



Effects of Irrigation, Cultivar, and Plant Density on Cotton Within-Boll Fiber Quality

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ABSTRACT

This study was designed to determine how within-boll fiber quality of cotton (*Gossypium hirsutum* L.) is affected through irrigation, cultivar, and plant density management. Field experiments were conducted in 2006 and 2007 using two contemporary cultivars, arranged in a split-split plot design with two irrigation rates (6.33 and 4.32 mm d⁻¹) as the main plot, plant density (79,071; 128,490; 197,677 plants ha⁻¹) as the subplot, and cotton cultivar (FM9063B2RF and ST4554B2RF) as the subsubplot. Plants from 3 m of one row from each plot were hand harvested by fruiting position. First fruiting position bolls from main-stem nodes 9 and 14 were hand harvested by seed position and ginned separately for Advanced Fiber Information System (AFIS) fiber quality analysis. Increased irrigation generally increased fiber length and upper quartile length, and decreased fineness and maturity ratio. Irrigation effects were greater on fiber length and maturity ratio at seed positions close to the apex of the locule. Increased plant density reduced both fineness and maturity ratio. The cultivar FM9063B2RF produced longer, more mature, and finer fibers than the ST4554B2RF. The overall lowest fiber quality (i.e., shorter and less mature fibers) occurred at seed positions close to the apex of the locule. The superior fiber quality (i.e., longer and more mature fibers) was from the middle to the base of the locule. Abundant rainfall diminished the effects of irrigation on fiber quality.

OVER THE PAST few decades cotton yields have improved considerably (Lewis, 2000). Meanwhile, the demand for high quality cotton fiber has escalated. Crop management practices to improve fiber quality while maintaining lint yield have become the focus of intense research. Several studies have reported lint yield in upland cotton is negatively related to fiber quality (Culp and Harrell, 1975; Green and Culp, 1990; Harrell and Culp, 1976; Meredith and Bridge, 1972; Pettigrew, 2004; Worley et al., 1974), that is, cotton plants need to sacrifice fiber quality to improve lint yield.

Thus, assessing strategies to improve fiber quality while maintaining yield levels is crucial and this process requires better understanding of the effects of crop management practices on cotton fiber quality. Bednarz et al. (2006) reported lower fiber quality resulted from increased plant density. Rain distribution and irrigation strategies (Balkom et al., 2006; Lascano and Hicks, 1999), and cultivars (Bradow and Davidonis, 2000) could also affect cotton fiber quality. It is already known that lint produced on monopodial branches, more apical main stem nodes, and more distal sympodial branch fruiting positions (i.e., exterior fruiting positions) tend to have lower fiber quality (Bernhardt et al., 1986; Davidonis et al., 2004). However, very

little is known about the effects of crop management practices on the fiber quality at the within-boll (locule/seed) level. Feng et al. (2010) found significant effects of irrigation and plant density on cotton within-boll yield components. Thus, it might be reasonable to assume that within-boll lint produced at different seed positions might differ in fiber quality and within-boll fiber quality might also vary with irrigation, cotton cultivar, and plant density. The objective of this investigation was to determine how within-boll fiber quality of cotton, across all seed positions, and by seed position, is affected by irrigation, plant density, and the cotton cultivars FM9063B2RF and ST4554B2RF.

MATERIALS AND METHODS

Experiments were conducted in 2006 and 2007 at the Agricultural Complex for Advanced Research and Extension Systems (AG-CARES) facility in Lamesa, TX on an Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs). All treatments were arranged in a split-split plot design with three replications where irrigation rate (6.33 and 4.32 mm d⁻¹) was the main plot, variety (FM9063B2RF and ST4554B2RF) was the subplot, and plant density (79,000 plants ha⁻¹; 128,400 plants ha⁻¹; 197,600 plants ha⁻¹) was the sub-subplot. In 2006, cotton was planted 11 May and harvested 31 October. In 2007, cotton was planted 15 May and harvested 4 November. Fertilizer applications included 132 kg N ha⁻¹ and 56 kg P₂O₅ ha⁻¹ each year. Weeds were controlled with herbicides and in-season cultivation. The herbicides used included prometryn [2,4-bis(isopropylamino)-6-methylthio-s-triazine] preemergence at 1.12 kg ai ha⁻¹ and two in-season postemergence topical glyphosate [N-(phosphonomethyl) glycine] applications at 0.84 kg ae ha⁻¹. Aldicarb [2-methyl-2-(methylthio)propionaldehyde O-(methylcarbamoyl)oxime] was

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Abbreviations: AFIS, advanced fiber information system; SDI, subsurface drip irrigation; UQL, upper quartile length.

applied in-furrow at planting at $0.6 \text{ kg a.i. ha}^{-1}$. No additional insecticide applications were made.

