ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.19, n.11, p.1057–1063, 2015
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v19n11p1057-1063

Fiber quality of upland cotton under different irrigation depths

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Key words:
Gossypium hirsutum L. r. *latifolium* H.
water deficit
fiber intrinsic characteristics

ABSTRACT

Aiming to evaluate the effect of irrigation depths on fiber quality of upland cotton, an experiment was conducted from July to December 2010 in Barbalha-CE, Brazil. The treatments consisted of a factorial combination of two upland cotton cultivars (BRS Aroeira and BRS Araripe) and five irrigation depths (260.93, 418.93, 514.21, 711.81 and 894.68 mm), arranged in a split-plot design with four replicates. A line-source sprinkler irrigation system was used and irrigation depth in the control treatment was calculated according to the crop evapotranspiration. The analysed fiber quality variables were: fiber percentage, length, uniformity, short-fiber index, resistance, elongation at rupture, micronaire index, maturity, degree of yellowing, reflectance degree and count strength product (CSP) index. The irrigation depths influenced fiber length, short-fiber index, strength, micronaire index, maturity and reflectance degree. The cultivars influenced fiber percentage, length and color (degree of yellowing). The best results of fiber quality were found with irrigation depths of 514.21 and 418.93 mm for the upland cotton cultivars BRS Araripe and BRS Aroeira, respectively.

Palavras-chave:
Gossypium hirsutum L. r. *latifolium* H
déficit hídrico
características intrínsecas da fibra

Qualidade da fibra do algodoeiro herbáceo sob diferentes lâminas de irrigação

RESUMO

Objetivando avaliar o efeito da irrigação sobre a qualidade da fibra do algodoeiro, experimento foi conduzido no município de Barbalha, CE, no período de julho a dezembro de 2010. Os tratamentos consistiram da combinação fatorial de duas cultivares de algodoeiro herbáceo (BRS Aroeira e BRS Araripe) e de cinco lâminas de irrigação (260,93; 418,93; 514,21; 711,81 e 894,68 mm). Utilizou-se o delineamento em blocos casualizados dispostos em faixas, com quatro repetições. Foi utilizado um sistema de irrigação por aspersão em linha sendo a lâmina controle (711,81 mm) aplicada em função da evapotranspiração da cultura. As variáveis analisadas foram: percentagem de fibra, comprimento, uniformidade, índice de fibras curtas, resistência, alongamento à ruptura, índice micronaire, maturidade, grau de amarelamento, reflectância e índice de fiabilidade. As lâminas de irrigação influenciaram o comprimento, o índice de fibras curtas, a resistência, o micronaire, a maturidade e a reflectância da fibra. As cultivares influenciaram a porcentagem, o comprimento e a cor da fibra (grau de amarelamento). A cultivar BRS Araripe obteve a melhor qualidade de fibra com a lâmina de irrigação de 514,21 mm e a BRS Aroeira com a de 418,93 mm.

Protocolo 344-2014 – 30/09/2014 • Aprovado em 08/05/2015 • Publicado em 03/10/2015

Introduction

Cotton fiber has various industrial applications, among which: manufacture of yarns for weaving, preparation of absorbent cotton for nursing, making felt, blankets and stuffing, obtaining cellulose, photographic films and radiographic plates etc. (Beltrão et al., 2011). Brazil, the fifth largest producer in the world, produced more than 1.73 million tons in the 2013/2014 season (CONAB, 2014).

Due to its tolerance to water stress, the cotton crop is a relevant alternative for the northeast semi-arid region, which has the problem of irregular rainfalls. One way to overcome this obstacle is the use of irrigation, and its adequate management is indispensable for higher use efficiency of water resources (Carvalho et al., 2011).

The technological characteristics of cotton fiber are intrinsically related to hereditary factors of cotton, but suffer the influence from the volume of water applied in the different crop stages. The most relevant physical properties of fibers are: length, uniformity, resistance, elongation, maturity, micronaire index, reflectance degree, yellowing, short-fiber index and count strength product (CSP). Thus, using irrigation in order to obtain fibers that are compatible with the market is one of the alternatives for the northeast semi-arid region, especially in the dry period of the year (Dagdelen et al., 2006), since it decreases risks, ensures yield levels and fiber quality (Hussein et al., 2011; Luo et al., 2013). According to Davidonis et al. (2004), irrigation increases fiber maturity, while a severe water deficit during fiber elongation reduces not only length, but also maturity, causing the production of immature fibers and reducing quality. Balkcom et al. (2006) indicate that micronaire and irrigation level are negatively correlated.

