Effect of irrigation and planting geometry on cotton fiber quality and seed composition

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Keywords: Cotton, fiber quality, seed composition, micronaire, fiber length

DOI: https://doi.org/10.21203/rs.3.rs-76100/v1

Abstract

Background: Cotton fiber quality and seed composition play vital roles in the economics of cotton production systems and cotton seed meal industry. The objective of this research was to examine the effects of different levels of irrigation and planting geometries on fiber quality and seed composition of cotton (*Gossypium hirsutum* L.). A two-year study was conducted in 2018 and 2019 on a Dundee silt loam soil in the Southeast USA with a warm and humid climate. Irrigation treatments were, irrigating every furrow (FI, full irrigation) and alternate furrow (HI, half irrigation), and no irrigation (RF, rainfed), and planting geometries were a single-row (SR) and twin-row (TR) on ridges spaced 102 cm apart. Fiber quality was tested by using the High-Volume Instrument (HVI) and Advanced Fiber Information Systems (AFIS). Seed protein, oil, and fiber were estimated using near-infrared reflectance spectroscopy.

Results: The results showed irrigation and planting treatments played a significant role in fiber quality and seed composition. Across irrigation treatments, significant differences were seen in fiber properties, including micronaire, uniformity, upper half mean length (UHML), strength, yellowness, short fiber, upper quartile length (UQL), fineness, maturity ratio, and neps. The micronaire was negatively affected by irrigation as FI-SR, FI-TR, HI-SR, and HI-TR had recorded 11-12% over the RF-SR and TR treatments. The planting geometry played a minor role in determining fiber quality traits like micronaire and nep count. Irrigation treatments recorded significantly lower protein content by 3-4 % than rainfed, while oil content significantly increased by 6-10 %.

Conclusions: The results of the study indicate a potential for improving cotton fiber and seed qualities by managing irrigation and planting geometries in cotton production systems in the Mississippi Delta region.

Introduction

The United States of America (USA) is one of the countries producing high-quality cotton in the world (https://www.ers.usda.gov/topics/crops/cotton-wool/cotton-sector-at-a-glance/). Comprehensive data of cotton fiber and cottonseed qualities are essential information required for maintaining high-quality cotton production in response to changing technology and agronomic management practices (Roth, 2010). In the state of Mississippi, USA, cotton is grown in over 0.25 M ha with an estimated production of 1.46 M bales (USDA-NASS, 2019). In this region, traditionally, cotton was planted in a single row (SR) on raised beds spaced between 96 and 102 cm apart. Currently, over 60% of the cotton acreage is irrigated (Kebede et al., 2014). Interestingly enough, planting the same number of seeds in twin-row (TR) (two rows spaced between 18 and 38 cm on seedbeds centered on raised beds spaced between 96 and 102 cm) compared to SR has been reported to enhance yield and net returns in soybean and cotton (Reddy and Boykin, 2010; Pinnamaneni et al., 2020).

Reliable fiber quality measurement became available with the advent of High Volume Instrument (HVI) in the late 1960s and Advanced Fiber Information System (AFIS) in the 1980s. Cotton researchers, since the 1960s, have used HVI fiber measurements as their primary source of data while making selections and advancing plant populations for fiber quality improvement. The AFIS helps in predicting spinning performance as well as yarn quality as it completely characterizes the within-sample distribution of the fiber length of individual fibers. The HVI method had fewer data available such as micronaire, upper half mean length (UHML), fiber length, strength, trash, yellowness, uniformity index. In contrast, the AFIS method offers finer details of fiber such as nep, length by number, length by weight, short fiber content by number and weight, upper quartile length (UQL), dust, fineness, and maturity ratio. Fiber quality is a critical attribute in determining the cotton profitability, and virtually every bale (around 228 kg of lint) of cotton produced in the USA was subjected to the High Volume Instrument (HVI) fiber quality assessment controlled by the United States Department of Agriculture-Agricultural Marketing Service (USDA-AMS). The fiber quality properties such as short fiber stickiness, trash contents, color, fiber length, and micronaire have been included in the commercial system for cotton pricing and marketing (Bowman and Ethridge, 1992; Ge et al., 2008). The U.S. textile industry has gradually adopted more open-end rotor spinning, with a much higher turnover rate, thereby increasing the importance of cleanliness and strength. At the same time, fiber length and micronaire are less critical. Fiber quality is the culmination of many interacting factors that include cultivar choice and crop management, and climate during the season. When fiber quality is poor, producers assume that the cotton that came out of the boll while in the field was exposed to adverse events such as untimely rain, insect secretions, or dust, that are often beyond the grower's control (Pettigrew, 2010).