The field experiment was performed within a 2.4 ha area divided into six zones, with 16 rows each (1 m rows by 244 m long) irrigated by subsurface drip irrigation (SDI). Three irrigation zones received 4.32 mm d^{-1} , which is the common deficit irrigation applied by the farmers in the area. An additional three zones received 6.33 mm d^{-1} , which corresponds to the average crop evapotranspirative demand for SDI in the Texas High Plains. Irrigation laterals were installed at 30-cm depth with emitter spacing of 60 cm. Laterals were positioned in alternate furrows providing irrigation for two 1 m wide beds. In 2006, preplant and seasonal irrigations were 125 and 300 mm, respectively, in the lower irrigation rate treatment and 186 and 460 mm in the high irrigation rate treatment. Rain from 1 May 2006 to 30 Sept. 2006 totaled 163 mm. In 2007, preplant and seasonal irrigations were 115 and 165 mm, respectively, in the low irrigation rate treatment and 170 and 254 mm in the high irrigation rate treatment. Seasonal rain from 1 May 2007 to 30 Sept. 2007 totaled 466 mm.

Data Collection

Box Picking

For each of the 36 plots (2-irrigation rates; 2 cultivars; 3 plant densities; 3 replications), 3 m of plants from a center row were hand harvested. The first sympodial position bolls from mainstem nodes 9 and 14 (Fig. 1) of each plot were harvested to compose the 72 primary samples (36 plots; 2 nodes; 1 boll position).

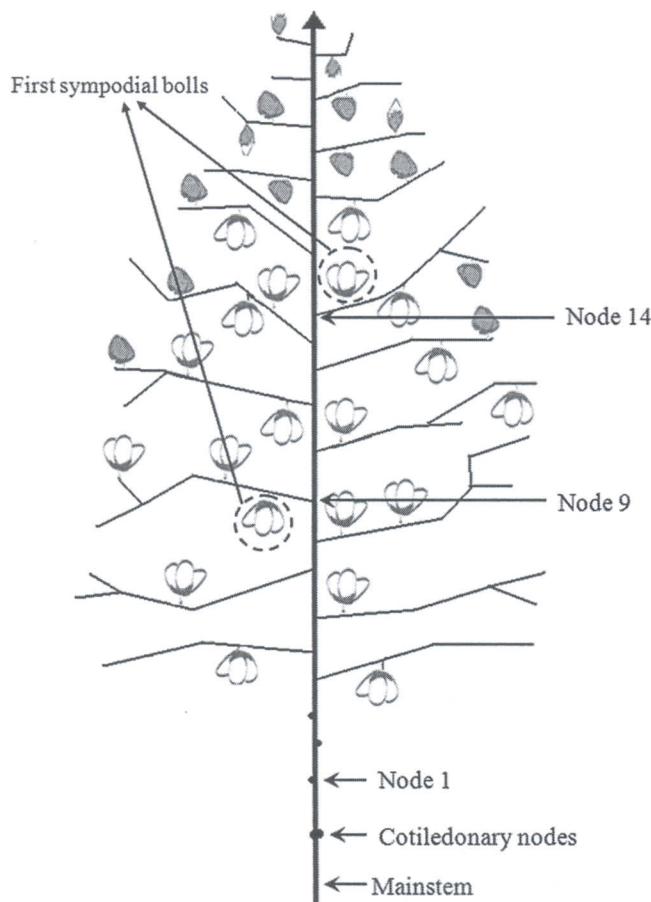


Fig. 1. Cotton plant diagram. The first sympodial position bolls from mainstem nodes 9 and 14 are highlighted with the dashed circle.

Locule Mapping and Fiber Quality Analysis

For each of the 72 primary samples, a subsample was taken for locule mapping. In each of these subsamples, locules from each boll were spread apart by hand. The middle of the locule was determined by extracting the seeds and finding the middle seed (Fig. 2). Seeds were numbered, with the seed in the middle of the locule designated as position 0. Seeds from position 0 toward the base were numbered from -1 to -4 , while seeds from position 0 toward the apex were numbered from 1 to 4 .

Each of the 72 primary subsamples were split by seed position, composing 9 sub-subsamples each and totaling 648 sub-subsamples (2 nodes; 1 boll position; 9 seed positions; 36 plots). After locule mapping, a small laboratory table-top gin was used to separate seed and lint of each sub-subsample individually.