Many researchers have conducted studies on the development of cotton cultivars for irrigated cultivation, aiming to increase yield levels and the quality of the final product, the fiber, making cotton an economically viable crop for the Northeast region. For this, studies using different cultivars are performed in order to investigate the effects of different irrigation depths, meeting the demand of each region. In this context, this study aimed to analyze the quality of fibers of the upland cotton cultivars BRS Aroeira and BRS Araripe, subjected to different irrigation depths.

Material and Methods

The experiment was carried out from July to December 2010, at the Experimental Field of Embrapa Cotton, in the municipality of Barbalha-CE, Brazil (7° 19' S; 39° 18' W; 409.03 m). The area is located in the Mesoregion of South Ceará and in the Microregion of Cariri (Ledo et al., 2011).

According to Köppen's classification, the climate of the region is "CSa", subtropical with hot, dry summers and rains in autumn and winter. The soil in the area was classified as a Fluvic Neosol (EMBRAPA, 1999), with high water table level and insufficient drainage. Physical-hydric characterization of the soil was performed in the Soil Physics Laboratory of the Agricultural Research Company of Pernambuco (IPA) and chemical analyses were performed in the Laboratory of Soil and Plant Nutrition of Embrapa Cotton. The experiment was irrigated using water from a nearby artesian well, which showed medium salinity and low sodium concentration.

Soil preparation in the experimental area was performed 15 days before planting, by one plowing with a scarifier plow and two harrowings with a leveling harrow. The upland cotton cultivars were planted in a spacing of 1.0 x 0.2 m, on July 16, 2010. Fertilizations were performed according to the soil analysis and cultural practices (control of weeds, pests and diseases) according to the recommendations for the crop.

A conventional line-source sprinkler system was used for irrigation and consisted of a central line of closely spaced sprinklers, which applied decreasing levels of water as the distance of the sprinkler increased perpendicularly. The mean application intensity of each sprinkler, measured using pluviometers in the second strip (control strip), was 9 mm h^{-1}.

Before planting, an irrigation was performed in the entire area in order to bring soil water content to field capacity. Then, an irrigation interval of 4 days was adopted for 20 days, applying a total water depth of 86.40 mm, to guarantee good seed germination and initial growth of the cultivars. Only after that, the treatments were applied. Water replenishment to the crop was performed using an irrigation interval of 7 days. The treatments consisted of a 2 x 5 factorial scheme, with two cultivars of upland cotton (BRS Aroeira and BRS Araripe), which constituted the strips, and five irrigation depths [L1 = 260.93 mm (37% ETc); L2 = 418.93 mm (59% ETc); L3 = 514.21 mm (72% ETc); L4 = 711.81 mm (100% ETc) and L5 = 894.68 mm (126% ETc)], constituting the subplots. The irrigation depths were determined according to the distance of the sprinkler, based on the control (L4 = 711.81 mm), which was calculated through the Crop Evapotranspiration – ETc. The treatments were installed in a randomized block design with four replicates, totaling 40 subplots arranged in strips. The experimental plots and subplots had areas of 15 x 12 m and 3 x 12 m, respectively.

The water volume corresponding to 100% ETc was determined using the direct measurement of the water depth collected in the second strip using collector cups (711.81 mm), referred to as control water depth. The water depths measured in the other treatments were obtained as a function of the longitudinal distance in relation to the line of sprinklers (reference of the line-source system). ETc was determined through the multiplication of reference evapotranspiration (ET_0), calculated through the Penman-Monteith method (Allen et al., 2006), by the crop coefficient for cotton (Kc), recommended by Bezerra et al. (2010).

For the development stage, the following Kc values were used: 0.76 for phase I (5 to 20 DAP); 0.95 for phase II (21-41 DAP), 1.09 for phase III (42-82 DAP) and 0.88 for phase IV (83-103 DAP). The meteorological data used in the calculation of ET_0 were obtained from the Automatic Weather Station of the National Institute of Meteorology-INMET, located in Barbalha-CE, 500 m distant from the experimental area.