Irrigation affects lint quality in multiple ways, particularly during the fiber elongation phase: ginning percentage; fiber length, strength, uniformity, fineness, micronaire, and short fiber content (Pettigrew, 2004; Balkcom et al., 2006; Basal et al., 2009; Pettigrew and Dowd, 2011; Feng et al., 2014; Zhang et al., 2016; Sui et al., 2017; Witt et al., 2020). In a study conducted in the MS Delta, irrigation improved cotton yield and fiber length (Sui et al., 2017). A 1.5 m row spaced cotton matured more slowly than 1.0 m cotton, which led to more durable and longer cotton fibers with overall better fiber quality (Bartimote et al., 2017). Stephenson et al. (2011) reported that planting patterns didn't affect fiber length (28.7 mm), micronaire (4.3), strength (287–288 kN m kg^{-1}), or uniformity (83.5–84.3%). Also, fiber length (28.5–28.7 mm), micronaire (4.2–4.4), strength (286–290 kN m kg^{-1}), or uniformity (83.6–84.2%) weren't affected by plant density. Previous work indicated that plant density slightly affected micronaire while it does not affect either fiber strength or uniformity (Pettigrew and Dowd, 2011). Darawsheh et al., (2009) observed decreased fiber length and micronaire when plant densities were increased, but fiber strength and uniformity were not affected (Darawsheh and Khah, 2009). A two-year study in the MS Delta on fiber quality demonstrated that cotton produced in 38-cm single and 38-cm twin rows on 102-cm beds was equal to or better than cotton produced in conventional 102-cm rows (Boykin and Reddy, 2010).

The processing of cottonseed yields primarily four products: linters, hulls, oil, and meal (i.e., protein). While the linters and hulls have commercial uses, the oil and protein attract more attention due to their sheer value. The dairy industry particularly values the whole seed due to its high protein (35%) and oil (30%) content to feed ruminants, and its use is gradually increasing over the years (Arieli, 1998). Historically, the main objective of cotton breeding has been the improvement of fiber yield and lint quality, while research on seed composition was relatively relegated. Correlations have been noted for protein, oil, and the oil's iodine value with rainfall and temperature patterns from data recorded across several locations and years (Stansbury et al., 1956). The data from the recent variety trials revealed significant associations between fatty acid composition and the prevailing weather conditions (Dowd, 2015). There's an abundant genetic variability for seed traits that offers great potential and promise for future compositional improvements, but our understanding is limited to how environmental factors alter seed composition.

In a recent study conducted in MS Delta, it was demonstrated that TR planting geometry enhanced cotton lint yield by 10.62% in 2018 and 17.62% in 2019 (Pinnamaneni et al., in press). Little is yet known of the impact of such yield enhancement on the lint quality and seed composition under different irrigation levels. When the individual effects of irrigation and planting geometry on cotton yield, fiber quality, and seed composition were widely investigated, studies looking at their interactions were lacking. Also, research conducted on planting geometry (PG) or irrigation effects on fiber quality tried to dwell on either HVI data or AFIS data, rather than combined analysis. The objectives of this study were to examine the effects of irrigation levels (Rainfed, RF; Full/all row irrigation, FI; half/alternate row irrigation, HI) and two planting geometries (single-row, SR; twin-row, TR) and their interactions on (i) cotton fiber quality, (ii) cottonseed quality.

Materials And Methods

Cultural Practices

A two year (2018-19) field experiment with Cotton (cv. FiberMax1944GLB2) was conducted at the USDA-ARS Crop Production Systems Research Unit's research farm, Stoneville, MS, USA (33° 42' N, 90° 55' W, elevation: 32 m above mean sea level). The soil was a Dundee silt loam (fine silty, mixed, active, thermic Typic Endoaqualfs) with 0.87% organic matter, 0.44% carbon, 0.06% nitrogen, 50 mg Kg^{-1} P, 220 mg Kg^{-1} K, 348 mg Kg^{-1} Mg, 2057 mg Kg^{-1} Ca, 2.1 mg Kg^{-1} Zn, 9.1 mg Kg^{-1} S, 16.6 CEC, and 1.28 g cm^{-3} bulk density averaged across 60 cm soil depth. The field saturated hydraulic conductivity (K_{fs}) of the soil, as measured in this study, ranged from 0.41 to 1.22 cm hr^{-1}. Field preparation consisted of sub-soiling, disking, and bedding in the fall. The raised-ridge seedbeds were re-furbished in the spring and before planting, tops of the seedbeds were smoothed as needed to plant cotton in SR and TR planting geometries. Glyphosate at 1.12 kg a.i. ha^{-1} was applied about one month before cotton planting to kill the existing weeds. A 7300 vacuum planter (John Deere, East Moline, IL) was utilized to plant in the SR planting geometry. TR geometry planting was done using a Monosem NG + 3 TR vacuum planter (ATI, Inc. Monosem, Lenexa, KS) that was set to achieve a plant population density of 120,000 plants ha^{-1}. Actual plant populations were estimated at harvest by counting plants in 1 m^2 area in the two center rows at three randomly selected locations in each plot. Fertilizer application, weed control, and insect control programs were standard for cotton production. Isolated weed occurrences from time to time were hand hoed as needed.

