WATER USE, YIELD AND FIBER QUALITY RESPONSE OF SIX UPLAND COTTON CULTIVARS TO IRRIGATION

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Abstract

Cotton (*Gossypium* spp.) cultivars that can use water more efficiently and sustain yield and fiber quality under water stress in thermally limited environments is essential for sustainable cotton production in the North Texas High Plains. A field study examined the lint yield, yield component, and fiber quality response of six early to medium maturity upland cotton (*G. hirsutum* L.) cultivars to four irrigation rates during two growing seasons. Crop water use was estimated using soil water balance in conjunction with measurements of root zone soil water, precipitation, and irrigation depths. Hand-harvested seed cotton was ginned to determine lint yield and fiber quality using standard procedures. Profile water use and rooting depth did not vary with cultivar. In both years, cultivar significantly influenced lint yield. In 2016, irrigation did not significantly increase lint yield because of slow accumulation of thermal energy during the growing season that delayed maturity. In 2018, irrigation significantly increased lint yield for all cultivars. Fiber quality was significantly influenced by cultivar. Irrigation level also significantly influenced most fiber quality properties, with micronaire and fiber length exhibiting the greatest response to irrigation. Lint yields exceeding 1500 lbs. acre^{-1} were attainable at full irrigation, although accumulation of the required thermal energy is likely inadequate in most growing seasons in this environment. Both the selection of a suitable cultivar and the management of irrigation level to match accumulated thermal energy are necessary to optimize water productivity in this region.

Introduction

The declining saturated thickness of the Ogallala Aquifer and associated reductions in well capacities has increased production risks for producers in the North Texas High Plains, especially for crops that are sensitive to water deficits such as maize (*Zea mays* L.). Cotton is a profitable crop that is suitable for production in the North Texas High Plains with reduced water consumption compared with other crops (Howell et al., 2004). This region of Texas, however, is in a thermal environment that is marginal for cotton with heat unit accumulations of 1800 – 2000 ºF and 2000 – 2200 ºF in 3 out of 4 years for the more northerly and southerly counties, respectively (Esparza et al., 2007). Although irrigation at deficit levels can reduce lint yield, it can also speed maturity (Pettigrew, 2004) that can partly explain for greater lint yields under moderate deficit irrigation during growing seasons with limited heat unit accumulation (Howell et al., 2004). Interaction between cultivar maturity and thermal environment also influences the yield potential. In these thermally limited short season environments, a shift of boll production to higher nodes typical of later maturity cultivars can reduce lint yield and fiber quality (Snowden et al., 2013). Irrigation level can significantly influence fiber quality with micronaire showing variable response to irrigation depending on the growing season (Snowden et al., 2013) and fiber length increasing with increasing irrigation (Pettigrew, 2004). These past studies have demonstrated that cultivars respond differently to irrigation and environment (Ulloa et al., 2019) and emphasized that optimizing cotton yield and quality in thermally limited environments will require a proper cultivar choice in conjunction with a suitable level of irrigation. The objectives of this study were to examine the lint yield, yield component, and fiber quality response of six early to medium maturity upland cotton (*G. hirsutum* L.) cultivars to four irrigation levels at the Conservation and Production Research Laboratory in Bushland, TX.

Materials and Methods

A study was initiated in 2014 to examine the effect of irrigation level on lint yield and quality of six commercial upland cotton cultivars with early to medium maturity ratings. The experimental field was at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX (35° 11.42' N, 102° 5.30' W, 3840 m asl) on Pullman clay loam (Fine, mixed, superactive, thermic Torrertic Paleustoll) with < 1% slope. Field plots were irrigated using a subsurface drip system consisting of eight zones each 793 ft. long × 33 ft. (12 rows) wide. Driplines (Typhoon 990, Netafim Ltd., Tel Aviv, Israel) were spaced 5 ft. apart at a depth of 11 – 12 inches and centered between alternate 30-inch crop rows with a 12 inch spacing between emitters (0.22 gallons h^{-1} at 10 psi). Each zone was furnished with a control valve to regulate downstream pressure to 10 psi and a flow meter to quantify the volume of each irrigation application. Experimental plots (80 ft. long × 15 ft. (6 rows) wide) were arranged within a split plot design with four irrigation levels on main plots and six cultivars randomized within subplots and four replications per treatment. Each irrigation zone consisted of two main plots, each 240 ft. long × 33 ft. wide (3 × 2 replicate plots) so that blocking controlled for the distance of the dripline from the control valve as well as the zone.