The technological characteristics of the fiber were determined in a standard sample of 20 bolls collected from the mid-section of the plants before harvesting; measurements were performed using the HVI (High Volume Instrument) device, at the Laboratory of Fiber and Yarn Technology of Embrapa Cotton. The technological characteristics evaluated in the fiber were: micronaire index (µg in^{-1}), fiber length (mm), length uniformity (%), short-fiber index (%), fiber resistance (gf tex^{-1}), elongation at rupture, CSP index, maturity, yellowing and reflectance degree. The results were subjected to analysis of variance (F test) and the means were compared by Tukey test at 0.05 probability level for qualitative variables (cultivars) and regression for quantitative variables (irrigation depths).

Results and Discussion

The results of the analysis of variance and means comparison test for the characteristics fiber percentage, length, uniformity, short-fiber index, resistance and elongation at rupture of upland cotton cultivars subjected to different irrigation depths are shown in Table 1.

According to the results in Table 1, the cultivar BRS Aroeira showed fiber percentage of 44.25%, while BRS Araripe showed 42.77%, that is, 3.34% lower. These results are important and satisfactory, since cotton farmers prefer cultivars with fiber percentage above 40% for a higher benefit, because the price of fibers is higher than the price of seeds.

Table 1. Summary of the analysis of variance and means comparison test for fiber percentage (%FIB), length (LNG), uniformity (UNF), short-fiber index (SFI), resistance (RES) and elongation at rupture (ELG) of upland cotton cultivars under different irrigation depths in Barbalha-CE, Brazil, 2010

Source of variation	DF	Mean square					
		%FIB	LNG	UNF	SFI	RES	ELG
Block	3	0.01 ns	0.25 ns	0.15 ns	0.23 ns	0.20 ns	0.03 ns
Cultivars	1	21.97*	3.21*	0.60 ns	1.02 ns	0.16 ns	0.11 ns
Residue a	3	0.31	0.21	0.25	0.43	2.68	0.04
Irrigation	4	0.38 ns	2.01**	1.57 ns	1.07*	4.66 ns	0.24 ns
Residue b	12	0.58	0.25	0.58	0.25	1.25	0.10
IRRIG x CULT	4	0.43 ns	0.36 ns	0.62 ns	1.62 ns	5.45**	0.30**
Residue c	12	0.35	0.29	0.35	0.61	0.57	0.05
CV a (%)		1.29	1.53	0.60	18.54	5.15	4.56
CV b (%)		1.75	1.66	0.90	14.32	3.51	7.24
CV c (%)		1.37	1.80	0.70	22.11	2.37	4.95
		Means					
Cultivars		(%)	(mm)	(%)	(%)	(gf tex^{-1})	(%)
BRS Aroeira		44.25 a	29.90 b	84.78 a	3.39 a	31.79 a	4.52 a
BRS Araripe		42.77 b	30.47 a	85.02 a	3.71 a	31.92 a	4.62 a

** and *Significant at 0.01 and 0.05 probability level, respectively; ns - Not significant at 0.05 probability level; DF – Degrees of freedom; CV – Coefficient of variation; Means followed by the same letters do not differ by Tukey test

No significant effect was observed on fiber percentage for the applied irrigation depths, which corroborates the results obtained by Cordão Sobrinho et al. (2007), Méndez-Natera et al. (2008), Basal et al. (2009), Onder et al. (2009) and Hussein (2011). According to the experimental results, these authors showed that fiber percentage is not affected by different irrigation depths, since it is determined by the genetic characteristics of the cultivars.

As to fiber length, there was significant difference for cultivars and irrigation depths, but not for the interaction between these factors. The cultivar BRS Araripe showed mean length of 30.47 mm, which is classified as medium (Carvalho, 2013), compared with 29.90 mm by BRS Aroeira, also considered as medium. Comparatively, BRS Araripe showed increment of 1.85% in relation to BRS Aroeira, a result corroborated in the literature by Vidal Neto et al. (2006).