Cotton cv. FiberMax1944GLB2 - a medium-maturing variety with broad adaptation, excellent yield potential, and outstanding fiber quality - was planted on 8 May (2018) and 16 May (2019). The experiment was conducted in a split-plot arrangement of treatments in a randomized complete block design with six replications. The three irrigation regimes FI, HI, and RF are considered main plots while subplots consisted of two planting geometries, SR - rows evenly spaced at 102 cm and TR – two rows spaced at 25 cm apart on 102 cm centered seedbeds. Each plot consisted of four SR or 8 TR and 40 m long. Sensors for measuring soil-matrix water potential (Watermark sensors, Irrometer Company, Inc, Riverside, CA USA) were installed at soil depths of 15, 30, and 60 cm in selected representative plots. Irrigations were scheduled based on a soil matrix potential of about – 90 kPa at 45 cm soil depths, as recommended by Plumblee et al. (2019). The amount of irrigation water applied during each season in each plot was measured using a flow meter. In 2018, a total of 17.5 cm water was applied in the FI treatments in five irrigation events of 3.5 cm each applied through every furrow on May 15, June 21, June 29, July 6, and August 4, while the HI treatments received the half the amount of water on the same dates applied in every other furrow (skip furrow irrigation). The total amount of water applied in HI was about 8.85 cm against 17.5 cm in the FI. In 2019, total irrigation applied was 15.2 cm in the FI treatment in four irrigation events of 3.8 cm each on May 26, June 29, July 24, and August 6, while in HI treatments, 7.5 cm of water was applied on the same dates. Irrigations were not applied after the first boll cracking stage of the growth of cotton.

During mid-to-late September each year, cotton was defoliated using a two-step process. Defoliation was initiated when approximately 65% of the bolls had opened in mid-September. In the first application, a mixture of 0.035 kg thidiazuron ha^{-1} and 0.0175 kg diuron ha^{-1} was applied on the crop canopy. One week later, a mixture of 0.035 kg thidiazuron ha^{-1}, 0.0175 kg diuron ha^{-1}, and 1.68 kg ethephon ha^{-1} were applied as a second step to complete the defoliation and facilitate the opening of the remaining unopened bolls. Approximately two weeks after the second defoliant application, yield data was collected by handpicking from 1 m^2 section in the two center rows at three randomly selected locations in each plot.

Data Collection

Weather data was collected from the Mid-South Agricultural Weather Service, Delta Research and Extension Center, Stoneville, MS. The growing degree days (GDD) were calculated using a base temperature of 10 ^{o}C for cotton growth (Desclaux and Roumet, 1996). After physiological maturity, above-ground biomass was harvested from a 1 m^{-2} section of middle two-rows from each plot at three locations, avoiding the row ends - one row sampled for the SR pattern and two rows sampled for the TR pattern. Seed cotton was ginned on a 10-saw laboratory gin (USDA-ARS Cotton Ginning Lab, Stoneville, MS), and the lint yield was calculated on a per hectare basis.

Fiber Quality Analysis

Ten subsamples were collected after the lint cleaner from each sample for fiber quality analysis, five of them for testing with AFIS, and five for HVI. All lint samples for HVI were analyzed in the USDA ARS Cotton Ginning Research Unit (CGRU) in Stoneville, MS. At the same time, AFIS analysis was performed at Fiber and Biopolymer Research Institute, Texas Tech University, TX. Fiber quality parameters measured with both AFIS (nep, short fiber content -SFC, upper quartile length -UQL, fineness, maturity ratio, fiber length by number, fiber length by weight, trash, dust and HVI instruments (micronaire, fiber length, uniformity index, strength, elongation, yellowness, reflectance, upper half mean length (UHML).

Seed Composition Analysis

Mature cotton seeds were collected, acid delinted, and analyzed for protein and oil. Briefly, approximately 25 g seed was ground using a Laboratory Mill 3600 (Perten, Springfield, IL). Near-infrared reflectance, according to Wilcox and Shibles (2001) and Bellaloui and Turley (2013), using a diode array feed analyzer

AD 7200 (Perten, Springfield, IL) was employed to estimate protein and oil. Perten's Thermo Galactic Grams PLS IQ software was used for calibrations, and the calibration equation was established according to AOAC methods (Association of Official Analytical Chemists, AOAC, 1990). Cottonseed protein and oil were expressed on a seed dry matter basis (Bellaloui and Turley, 2013).

Statistical Analyses

Statistical analyses were performed by analysis of variance (PROC MIXED; SAS Institute, 1996). Because all irrigation, planting date, treatments remained in their original location each year, years were treated as a repeated measurement when conducting a combined analysis across years. With the year, irrigation, planting geometry, and their interactions as fixed effects and replication and whole plot (irrigation) as random effects. Random effects used in this model for the comparison across years were irrigation X year, planting geometry X year, and irrigation X planting geometry X year. Treatment means were separated at the 5% level of significance using Fisher's protected least significant difference (LSD) test.

Results

Weather and Lint yield

The weather variables varied significantly during the two cropping seasons in 2018 and 2019 (Fig. 2). The period of reproductive growth and boll filling (July - September) during 2019 was warmer with 92 GDD more than 2018. In general, the 2018 crop season was less wet (730.8 mm in 2018, and 895.9 mm in 2019) and had less cumulative solar radiation of 458 MJ m^{-2} than 2019 (2447 MJ m^{-2} in 2018 vs. 2905 MJ m^{-2} in 2019). However, vegetative growth (May - July) in 2018 coincided with periods of lower rainfall (203 mm in 2018 vs. 578 mm in 2019) and higher mean minimum and maximum temperatures. Hence, the analysis of variance (ANOVA) revealed year has significant interaction on most of the fiber quality (Table 1a) and seed composition s (Table 1b).