The 648 lint sub-subsamples were sent to the Texas Tech University Fibers and Biopolymers Research Institute for fiber quality analysis. Fiber quality was determined using advanced fiber information system (AFIS). The fiber quality parameters analyzed were fiber length (weight based), upper quartile length (UQL), fineness, and maturity ratio.

Statistical Analyses

Precipitation and reference evapotranspiration from May through October, which were different in 2006 and 2007 (data not shown), were recorded by a weather station located in the experimental field. Due to these weather differences, each year was analyzed separately. The experimental design used was a split-split-split-split plot in space (field plots) and time (nodes and seed positions). Data analysis was conducted using Proc MIXED (SAS, Ver. 9.2, 2004) and Proc GLM (ANOVA). The fixed effects appeared in the model statistical statement with the ddifm = satterth (Satterthwaite) option which computes the correct df for each fixed effect based on a solution of random effects. When all data were present, the fixed effects and

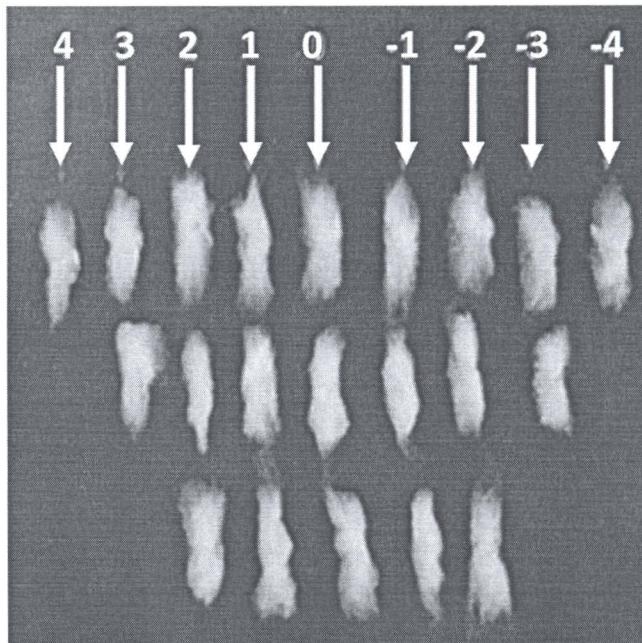


Fig. 2. Boll's locule mapping. Seeds were numbered, with the seed in the middle of the locule designated as position 0. Seeds from position 0 toward the base were numbered from -1 to -4 , while seeds from position 0 toward the apex were numbered from 1 to 4 .

Table 1. Advanced fiber information system (AFIS) fiber length, upper quartile length (UQL), fiber fineness, and maturity ratio as a function of irrigation rate, plant density, and cultivar in studies conducted in Lamesa, TX, in 2006 and 2007. The data presented are the mean of all seed positions.

Main effects	Fiber length		UQL		Fineness		Maturity ratio	
	2006	2007	2006	2007	2006	2007	2006	2007
Irrigation, mm d ⁻¹	6.33	2.72a†	26.2a	3.20a	3.18a	171.26b	174.47a	0.912b
	4.32	26.4b	25.9a	3.10b	3.12a	176.07a	179.26a	0.929a
Plant density, plants ha ⁻¹	79,000	26.9A‡	26.2A	3.1A	3.15A	175.25A	181.4A	0.92A
	128,400	26.7A	26.2A	3.1A	3.1A	173.85AB	173.0B	0.91A
	197,600	26.7A	25.9A	3.15A	3.12A	171.90B	176.1B	0.90B
Cultivar	FM9063B2RF	27.7d§	26.9d	3.30d	3.25d	167.16e	174.16e	0.924d
	ST4554B2RF	25.9e	25.4e	3.02e	3.05e	180.17d	179.57d	0.908e
Source of variation					P > F			
Irrigation (I)	<0.001	0.51	0.002	ns	<0.001	0.09	<0.001	0.06
Plant density (P)	ns¶	ns	ns	ns	0.02	0.02	0.04	<0.001
Cultivars (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.03	<0.001
I × P	ns	ns	ns	ns	ns	ns	ns	0.06
I × C	ns	ns	ns	ns	ns	ns	ns	ns
P × C	ns	ns	ns	ns	ns	ns	ns	ns
I × P × C	ns	ns	ns	ns	ns	ns	ns	ns

† a, b denote the differences between irrigation rates.

‡ A, B denote the differences between plant densities.

§ d, e denote the differences between cultivars.

¶ ns denotes not significant at 5% level.

random effects were independently determined. There were 648 nodes and positions among the 36 field plots.