Upland cotton cultivars (Table 1) were sown in 2014, 2015, 2016, and 2018 in a north-south row orientation with a 6-row vacuum seeder at a rate of 62,000 seed $acre^{-1}$ and a row spacing of 30 inches. Because of heavy rainfall, hail, soil crusting, and poor plant emergence in 2014 and 2015, a successful stand was established only in 2016 (05/26 planting) and 2018 (05/21 planting) cropping seasons. Spring oats (*Avena sativa*, L.) was seeded in 2017 and terminated with glyphosate prior to inflorescence.

Imposed irrigation treatments were based on a 100% irrigation level that maintained plant available water within the rooting zone (0 – 4.6 ft.) at or above 50 percent of plant available water at field capacity. The 66% and 33% irrigation rates were achieved by omitting one and two, respectively, of every three irrigations applied at the 100% level. The dryland treatment was not irrigated except as necessary to establish the crop. Prior to cutout, applied irrigation depths were nominally 1 inch whereas after cutout, irrigation depths were restricted between 0.5 – 0.8 inches but were applied more frequently. In 2016, an irrigation of 1.54 inches was applied to all treatments 20 days after planting to assist with stand establishment. In 2018, an irrigation of 4.69 inches was applied to all treatments 2 days after planting for a 70-h period to wet the seed zone and guarantee germination.

Weeds were controlled using one application of incorporated trifluralin prior to seeding, a pre-plant application of paraquat dichloride (only in 2016), and a pre-emergent application of S-metolachlor. Weeds were also controlled during the growing season with glyphosate and by hand hoeing. Extractable nutrients determined in soil samples collected in the spring prior to planting were used to determine nitrogen and phosphorus fertilizer application rates. All of the required P and 27 lbs N $acre^{-1}$ liquid fertilizer was injected with a knife applicator prior to planting and the remaining nitrogen was applied as UAN by fertigation through the dripline between first square and first flower.

Solar irradiance, wind speed, air temperature and relative humidity were measured at a weather station in an adjacent field planted to a small grain crop. Precipitation was measured with a tipping bucket rain gage at the edge of the cotton field. Reference evapotranspiration (ETo) was calculated from monitored variables using the ASCE standardized reference evapotranspiration equation for a short reference crop at a 1-h time step (Allen et al., 2005). Growing degree days were evaluated using a 60°F base temperature and no upper temperature threshold using Method 1 of McMaster and Wilhelm (1997). Neutron moisture gages (model 503DR, InstroTek, Inc., Raleigh, NC) were used to determine soil water contents from 0.1- to 2.3-m depth in 0.2-m increments at 6 to 14-day intervals for 33 selected experimental plots throughout the growing season. Three replicates of each of the following treatments were monitored with the neutron probe: DP1212 B2RF or DP1216 B2RF at the 33%, 66%, and 100% irrigation levels; FM2011 GT at the 33%, 66%, and 100% irrigation levels, FM2484 B2F at the 33%, 66%, and 100% irrigation levels; and PHY333 WRF at the 33% and 100% irrigation levels. The neutron probe was previously calibrated using methods described by Evett and Steiner (1995) with separate linear calibrations for the A, Bt, and Btk horizons. Stored soil water within the rooting zone of the plots monitored at the 100% irrigation level in addition to reference ETo were used to plan irrigations throughout the growing season.

Seed cotton was picked by hand in 2 m (6.56 ft.) × 2 inner plot rows within each plot replicate with one of the rows centered on the neutron probe access tube for replicates where water contents were monitored. Measurements included plant density and the number of opened and unopened (green) bolls. Bolls that were cracked yet seed lint was not accessible by hand picking were considered unopened. Harvest aids were not used in the study. Seed lint cotton was ginned on a 20-saw gin (Compass Systems Model TT 520, Carmel, IN) at the USDA-ARS Plant Stress and Germplasm Development Research Laboratory in Lubbock. Fiber quality analysis of the lint was evaluated using the High Volume Instrument (HVI) classification at the Fiber and Biopolymer Research Institute at Texas Tech University, Lubbock, TX.