Table 1
a. Significance of the main effects of irrigation regimes, year, and planting geometry (PG) and their interactions on fiber quality traits at Stoneville, MS during crop seasons

Source of variance	df	Micronaire	UHML	Uniformity	Strength	Reflectance (Rd)	Yellowness (+b)	Nep	SFC	UQL	VFM	Fineness	Maturity ratio
Irrigation level	2	*	*	*	**	ns	ns	*	*	*	*	*	*
PG	1	*	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns
Year	1	ns	**	ns	ns	*	*	ns	ns	ns	*	ns	*
Irrigation level*PG	2	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irrigation level*Year	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PG*Year	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irrigation level*PG*Year	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ns: non-significant; * Significantly different at P ≤ 0.05 level; ** Significantly different at P ≤ 0.01 level													
UHML: upper half mean length; SFC: short fiber content; UQL: upper quartile length; VFM: visible foreign matter													

Table 1
b. Effects of irrigation regimes, year, and planting geometry (PG) and their interactions on seed composition traits at Stoneville, MS, during 2018-19 crop seasons

Source of variance	df	Protein	Oil	Fiber
Irrigation level	2	**	***	ns
PG	1	ns	ns	ns
Year	1	**	**	ns
Irrigation level*PG	2	ns	ns	ns
Irrigation level*Year	2	*	**	ns
PG*Year	1	ns	ns	ns
Irrigation level*PG*Year	2	ns	ns	ns
ns: non-significant; * Significantly different at P ≤ 0.05 level; ** Significantly different at P ≤ 0.01 level; *** Significantly different at P ≤ 0.01 level				

The average lint yields in the irrigation and planting geometry combinations in this study were 1779 kg ha^{-1} in FI – SR, 2029 kg ha^{-1} in FI -TR, 1803 kg ha^{-1} in HI-SR, 2082 in kg ha^{-1} in HI-TR, and 1573 kg ha^{-1} in RF-SR, and 1788 kg ha^{-1} in RF-TR (Pinnamaneni et al., in press). The average final plant-stand established in the FI and HI irrigated plots were 10.4 plants m^{-2} each in FI and HI irrigated TR plots and 8.6 plants m^{-2} in FI with SR and 8.2 plants m^{-2} in HI with TR planting geometries. The higher lint yield in HI treatments is probably due to optimum water availability in the active root zone. However, in FI, wherein excess water around the root zone, owing to heavy precipitation events following the irrigation coinciding boll formation and developmental stages in July and August leading to higher vegetative growth, boll drop, and immature boll formation (Letey and Dinar, 1986; Feng et al., 2014) (Fig. 1b). RF with TR planting geometries had 9.34 plants $m^{-2,}$ and there were 7.6 plants m^{-2} in RF with SR at harvesting. The TR planting geometry produced a significantly higher number of bolls (75 bolls m^{-2}) than SR (64 bolls m^{-2}) (Pinnamaneni et al., in press).

HVI Measurements

Micronaire

Micronaire represents the surface area of lint and is a measure of fiber fineness and maturity. Both irrigation and planting geometry has significantly affected micronaire (Table 1a). RF recorded a higher micronaire than the corresponding HI and FI treatments. As seen in Table 2a, among the two planting geometries, TR has consistently recorded a significantly higher micronaire by 3–7% on an average. Although most of the fiber quality parameters were significantly different for the year, micronaire differences were consistent in 2018–2019.

Table 2

a. Fiber quality characteristics of irrigation treatments (FI, HI, and RF) on cotton in a Dundee silt loam with single-row (SR) and twin-row planting (TR) geometries estimated by High Volume Instrument (HVI). FI is full irrigation, HI is half irrigation, and RF is rainfed.

Treatment	Planting geometry	Micronaire (MIC)			Uniformity (%)			Upper half mean length (UHML) (mm)			Strength (kN m kg^{-1})		
		2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
FI	SR	4.26d	3.95d	4.11d	82.65c	82.85bc	82.8b	1.36a	1.34ab	1.35a	31.18a	31.85a	31.5a
	TR	4.29d	4.51b	4.40b	83.37a	83.03bc	83.2b	1.35a	1.30c	1.33b	31.92a	32.15a	32.0a
HI	SR	4.21d	4.26c	4.24c	84.80a	83.87ab	84.3a	1.35a	1.31bc	1.33b	31.22a	32.73a	32.0a
	TR	4.45c	4.37b	4.41b	84.58a	83.73ab	84.2a	1.36a	1.30bc	1.33b	30.45ab	30.51ab	30.5b
RF	SR	4.65b	4.78a	4.72a	80.58d	81.29d	80.9c	1.22d	1.20d	1.21c	30.56ab	29.90b	30.2c
	TR	4.91a	4.82a	4.87a	81.10d	81.00d	81.0c	1.21d	1.24d	1.23c	28.70b	29.24b	29.0c
Means within each column followed by the same letter or letters are not statistically different by LSD means ($P \leq 0.05$)													