According to the regression analysis with respect to the irrigation depths, fiber length increased until the irrigation depth of 667 mm (maximum point of the fitted model) and decreased by 1.03% until the irrigation depth of 894.68 mm (Figure 1A). The occurrence of water stress immediately after flowering and during the phase of fiber elongation can reduce its length, due to the direct connection with physiological mechanisms of cell expansion (Pettigrew, 2004). Other authors, like Sui et al. (2014), claim that increasing irrigation leads to an increase in fiber length.

Fiber uniformity was not significantly affected by irrigation depths, cultivars or by the interaction between both, as observed by Méndez-Natera et al. (2008) and Hussein (2011). Fiber uniformity means of 85.02 and 84.78% were obtained by the cultivars BRS Araripe and BRS Aroeira, respectively, which were classified as uniform (Santana et al., 2008).

No significant difference was observed in the short-fiber index for cultivars and the interaction. However, significant effect was observed for the irrigation depths and, according to the regression equation (Figure 1B), there was a decrease of 1.31% for each increase of 50 mm in the applied irrigation depth. According to Bradow & Davidonis (2000), although fiber length is a primarily genetic trait, the short-fiber index is dependent on, besides genotype, the cultivation conditions, which include water availability. Means short-fiber indices of 3.39 and 3.71% were obtained by the cultivars BRS Aroeira and BRS Araripe, respectively, which were classified as very low (Santana et al., 2008). These results are consistent with those required by the textile market, because the lower the

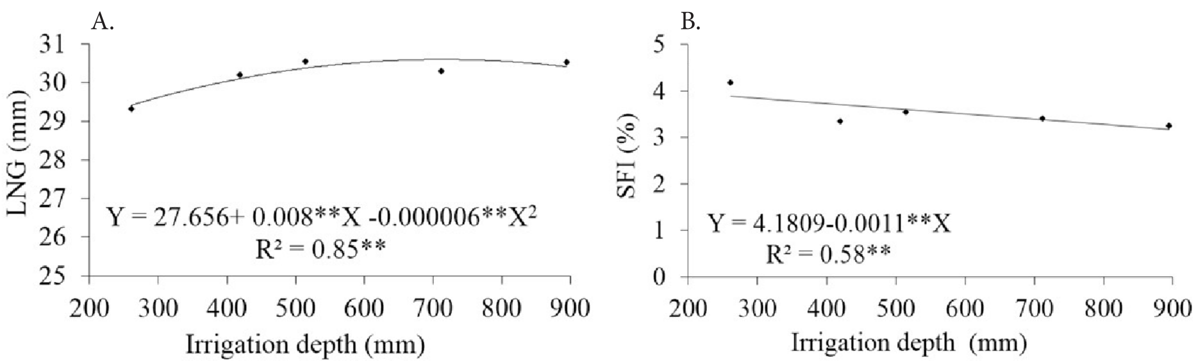

Figure 1. Fiber length (LNG) (A) and short-fiber index (SFI) (B) of upland cotton under different irrigation depths in Barbalha-CE, Brazil, 2010

short-fiber index, the better the fiber performance in the yarn manufacturing process and the higher is the interest of the market for the product.

According to Table 1, for the variables fiber resistance and elongation at rupture, there was no significant difference between the cultivars and irrigation depths. However, the interaction between factors was significant and its follow-up tests are shown in Figure 2.

According to Figure 2B, there was significant difference in fiber resistance between the cultivars only for the irrigation depth of 514.21 mm; however, both were classified as strong (Santana et al., 2008). The higher the fiber resistance, the higher its commercial value, because it improves the performance in the weaving process, quality gain and yield (Zhao et al., 2012).

For the follow-up test of irrigation depths for each cultivar (Figure 2B), the regression analysis was significant only for BRS Araripe, with maximum resistance at 750 mm, according to the regression equation, which is close to the irrigation depth of 100% ETc (711.81 mm). From this point on, there was a decrease in fiber resistance with the increase in irrigation depths.