Table 1. Cultivars evaluated in the study and associated maturity ratings. [1]

Cultivar	Maturity
Deltapine DP1212 B2RF (2016)*	Early
Deltapine DP1219 B2RF(2016)*	Medium
FiberMax FM2011 GT	Early
FiberMax FM2484 B2F	Medium
Stoneville ST4747 GLB2	Early-Medium
PhytoGen PHY333 WRF	Early
Deltapine DP1216 B2RF (2018)*	Early
Deltapine DP1820 B2RF (2018)*	Early-Medium

*In 2018, DP1212 B2RF and DP1219 B2RF were replaced by DP1216 B2RF and DP1820 B2RF, respectively, because of seed unavailability.

A two-way analysis of variance for the main effects of irrigation and cultivar was evaluated using the MIXED procedure in SAS 9.4 (SAS Institute, 2014) for a split-plot design. Mean separation and determination of least significant differences were evaluated using the Tukey adjustment or Tukey–Kramer adjustment for unbalanced designs. Interactions were also evaluated using contrasts of simple effects with the slice procedure in SAS. Effects were declared significant at the $\alpha = 0.05$ probability level and each year was evaluated separately.

Results and Discussion

Cumulative growing degree days and reference evapotranspiration (ETo) at harvest were similar in 2016 and 2018 (Figure 1), however the rate at which they accumulated during the growing season varied remarkably between years. In 2016, accumulation of growing degree days prior to first square were delayed because of cool weather. Consequently, plant emergence was not complete until 22 days after planting and first square, first white flower, and cutout were delayed compared with the 2018 growing season (Figure 1). Conditions just prior to and during cutout in 2016 consisted of cool daytime temperatures and 6 inches rainfall that further delayed cutout, especially for the medium maturity cultivars that continued to set bolls. Heat units accumulated more rapidly in September and October of 2016 compared with 2018. Beginning on 5 October, 2018, 6.85 inches of precipitation that was received during a three week period interfered with harvest except for the dryland plots which were harvested on 2-3 October. Most or all of the rain in October had been received prior to the harvest of the remaining plots. Seasonal irrigation amounts and water use varied considerably with year (Table 2) with greater water requirements in 2018 because the period of high crop water requirements coincided with high ETo (Figure 1). In both years in plots monitored for water contents, crop water use did not vary among cultivars ($P>0.05$). Likewise, rooting depth, based on the maximum depth of water extraction evaluated using neutron probe measurements, was not influenced by cultivar or irrigation level ($P>0.05$). However, rooting depth in 2016 was approximately 8 to 16 inches deeper compared with 2018 likely because of greater initial water contents deeper in the profile in 2016.

Irrigation and cultivar effects on lint yield and boll load varied strongly with respect to the growing season. In 2016, there was no significant response of lint yield to irrigation ($P=0.717$; Table 3) yet there was a strong cultivar effect ($P=0.001$) with early maturing cultivars DP1212 B2RF and FM2011 GT exhibiting significantly ($P\leq0.002$) greater yields compared with medium maturity cultivars (Figure 2). Contrasts of simple effects showed that the lint yield of the reported medium maturity cultivar DP1219 B2RF declined with increasing irrigation (Figure 2). In 2018, all cultivars responded strongly to irrigation ($P<0.001$). Cultivar effect on yield was significant only at the irrigation rates of 66% ($P=0.007$) and 100% ($P<0.001$). At the 100% irrigation level, mean lint yields of the early-medium and early cultivars ST4747 GLB2, DP1216 B2RF, and FM2011 GT were significantly greater ($P\leq0.039$) than the medium maturity cultivar FM2484 B2F. Open bolls tended to mimic lint yield results of each study year with a consistently significant cultivar effect ($P<0.001$) on boll number. The number of open bolls did not respond to irrigation in 2016 (P=0.929), although unopened and total bolls increased with increasing irrigation level (P<0.001 and P=0.002, respectively). These results in conjunction with the weather data suggest that there was inadequate thermal energy accumulation for boll maturation at the higher irrigation levels during 2016. In 2018, open, unopened, and total boll numbers significantly increased with increasing irrigation level (Table 3). Unopened bolls in 2018 comprised a small fraction of total bolls, however there was considerable square and fruit shedding observed under the dryland and 33% irrigation treatments that reduced the total boll numbers (Table 3 and Figure 2). Boll size was assessed by the grams of lint per boll (Table 3) was significantly influenced by cultivar in both years. Notably, the cultivar FM2011 GT exhibited a significantly greater boll size (P≤0.040) across irrigation rates compared to all other cultivars in both years. In 2016, boll size did not respond to irrigation level (P=0.183) whereas in 2018, an increase in boll size only occurred with increasing irrigation level from dryland to 33% (Table 3). In this respect, the number of open bolls was the predominant yield component contributing to lint yield over a range of crop water use levels.