Table 2

b. Fiber quality components of full (FI) and half irrigated (HI) and rainfed (RF) cotton grown in Dundee silt loam with single-row (SR) and twin-row planting (TR) geometries estimated by High Volume Instrument (HVI)

Treatment	Planting geometry	Reflectance (Rd)			Yellowness (+ b)			Trash (%)		
		2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
FI	SR	77.90	74.32	76.1	5.74	5.38	5.6	142.25a	233.40b	187.8a
	TR	77.83	73.97	75.9	6.43	5.34	6.5	112.54a	248 b	180.3a
HI	SR	78.50	74.45	76.5	6.47	5.75	5.5	121.16a	216.02 b	168.6b
	TR	78.63	72.86	75.7	6.05	5.95	6.0	122.5a	217.12 b	169.8b
RF	SR	78.41	74.18	76.3	6.03	6.01	6.0	130.21a	209.41 b	169.8b
	TR	77.43	72.85	75.1	6.12	5.76	6.1	155.24a	204.95b	180.1a
Means in each column followed by the same letter or letters are not statistically different by LSD means ($P \leq 0.05$)										

Fiber Strength

Fiber strength, an important parameter affecting yarn quality, was significantly affected by irrigation treatments while the planting geometry did not have any influence (Table 1a). There were no statistically significant differences in the fiber strength between the two irrigation treatments (HI and FI) in both the years, but the RF significantly decreased the fiber strength for both the seasons, as seen in Table 2a.

Uniformity

Irrigation has significantly affected uniformity in both the years, while PG does not affect fiber uniformity (Table 1a). Among the irrigation treatments, HI has recorded significantly higher fiber uniformity (HI-SR: 84.3 and HI-TR: 84.2) than FI treatments (FI-SR: 82.8 and FI-TR: 83.2) (Table 2a). This could be a result of excess water in the root zone during boll development and cracking resulting in more vegetative growth and immature bolls and, in some extreme cases, boll drop.

Upper Half Mean Length (UHML)

UHML is a crucial trait affecting the blend properties of yarn; hence the textile industry gives more importance. Irrigation has a significant positive impact on UHML (Table 1a). UHML was significantly lower in the rainfed treatments by about 9% on an average. However, like uniformity, UHML was not impacted by planting geometry, and the differences among HI and FI treatments were insignificant (Table 2a).

Reflectance (RD)

This trait is unaffected by neither irrigation nor planting geometry treatments (Table 1a). However, year-wise differences were significant. The mean of all the treatments in 2018 was 5.9% higher than that of 2019, probably due differences in air temperature and precipitation pattern

Yellowness (+b)

Yellowness is unaffected by neither irrigation nor planting geometry treatments like reflectance (Table 1a). However, year-wise differences were significant. The mean of all the treatments in 2018 was 7.7% higher than that of 2019, probably due to differences in GDD and precipitation patterns (Table 2a).

AFIS measurements

Length by number (Ln)

The length by number (Ln) was significantly affected by irrigation but not by planting geometry. However, the interaction between planting geometry and irrigation was insignificant (Table 1a). The Ln was significantly higher in both HI and FI treatments over RF in both the years by 9% and 10% in 2018 and 2019, respectively. The average Ln for FI, HI, and RF were 23.5 mm, 23.4 mm, and 21.4 mm, respectively (Table 2b).

Nep Count

Neps are measures of defects in cotton fiber. The measurement of nep count (both size and quantity) was commonly used to adjust in the processing machinery to reduce or eliminate the generation of mechanical neps. Nep count represents the number of neps observed in 0.5 g of the cotton fiber sample. Irrigation significantly contributed to nep count while planting geometry, or its interaction with irrigation did not influence nep count (Table 2a). On average, nep count in HI and FI was about 65% higher than that of RF cotton.

Short Fiber Content By Number (SFCn)

SFCn is expressed as a percentage of fibers which are shorter than 12.7 mm. High SFCn reduces the quality of yarn. There was no significant effect of irrigation and planting geometry in both the years (Table 1a). However, irrigated treatments, both HI and FI, recorded numerically higher SFCn values than that of RF treatment in both the years. In a two year study at Lubbock, TX indicated irrigation increased the SFCn, in contrast to the findings of the current study (Feng et al., 2014). This is probably due to the establishment of a better water balance between plant evapotranspiration demands and irrigation water applied.

Visible Foreign Matter (VFM)

Both the irrigation and year had a significant effect on VFM, while PG did not affect VFM (Table 1a). In 2018, VFM ranged between 2.5 to 3.15% while it ranged from 5.82 to 8.24% in 2019. The RF treatments have significantly lower VFM in both the years (Table 3a). This is probably due to diverse weather conditions during boll development, cracking, and harvesting.