Dagdelen et al. (2009) observed higher fiber resistance with water depth of 100% ETc, compared with other evaluated depths, and cite that fiber resistance decreases with the increase in water deficit. The same behavior was reported by Johnson et al. (2002), who found positive correlation between fiber resistance and soil water availability. As to the excess of water, some studies show that fiber resistance decreases with the increase in rainfall/irrigation, which can be confirmed with the decrease in the values of fiber resistance for irrigation depths above 750 mm (105% ETc). As to elongation at rupture, in the follow-up test for each cultivar in each irrigation depth (Figure 2D), there was significant difference between the cultivars for the irrigation depths of 260.93 and 514.21 mm. At the irrigation depth of 260.93 mm, the cultivar BRS Araripe was superior to BRS Aroeira and the opposite occurred for the irrigation depth of 514.21 mm, at which BRS Aroeira showed the best results. The obtained results agree with those of Balkcom et al. (2006), who reported that different irrigation depths affect fiber quality parameters like elongation at rupture. Means of 4.52 and 4.62% for elongation at rupture were obtained by the cultivars BRS Aroeira and BRS Araripe (Table 1), respectively, and were classified as very low (Santana et al., 2008), which is relevant because the lower the elongation at rupture, the higher yarn resistance.

For the follow-up test for irrigation depths in each cultivar (Figure 2C), there was no significant fitting of the regression equations. Wen et al. (2013) also found no significant differences for elongation.

The results of the analysis of variance and means comparison test for the characteristics micronaire index, maturity, reflectance degree, yellowing and CSP of the upland cotton cultivars under different irrigation depths are shown in Table 2.

There was no significant effect of cultivars on the variables micronaire index, maturity, reflectance degree and CSP; only degree of yellowing was affected (Table 2). For the simple effect of irrigation depths, there was significant effect by F test at 0.05 probability level for micronaire index, maturity and reflectance degree, but not for degree of yellowing and CSP (Table 2). The interaction between factors was significant for the variables micronaire index, maturity and CSP.

The micronaire index for the cultivar BRS Aroeira decreased linearly with the increase in irrigation depths (Figure 3A). For the cultivar BRS Araripe, there was a quadratic response, with an initial increase and a subsequent decrease after the irrigation depth of 500 mm (maximum point).

The decrease in micronaire index with the increase in irrigation depths is consistent with the results observed by Balkcom et al. (2006), who claim that micronaire index and irrigation level are negatively correlated. The micronaire index is an important commercial parameter of fiber quality (GE, 2007), thus high values (> 5.0) are classified as very coarse fibers, due to the increase in the percentage of irregularity and