RESULTS AND DISCUSSION

Mean Fiber Length by Weight and Upper Quartile Length

When analyzing the mean of all seed positions, irrigation effects were observed across seed positions for mean fiber length and UQL in 2006 (Table 1). Mean fiber length and UQL were improved by increased irrigation (Table 1). These effects were not observed in 2007.

The divergence between 2006 and 2007 is probably associated with differences in precipitation between both years (Fig. 1). The 2007 growing season received ~35% more rain than the 2006. Consequently, the irrigation demand throughout the 2007 growing season was reduced and the effect of irrigation rate was diminished. Additionally, and more importantly, the pattern of precipitation distribution was considerably different in 2006 and 2007. In 2006, there was very limited rainfall in the first 3 mo of the season. In August of 2006 the rainfall supplied only around 30% of crop evapotranspiration (data not shown). The majority of the in-season precipitation in 2006 occurred in September and October when the crop water demand was lower. Therefore, due to the lack of precipitation during the periods of crop establishment and maximum growth rate, the 2006 crop season was very responsive to irrigation.

At within-boll level, for the analysis by seed position, an interaction between irrigation and seed position was observed for mean fiber length in both years (Table 2). The longest fibers were found close to the seed position -2 (Fig. 3). Fiber length improved by increased irrigation across seed positions, except for positions 0 and 2 to 4 in 2007 (Fig. 3). Fiber length differences between irrigation rates were greater at seed positions closer to the base of the locule (Fig. 3).

Similar to mean fiber length, seed position -2 was found to be the one with the greatest UQL of all seed positions in both years (Table 2). The UQL decreased from seed position -2 toward both the apex and the base of the locule. The lowest UQL occurred at seed position +4 (Table 2).

Effects of plant density on fiber length and UQL were not observed for the mean of all seed positions (Table 1). Baker (1976) and Hawkins and Peacock (1971) also reported that fiber length and elongation were not influenced by plant density. Bednarz and Nichols (2005) also showed that, at the field level (i.e., when plots were machine harvested, blending seed cotton across fruiting positions, and ginned together), mean fiber length and UQL did not differ among plant densities. Additionally, Bednarz et al. (2006) showed that, at the canopy level (i.e., when plots were hand harvested, segregating seed cotton across fruiting positions, and ginned separately), the lower plant densities resulted in longer mean fiber lengths and greater UQL in only one of the studied environments.

When analyzing the mean of all seed positions, the FM9063B2RF cultivar produced greater mean fiber length and UQL than ST4554B2RF cultivar in 2006 and 2007 (Table 1). Furthermore, the differences in mean fiber length and UQL between FM9063B2RF and ST4554B2RF cultivars were greater in 2006 than in 2007, suggesting that the differences could be increased in years with lower rainfall.

Fiber Fineness and Maturity Ratio

At the within-boll level, for the mean of all seed positions, fiber fineness (linear density expressed in mTex, i.e., mg km⁻¹) decreased in response to increased irrigation rate in 2006, but the difference was not as evident in 2007 (significant at 10%) (Table 1). Once more, the abundance of rainfall in 2007 may have also diminished the irrigation effect on fiber fineness.

At the within-boll level, for the analysis by seed position, an irrigation by seed position interaction was observed in both years (Fig. 4). Irrigation affected fineness at all seed positions,

Table 2. Advanced fiber information system (AFIS) fiber length, upper quartile length (UQL), fineness, and maturity ratio in studies conducted in Lamesa, TX, in 2006 and 2007. The data represents the seed positions main effect across all treatments.

Seed position	Fiber length		UQL		Fineness		Maturity ratio	
	2006	2007	2006	2007	2006	2007	2006	2007
-4	26.9	26.2	3.14bc†	3.13bc	177.0	182.5	0.918	0.928
-3	27.1	26.6	3.17ab	3.16a	179.2	184.2	0.928	0.935
-2	27.4	26.6	3.20a	3.18a	177.6	180.0	0.927	0.928
-1	27.0	26.2	3.19a	3.16a	170.6	172.9	0.913	0.912
0	26.7	26.1	3.16bc	3.16a	169.8	172.3	0.909	0.911
1	26.5	25.9	3.15bc	3.14c	169.4	172.3	0.904	0.906
2	26.6	25.9	3.17ab	3.14c	171.5	175.3	0.904	0.908
3	26.4	25.8	3.13c	3.11c	173.2	177.0	0.900	0.906
4	26.2	25.4	3.09d	3.07d	174.5	175.8	0.898	0.900
Source of variation					P > F			
S‡	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
I × S	0.0141	0.0297	ns§	ns	0.0139	0.0321	0.0143	0.0311
P × S	ns	ns	ns	ns	ns	ns	ns	ns
I × P × S	ns	ns	ns	ns	ns	ns	ns	ns
C × S	ns	ns	ns	ns	0.0003	0.0017	<0.0001	<0.0001
I × C × S	ns	ns	ns	ns	ns	ns	ns	ns
P × C × S	ns	ns	ns	ns	ns	ns	ns	ns
I × C × P × S	ns	ns	ns	ns	ns	ns	ns	ns

† a, b, c, d, e denote the differences between seed positions at 5% level.