Table 3

a. Fiber quality characteristics of full (FI) and half irrigated (HI) and rainfed (RF) cotton grown in Dundee silt loam with single-row (SR) and twin-row planting (TR) geometries estimated by Advanced Fiber Information Systems (AFIS)

Treatment	Planting geometry	Nep (cnt/g)			Fiber length (n) (mm)			SFC (n) (%)			VFM (%)		
		2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
FI	SR	155.2b	132.5b	143.9b	23.88	23.11	23.5a	22.8	21.9	22.4	3.15a	8.14a	5.65a
	TR	168.9ab	141.5a	155.2a	23.37	23.62	23.5a	22.5	22.1	22.3	3.12a	8.24a	5.68a
HI	SR	176.4a	146a	161.2a	23.62	23.11	23.4a	23.6	22.5	23.0	2.61b	7.8a	5.21b
	TR	168.4ab	132.6b	150.5b	23.62	23.11	23.4a	22.5	23.3	22.9	2.62b	7.7a	5.16b
RF	SR	102.6c	84.5c	93.6c	21.59	21.08	21.3b	21.5	20.8	21.3	2.5b	6.84a	4.67c
	TR	95.8c	88.6c	92.2c	21.84	21.34	21.6b	20.6	20.5	20.5	2.66b	5.82a	4.24c

Means followed by the same letter or letters are not statistically different by LSD means (P ≤ 0.05) SFC: short fiber content; VFM: visible foreign matter

Table 3

b. Fiber quality components of full (FI) and half irrigated (HI) and rainfed (RF) cotton grown in Dundee silt loam with single-row (SR) and twin-row planting (TR) geometries estimated by Advanced Fiber Information Systems (AFIS)

Treatment	Planting geometry	SFC (n)			UQL (w)			Maturity ratio			Fineness		
		2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
FI	SR	8.15a	7.1ab	7.63c	1.33a	1.29bcd	1.31a	0.94b	0.94c	0.94c	166.2c	176.5bc	171.4b
	TR	7.17ab	6.8ab	6.99a	1.32ab	1.29bcd	1.31a	0.93c	0.95b	0.94c	167.8c	173.4c	170.6b
HI	SR	7.41ab	6.4b	6.91a	1.32ab	1.28 cd	1.30b	0.95b	0.95b	0.95b	172.5b	178.3b	175.4b
	TR	7.10ab	6.4b	6.75b	1.33a	1.28 cd	1.31a	0.93c	0.95b	0.94c	173.1b	177.6b	175.4b
RF	SR	6.62c	7.1ab	6.86a	1.30abc	1.27d	1.29c	0.96a	0.97a	0.97a	182.2a	184.7a	183.5a
	TR	6.35c	6.8ab	6.58d	1.29bc	1.27d	1.28d	0.97a	0.97a	0.97a	185.4a	186.8a	186.1a

Means in each column followed by the same letter or letters are not statistically different by LSD means ($P \leq 0.05$)

SFC: short fiber content; UQL: upper quartile length

Fineness

Irrigation is detrimental to this measurement, as the higher fineness of fiber is preferable to the processing industry (Table 1a). However, the interaction of irrigation with planting geometry was insignificant in both the years. As seen in Table 3b, rainfed cotton has higher fiber fineness (RF-SR: 183.5 and RF-TR: 186.1 millitex. However, the range for FI and HI treatments were between 170.6 to 175.4 millitex.

Maturity Ratio

Maturity ratio, a key component of fiber quality, has a significant inverse relationship with irrigation (Feng et al., 2014). Planting geometry and its interaction with irrigation were insignificant in both the years (Table 1a). The maturity ratio was highest in RF-SR and TR treatments (0.97), while it ranged between 0.94–0.95 in FI and HI treatments (Table 3b). It is believed that irrigation (continuously wet soil, with hardly any water deficits) propels the plant to vegetative growth, limiting the nutrients left in the soil for extraction during active fiber growth bolls, resulting in lower cellulose deposition(Letey and Dinar, 1986).

Upper Quartile Length (UQL)

Upper Quartile Length (UQL) denotes the length of the longest 5% of all fibers in the sample. The UQL is significantly affected by irrigation, while PG and irrigation interaction with PG were insignificant (Table 1a). As seen in Table 3b, the range for UQL is narrow 1.28 to 1.31, and both HI and FI treatments had significantly higher UQL than that of RF cotton (Table 3b).

Seed Composition Parameters

Protein

Irrigation had a significant negative effect on seed protein accumulation. The protein measured from the cotton seeds in the experiment were across the two years studied (Table 1b). However, the protein levels were not impacted by the PG. Both the RF treatments accumulated significantly higher protein accumulation (SR: 24.8 and TR: 23.55) than FI (SR: 23.1 and TR: 22.8) and HI (SR: 23.2 and TR: 22.8), respectively (Fig. 2a).

Oil

Seed oil content was significantly affected by irrigation in both the years (Table 1b), while PG had no impact on oil accumulation. The average oil content in rainfed treatments was 2.2% higher in 2018, while 2019 recorded over 5.4% than that of HI and FI treatments (Fig. 2b).

Fiber

The seed fiber plays a vital role in meeting the dietary fiber requirements of animals as most of the cotton after gossypol extraction is fed as cake to animals. In the current study, neither irrigation nor PG had any impact on seed fiber. The seed fiber values ranged from 20.2 to 23.1% (Fig. 2c).

The availability of soil water primarily determines the ability of individual cells within a plant to expand, and both root tips growing through the soil as well as fibers elongating on seed coats in the bolls are no exception to it. Apart from limiting the plant growth, soil water stress triggers hormonal differences, particularly during reproductive growth resulting in senescence in fruiting bodies such as squares and bolls. Hence, efficient irrigation management involves reducing moisture stress at critical growth stages such that plants have the maximum capacity to initiate, retain, grow, and produce mature bolls, which results in twin objectives of higher fiber quality and better seed composition.