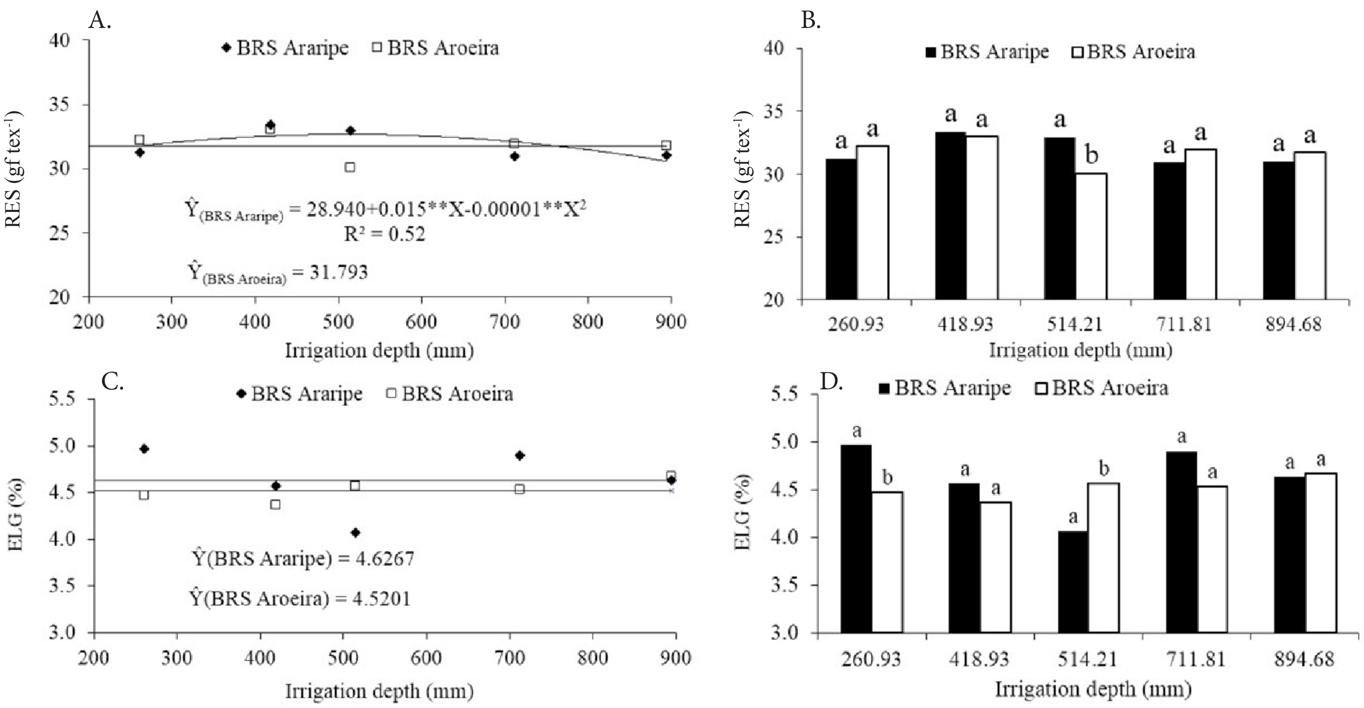

Figure 2. Fiber resistance (A and B) and elongation at rupture (C and D) of two upland cotton cultivars as a function of different irrigation depths

Table 2. Summary of the analysis of variance and means comparison test for micronaire index (MIC), maturity (MAT), reflectance degree (RD), degree of yellowing (+B) and count strength product (CSP) of upland cotton cultivars under different irrigation depths in Barbalha-CE, Brazil, 2010

Source of variation	DF	Mean square				
		MIC	MAT	RD	+B	CSP
Block	3	0.03 ns	0.15 ns	2.07 ns	0.05 ns	7626.52 ns
Cultivars	1	0.00 ns	0.04 ns	18.67 ns	0.25*	39988.86 ns
Residue a	3	0.01	0.15	2.16	0.00	4215.58
Irrigation	4	0.19**	2.39**	22.16**	0.17 ns	36033.84 ns
Residue b	12	0.02	0.35	3.07	0.10	16918.22
IRRIG x CUL	4	0.07**	1.15**	2.84 ns	0.17 ns	43507.14**
Residue c	12	0.01	0.12	2.58	0.10	7107.31
CV a (%)		2.08	0.44	1.85	1.08	2.31
CV b (%)		2.83	0.66	2.21	3.94	4.62
CV c (%)		2.26	0.40	2.02	4.00	2.99
		Mea ns				
Cultivars		(μg in^{-1})	(%)	-	-	-
BRS Aroeira		4.99a	89.26a	80.18a	8.17b	2783.45a
BRS Araripe		5.01a	89.20a	78.82a	8.33a	2846.69a

** and *Significant at 0.01 and 0.05 probability level, respectively; ns - Not significant at 0.05 probability level; DF – Degrees of freedom; CV – Coefficient of variation; Means followed by the same letter do not differ by Tukey test

imperfections in the yarn cross section. However, low values (< 3.5) suggest that the fiber is immature and can cause defects in the fabric (neps) and, consequently, low dye affinity during the finishing process (Kljun et al., 2014).

As to the analysis of micronaire index for the cultivars in each irrigation depth (Figure 3B), there was significant difference between cultivars only for the irrigation depth of 260.93 mm. This suggests that the cultivars behave differently only for low irrigation depths, with higher results for BRS Aroeira in comparison to BRS Araripe.

The variable fiber maturity (Figure 4A) in the cultivar BRS Aroeira showed a linear decrease as irrigation depths increased. For BRS Araripe, there was a quadratic response to the increase in irrigation depths, with an initial increase and a subsequent decrease after 750 mm (maximum point). It is important to point out that even the lowest maturity values are classified as very mature, according to Santana et al. (2008).

For the follow-up tests of cultivars in each irrigation depth (Figure 4B), fiber maturity differed statistically between cultivars only for the irrigation depth of 260.93 mm, as observed for the micronaire index. This indicates that the cultivars behave differently only for the application of low irrigation depths. For this irrigation depth, BRS Aroeira showed higher fiber maturity in comparison to BRS Araripe.