‡ S denotes seed position; I denotes irrigation rates; P denotes plant density; and C denotes cotton cultivars.

§ ns denotes not significant at 5% level.

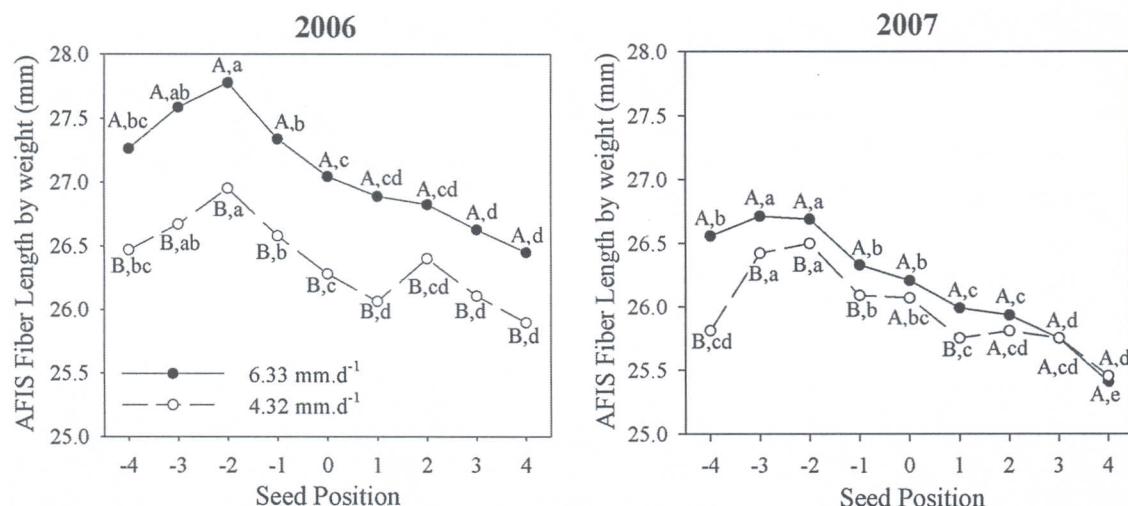


Fig. 3. Advanced fiber information system (AFIS) fiber length by weight as a function of seed position for two irrigation treatments (4.32 and 6.33 mm.d^{-1}) in Lamesa, TX, in 2006 and 2007. First symodial position. a, b denote the mean differences between seed position within irrigation treatments. A, B denote the mean differences between irrigation treatments within seed position. Means with same letter are not significantly different at $P = 0.05$ level.

except position -4. The greatest irrigation effects on fiber fineness were found at the apex of the locule (Fig. 4). The lowest fiber fineness occurred at the mid-locule for both irrigation rates in 2006 and 2007 (Fig. 4). In both years, fiber fineness gradually increased from the mid-locule toward the base and the apex of the locule. Additionally, the greatest values of fiber fineness occurred at the base of the locule in 2006 and 2007 (Fig. 4).

When the mean of all seed positions was analyzed, fineness was reduced with increased plant density in 2006 and 2007 (Table 1). Similar results were found by Bednarz and Nichols (2005) at the field level (i.e., when plots were machine harvested, blending seed cotton across fruiting positions, and ginned together), and by Bednarz et al. (2006) at the canopy level.

For the mean of all seed positions, the FM9063B2RF cultivar had lower fiber fineness than the ST4554B2RF cultivar. Similar to the irrigation effects, differences in fiber fineness due to cultivar were greater in 2006 than in 2007, possibly due to the differences in rainfall pattern (Table 1).

A cultivar by seed position interaction was observed in 2006 and 2007 for fiber fineness at the within-boll level by seed position analysis (Fig. 5). Differences between FM9063B2RF and ST4554B2RF were more pronounced with seed positions closer to the apex. The FM9063B2RF cultivar had lower fiber fineness than the ST4554B2RF cultivar in all seed positions except for seed positions -4 to -2 in 2007 (Fig. 5). For both cultivars, the lowest fiber fineness occurred at the mid-locule (positions -1 to +1) (Fig. 5).