Discussion

Pinnamaneni et al. (in press) reported responses of cotton lint and seed yield to PG and irrigations. They demonstrated that all-row irrigation (FI) would not result in any yield advantage over alternate row irrigation: TR planting geometry produced 10.6% in 2018 and 17.6% in 2019. The lack of irrigation response is probably due to the presence of excess water around the root zone, owing to heavy precipitation events following the irrigation. This situation probably resulted in nutrient leaching, lower water uptake resulting in the redistribution of energy allocation within the plant leading to higher vegetative growth at the expense of reproductive growth in humid climates (Letey and Dinar, 1986; Wanjura et al., 2002; Feng et al., 2014). This is understandable as cotton was initially perennial and abiotic stress can trigger more vegetative growth. This also coincided with boll formation and developmental stages in July and August (Fig. 1b). Another study conducted in the MS Delta demonstrated that the growth and development of individual cotton plants would be reduced to some degree under deficit irrigation, and fiber and seed composition affected accordingly (Bellaloui et al., 2015).

The fiber quality parameters, both HVI and AFIS, were significantly impacted by irrigation rates (FI, HI, and RF), and only micronaire and nep count were influenced by planting geometry (SR and TR). For some parameters like UHML, reflectance, yellowness, VFM, and maturity ratio, the year-wise response appears to be inconsistent owing to the variations in GDD, precipitation, and solar radiation, particularly during the months of July-September that coincides with boll development and maturation. In this study, micronaire was 11% higher in 2018 and 12% higher in 2019 than the average of HI and FI treatments. The acceptable level of micronaire was between 3.5 and 4.9%. The best level of micronaire range from 3.7 to 4.2% and the quality goes down when it is > 4.9 or < 3.5. It varied from 3.95 to 4.91 in this study. Similar results were reported by Dagdelen et al. (2009), Feng et al. (2014), and Zhang et al. (2016). TR geometry recorded up to 6% higher micronaire while nep count was lower in TR planting geometry, with some degree of inconsistency. These observations are like the findings of Reddy et al. (2009), Stephenson et al. (2011), and Feng et al. (2014). Stephenson et al. (2011) showed that the micronaire, strength, and reflectance were higher, and nep count and seed coat nep count were lower for 38-cm twin rows than for 102-cm solid rows based on a two-year study conducted in Louisiana. During fiber developmental stages in the cotton plant, many factors, including weather conditions, nutrient and water stresses, defoliant application time, and cultivar, can impact micronaire (Hake et al., 1990). Overall, planting geometry differences were not found for length, uniformity, yellowness, trash by HVI or for upper quartile length, short fiber content, fineness, immature fiber content, or maturity ratio by AFIS, with some inconsistency between years. Fiber length and uniformity were higher in HI and FI over RF, while fineness and maturity ratio were higher in RF treatment, which agrees with Feng et al. (2014), Dagdelen et al. 2009, and Pettigrew (2004). Irrigated cotton had higher SFC than the RF treatments, contrary to the observations of Sui et al. (2017), who used a cotton picker for sampling vis a vis hand picking in the current study. This can be explained by irrigation and precipitation during boll development maturation drives the plant towards the vegetative phase, resulting in a lower deposition of cellulose in the developing fibers. This is further vindicated by the inverse relationship of irrigation with the maturity ratio in this study. Similar results were reported earlier (Wanjura et al., 2002; Dağdelen et al., 2009; Feng et al., 2014). The reduced fiber strength in this study under rainfed condition confirms earlier observations of the involvement of carbohydrate and energy metabolisms in fiber development and carbon skeletons for the synthesis of cell wall polysaccharides and fatty acids (Yang et al., 2008). Moisture stress impacts negatively the formation of the actin cytoskeleton that triggers the secondary cell wall synthesis, a key component in determining the fiber strength (Wang et al., 2010).

The cottonseed and its products have a high demand from the dairy and food-related industries. It has previously been documented to be affected by variety, planting date, and irrigation (Pettigrew and Dowd, 2012). In this study, protein accumulation was negatively affected by irrigation, while it had a significant positive impact on seed oil content. Seed fiber is not impacted by irrigation. All three seed composition traits studied here were not influenced by PG (SR and TR). However, most often, protein and oil accumulation are genotype-dependent. These observations confirm with those of Pettigrew and Dowd (2012) and Bellaloui and Turley (2013).

Conclusion

The results from this study demonstrate that (i) environmental conditions such as precipitation and solar radiation during boll development and cracking heavily impact fiber quality and seed composition. (ii) Among irrigation and planting geometry, irrigation had a more significant effect on fiber quality and seed composition. (iii) Irrigation may not always result in better fiber quality with desirable seed composition. (iv) It appears irrigation had an inverse relationship with protein accumulation while it had a limited positive effect on oil content. Irrigation did not affect seed fiber content. Overall, both the fiber quality and seed composition parameters are profoundly impacted by the irrigation than PG at critical stages of boll development and seed maturation.