Reflectance degree (Figure 5) increased with the increase in irrigation depths. According to Bradow &

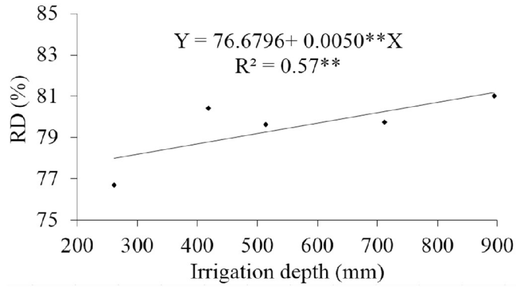

Figure 5. Fiber reflectance degree (RD) of upland cotton as a function of different irrigation depths in Barbalha-CE, Brazil, 2010

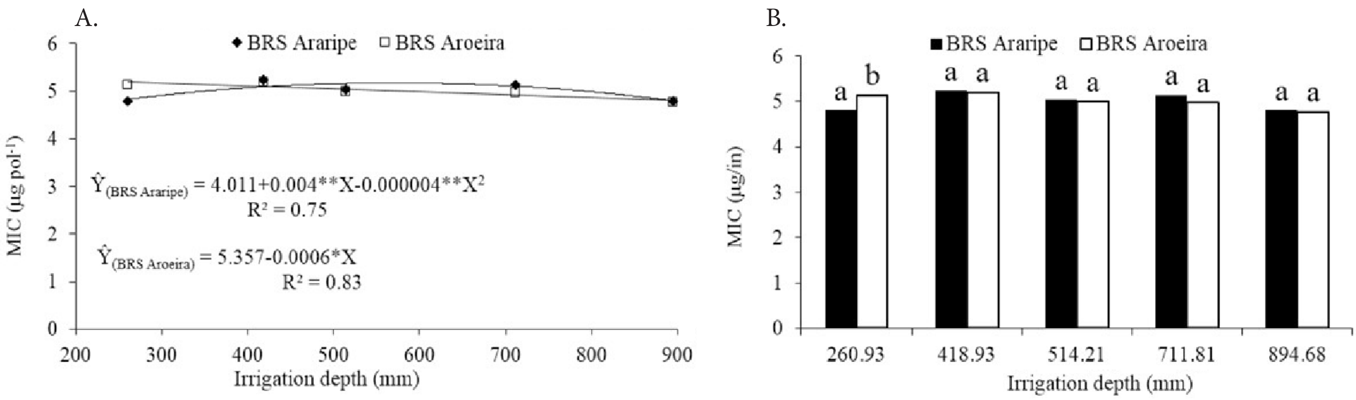

Figure 3. Micronaire index (MIC) of two upland cotton cultivars as a function of different irrigation depths

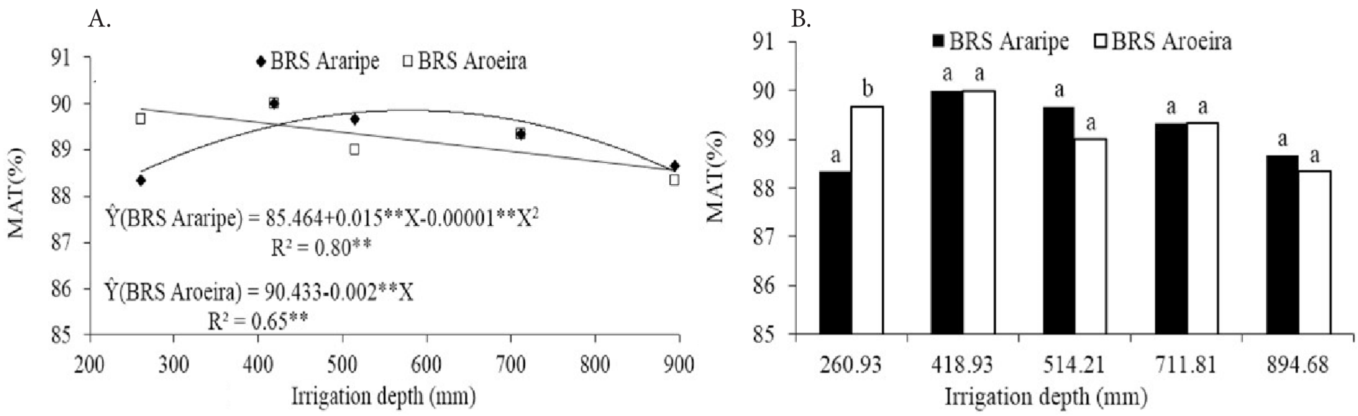

Figure 4. Fiber maturity (MAT) of two upland cotton cultivars as a function of different irrigation depths