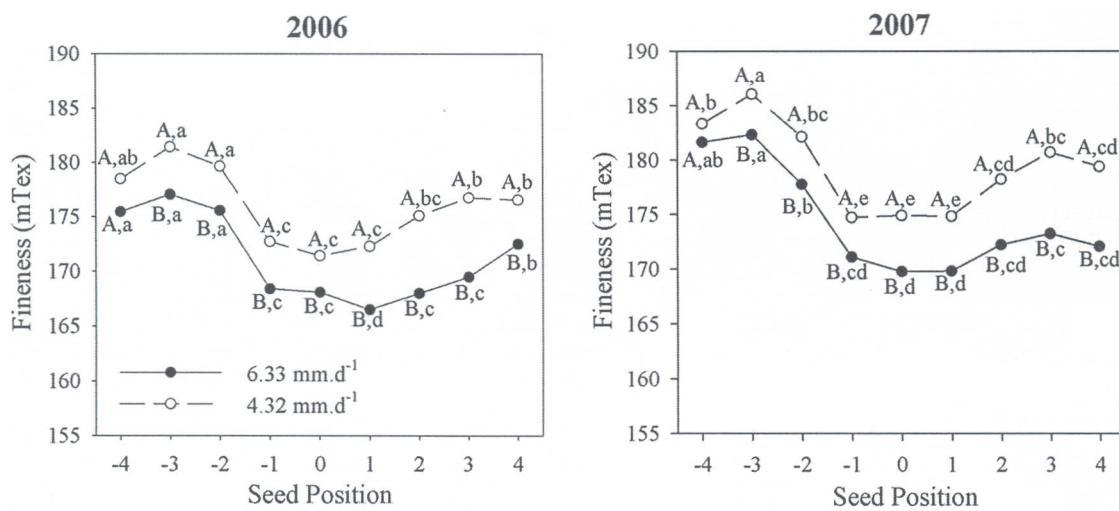


Fig. 4. Advanced fiber information system (AFIS) fiber fineness as a function of seed position for two irrigation treatments (4.32 and 6.33 mm.d^{-1}) in Lamesa, TX, in 2006 and 2007. First sympodial position. a,b denote the mean differences between seed position within irrigation treatments. A, B denote the mean differences between irrigation treatments within seed position. Means with same letter are not significantly different at $P = 0.05$ level.

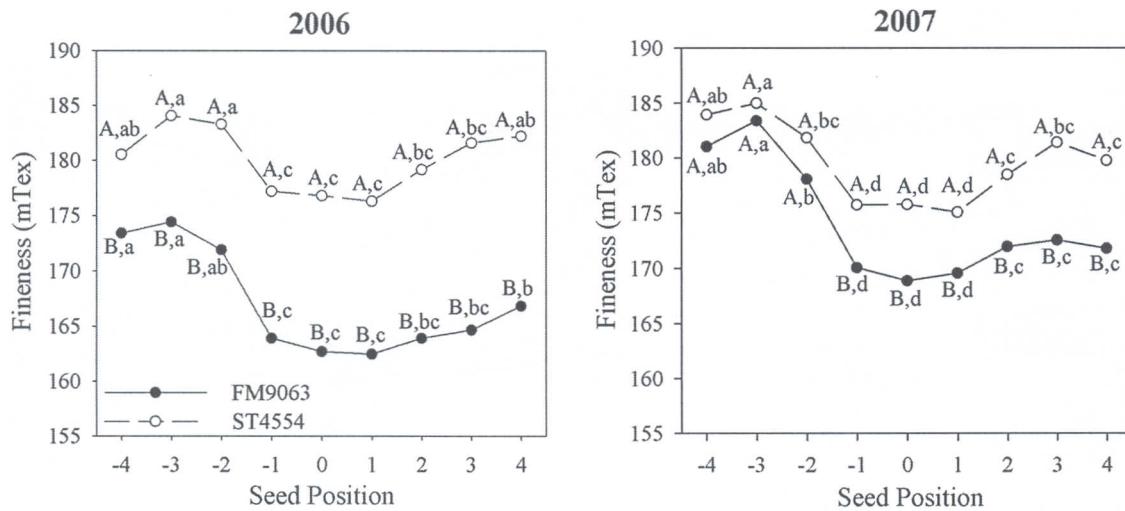


Fig. 5. Advanced fiber information system (AFIS) fiber fineness as a function of seed position for two cotton cultivars (FM9063B2RF and ST4554B2RF) in Lamesa, TX, in 2006 and 2007. First sympodial position. a,b denote the mean differences between seed position within cotton cultivar treatments. A, B denote the mean differences between cotton cultivar treatments within seed position. Means with same letter are not significantly different at $P = 0.05$ level.