Abbreviations

HVI: High Volume Instrument; AFIS: Advanced Fiber Information System; FI: Full irrigation; HI: Half irrigation; RF: Rainfed; UHML: Upper Half Mean Length; UQL:Upper Q

Declarations

Acknowledgements

I would like to acknowledge the support of the USDA-AMS at Dumas, AR for HVI analysis and Fiber and Biopolymer Research Institute, Texas Tech University, Lubbock, TX for AFIS analysis.

Authors’ contributions

Pinnamaneni collected most of the data, data analysis and manuscript preparation. Anapalli, Sui and Reddy contributed to designing the experiment and manuscript editing. Nacer performed seed composition analysis. The author(s) read and approved the final manuscript.

Funding

Funding was made available through the USDA-ARS internal project No: 6066-13000-005-00D

Availability of data and materials

Review of data is available and there are no competing interests. All data presented within is the corresponding authors' data and is available upon request.

Ethics approval and consent to participate: N/A

Consent for publication

All Authors have provided ethical approval and consent to participate as well as consent for publication.

Competing interests: None of the authors have any competing interests within the scope of this experiment and its publication.

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Figures

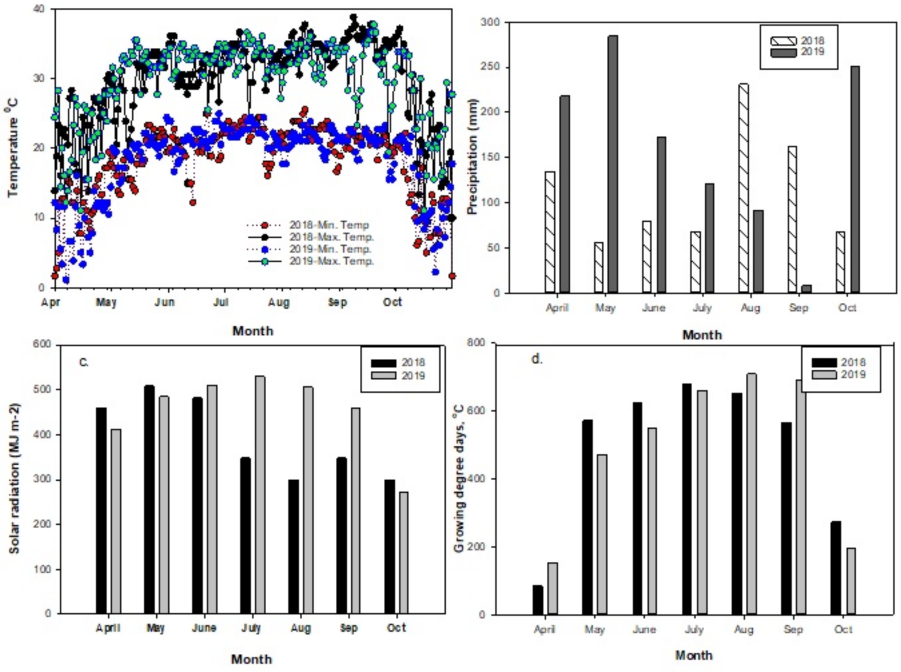

Figure 1

Measured (a) air temperature, (b) precipitation, (c) solar radiation, and (d) growing degree days (GDD) for 2018 and 2019 cotton growing seasons at Stoneville, MS.

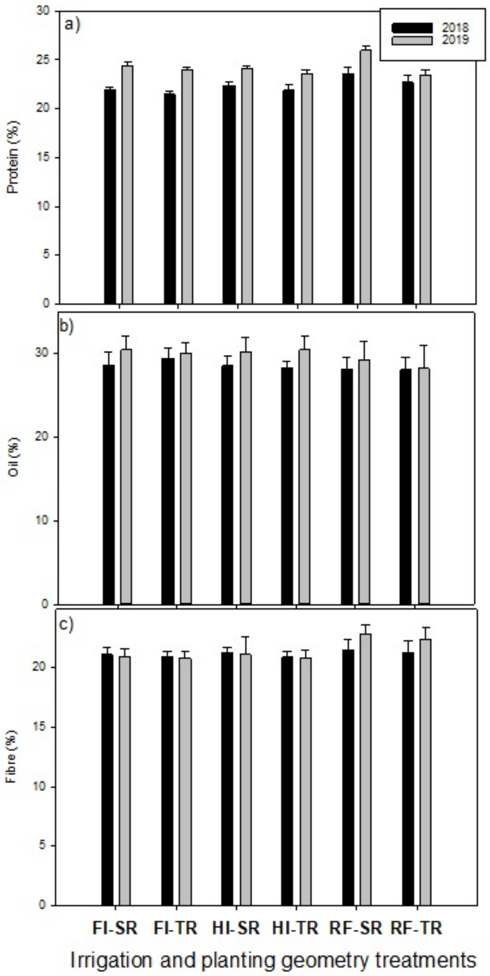

Figure 2

Effect of irrigation and planting geometry on seed composition traits in 2018 and 2019 seasons a) protein b) oil c) fiber. FI: full irrigation, HI: half irrigation, RF: rainfed; SR: Single-row and TR: twin-row