor (Ky), it is an indicator of whether the culture is tolerant to water stress. When the response factor is greater than 1, it indicates that the relative decrease in yield for a given deficit irrigation is proportionally greater than the relative decrease in the irrigation depth or evapotranspiration (Steduto et al., 2012).

The relative decrease in yield (1-Ya/Ym) increased linearly with the decrease in the irrigation depth (1-La/Lm), with the coefficient of determination R^2 ranging from 0.8 to 0.9 (Figure 3). The Ky values for the cotton plant grown with deficit in the cultivation season were 0.632, 0.711, 0.784 and 0.858 for the FiberMarx 993, BRS 286, BRS 335 and BRS 336 cultivars respectively, showing that the FiberMax 993 and BRS 286 had the lower decrease in yield with the decrease of the irrigation depth, that is, a greater adaptation for the irrigated cultivation in the semi-arid (they can be used even in regions with less water availability, with the use of irrigation with deficit aiming at water saving and sustainability of the system).

According to a study published in FAO 66 (Steduto et al., 2012), after a survey of several works that relates the yield of cotton plant with irrigation with deficit, the value of Ky for the cotton plant can range from 0.46 to 0.99, depending on the time at which the plant was subjected to water stress and the type of irrigation, and this reveals that the culture is tolerant to water stress, confirming the results of this research.

The Ky values found in this study for all the cultivars evaluated are in accordance with those found in several studies published, such as the one by Doorenbos & Kassam (1979), who found Ky = 0.84; Yazar et al. (2002), Ky = 0.89; Dagdelen et al. (2009), Ky = 0.78 and Singh et al. (2010), Ky = 0.78, demonstrating that the cultivars used showed tolerance to water stress and may be listed as an option for the cultivation in irrigated areas in the semi-arid region, even in areas that require the use of irrigation with hydric deficit due to low water availability.

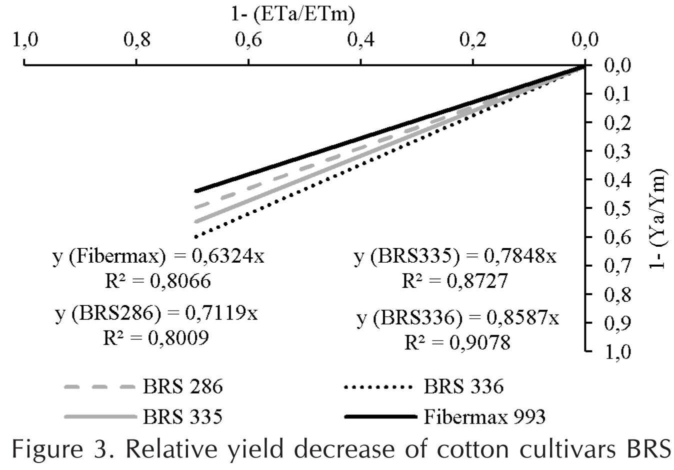


Figure 3. Relative yield decrease of cotton cultivars BRS 286, BRS 335, BRS 336, FiberMax 993 as a function of irrigation depth (pooled data)

Conclusions

1. The higher yield of seed cotton was achieved with the irrigation depth of 130% ETc (1,179 mm) for all the evaluated cultivars.

2. The water-use efficiency decreased with the increase of the irrigation depth, and the highest values obtained with the irrigation depth of 70% ETc.

3. The yield response factor (Ky) ranged from 0.632 to 0.858 for the different cultivars studied.

4. The FiberMax 993 and BRS 286 cultivars had the best results overall, thus being more adequate for irrigated cultivation in the semi-arid region.

5. The cotton cultivars evaluated in this research showed tolerance to water stress, and are also considered an option for irrigated cultivation in regions with low water availability and controlled deficit irrigation.

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