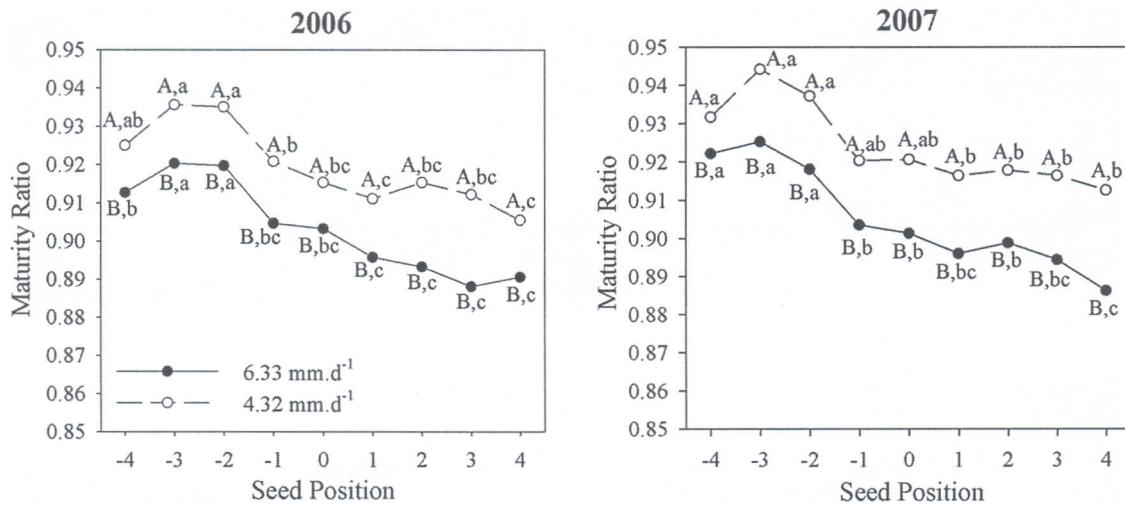


Fig. 6. Advanced fiber information system (AFIS) maturity ratio as a function of seed position for two irrigation treatments (4.32 and 6.33 mm.d^{-1}) in Lamesa, TX, in 2006 and 2007. First sympodial position. a,b denote the mean differences between seed position within irrigation treatments. A, B denote the mean differences between irrigation treatments within seed position. Means with same letter are not significantly different at $P = 0.05$ level.

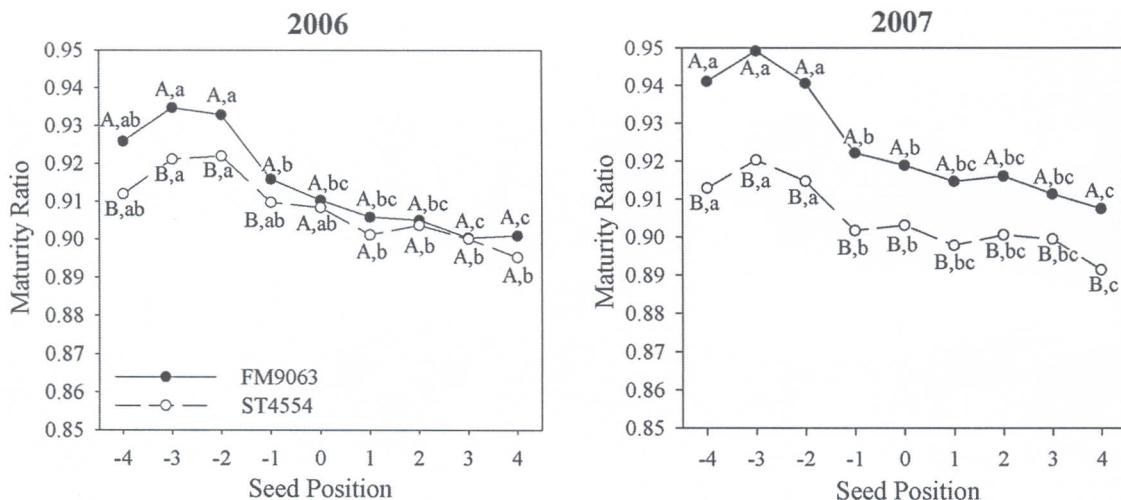


Fig. 7. Advanced fiber information system (AFIS) maturity ratio as a function of seed position for two cotton cultivars (FM9063B2RF and ST4554B2RF) in Lamesa, TX, in 2006 and 2007. First sympodial position. a,b denote the mean differences between seed position within cotton cultivar treatments. A, B denote the mean differences between cotton cultivar treatments within seed position. Means with same letter are not significantly different at $P = 0.05$ level.