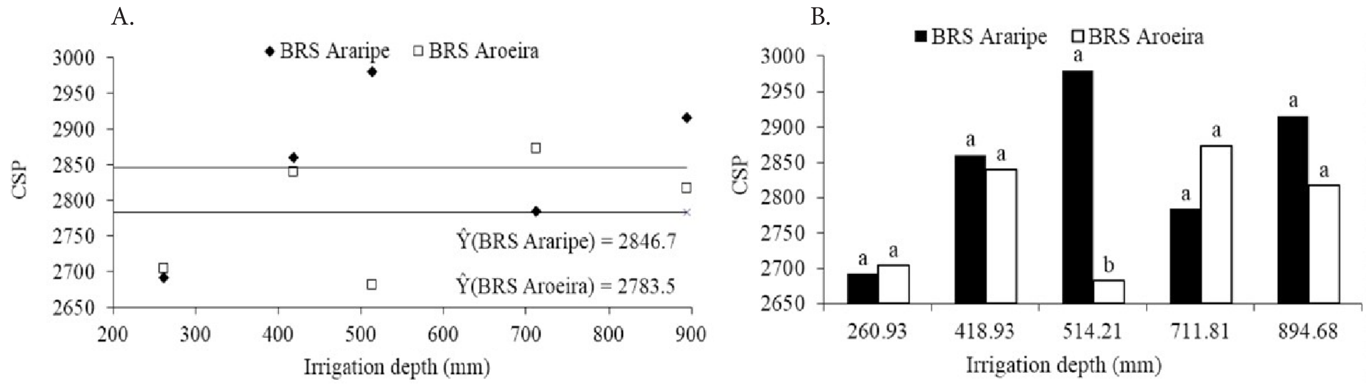

Figure 6. Count strength product (CSP) of two upland cotton cultivars as a function of different irrigation depths in Barbalha-CE, Brazil, 2010

Davidonis (2000), the color of the fiber is directly related to environmental factors during the cultivation season, which in the present study was the water stress. Other factors may have influenced these values, such as the application of defoliants and desiccants, pest attacks etc. It is important to point out that the higher the fiber reflectance, the lower the degree of grey and, consequently, the higher the interest for the textile industry.

Still with respect to cotton color, the degree of yellowing (+B) was equal to 8.17 for BRS Aroeira and 8.33 for BRS Araripe, which differed statistically by Tukey test at 0.05 probability level (Table 2). However, both are considered as medium and are within the standards of the modern textile industry (Santana et al., 2008). Knowing the +B value is important, because fiber color may not always be seen with naked eye, only under ultraviolet light. In addition, if the +B value is not controlled in the mixture, there can be problems, such as the barre pattern in the yarn, fabric and knit.

For both cultivars, the CSP index did not fit any regression equation as the irrigation depths increased (Figure 6A). Mean values of 2846.7 and 2783.5 were obtained for the cultivars BRS Araripe and BRS Aroeira, which were classified as very high (Santana et al., 2008) and were higher than those reported by Vidal Neto et al. (2006).

For the analysis of cultivars in each irrigation depth (Figure 6B), there was significant difference only for the irrigation depth of 514.21 mm, which shows that BRS Araripe had a CSP index 10% higher compared with BRS Aroeira. The CSP values obtained by the cultivars are interesting, since they translate the characteristic of yarn resistance, which depends especially on the individual fibers.

Conclusions

1. With respect to fiber quality, the irrigation depths influenced significantly and positively length, short-fiber index, micronaire, maturity and reflectance degree of cotton fibers.

2. The two cultivars differed for fiber percentage, length and degree of yellowing.

3. The best results of fiber quality were observed with irrigation depths of 514.21 and 418.93 mm, for the cultivars BRS Araripe and BRS Aroeira, respectively.

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