An irrigation effect on fiber maturity ratio was observed for the mean of all seed positions at the within-boll level in 2006. In 2007, the irrigation effects on fiber maturity ratio were significant only at the 10% level (Table 1). Again, the greater precipitation in 2007 may have also diminished the irrigation effects on maturity ratio. In general, increased irrigation rate resulted in decreased maturity ratio. Ritchie et al. (2004) also reported increased soil water may reduce fiber maturity. Bradlow and Davidonis (2000) proposed that any environmental factors that affect photosynthesis and cellulose synthesis have the potential to alter fiber maturity. The idea is that increased irrigation improved photosynthesis through increased stomatal conductance. Hence, improved photosynthesis increased the number of potential fruiting forms, which lengthened the boll development period and therefore decreased maturity ratio.

At the within-boll level by seed position analysis, an irrigation by seed position interaction was observed for maturity ratio in 2006 and 2007 (Fig. 6). Lower maturity ratio occurred close to the apex of the locule (Table 2). Liu et al. (2001), studying the individual fiber strength by seed position in the locule, found that the breaking strength was lower at the apex. If there is lower maturity at the apex (i.e., less cellulose deposition), the fibers should logically be weaker, which confirms the validity of this finding. The differences in maturity ratio between irrigation rates were greater from seed position +1 to seed position +4 (Fig. 6).

In 2006, for the mean of all seed positions at the within-boll level, fiber maturity ratio was reduced in the higher plant densities. The maturity ratio was not different between 79,071 and 128,490 plants ha^{-1} , but was reduced for 197,700 plants ha^{-1} (Table 1). An interaction of irrigation by plant density was found in 2007 at 6% level of probability. The interaction occurred only in the year of abundant rainfall when the irrigation effects were probably diminished. Bednarz and Nichols (2005) observed fiber maturity ratio reduction with increased plant density at the field level (i.e., when plots were machine harvested, blending seed cotton across fruiting positions, and ginned together) and Bednarz et al. (2006) showed a similar effect at the canopy level.

For the mean of all seed positions at the within-boll level, ST4554B2RF cultivar showed lower maturity ratio than the

FM9063B2RF cultivar (Table 1). At the within-boll level by seed position, a cultivar \times seed position interaction was observed in both years (Fig. 7). In 2006, the FM9063B2RF cultivar had greater fiber maturity ratio than ST4554B2RF at seed positions close to the base of the locule, between seed positions -4 and -1 (Fig. 7). In 2007, the differences between FM9063B2RF and ST4554B2RF cultivars maturity ratio were significant at 5% probability level throughout all seed positions. The differences in maturity ratio also decreased from the base to the apex of the locule (Fig. 7).

CONCLUSIONS

In this study, at the within-boll level, irrigation rate, plant density and cotton cultivar affected fiber quality. Increased irrigation generally improved fiber length and UQL, and decreased fiber fineness and maturity ratio. Irrigation effects were greater in 2006 presumably due to lack of rainfall, and were diminished in 2007, presumably due to abundant rainfall. Irrigation effects were greater at seed positions close to the base of the locule in fiber length and were greater at seed positions close to the apex of the locule in fiber fineness and maturity ratio.

Plant density did not affect fiber length and UQL. However, increased plant density reduced both fiber fineness and maturity ratio.

The FM9063B2RF cultivar produced longer, more mature, and finer fibers than the ST4554B2RF cultivar under lower (2006) and higher (2007) rainfall environments. Compared to ST4554B2RF, FM9063B2RF is a large seeded cultivar (Feng et al., 2010). Culp and Harrell (1975) suggested that small seeded cultivars might adjust more rapidly to adverse environmental conditions. It is interesting to find that fiber quality of FM9063B2RF was less sensitive to environment (fiber length in FM9063B2RF was less sensitive to irrigation rate and fineness in FM9063B2RF was less sensitive to plant density). However, FM9063B2RF and ST4554B2RF cultivars showed similar overall yields in this study (data not shown) under different environments.

Some clear patterns are shown regarding the effects of seed position on fiber quality. The overall lowest fiber quality (i.e., shorter, thicker, and less mature fiber) occurred at seed positions close to

the apex of the locule. Superior fiber quality (i.e., longer, finer, and more mature fiber) occurred closer to the base of the locule.

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