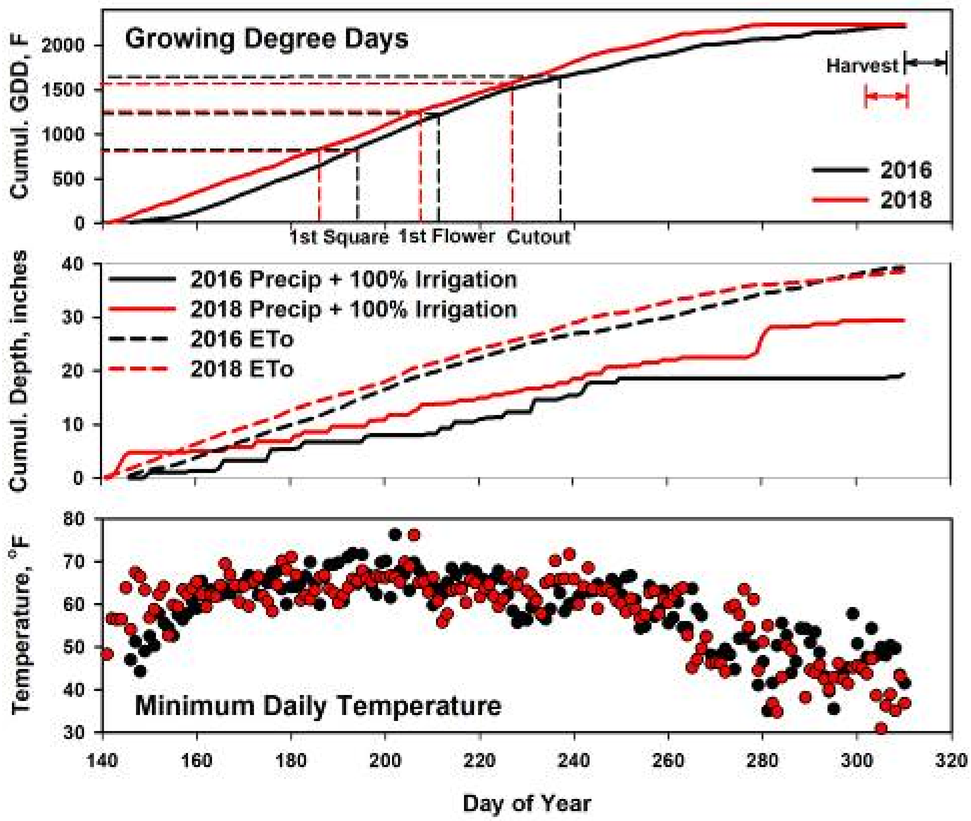

Figure 1. Environmental conditions and cumulative irrigation and precipitation depths during the two study years.

Table 2. Components of the crop water balance for each irrigation level pooled across cultivars. Change in stored soil water (Δ Storage) is mean stored soil water at harvest less stored soil water at planting for each irrigation level. Change in stored soil water under dryland was assumed equivalent to the 33% irrigation level. Runoff was approximated for a 2.5 inch rainfall event in 2016.

Year	Irrigation Level	Precipitation	Irrigation	Δ Storage	Runoff	Water Use
	¤	------------------------depth, inches------------------------				
2016	Dryland	10.08	1.54	-2.92	-1.38	13.16
	33%	10.08	4.63	-2.92	-1.38	16.25
	66%	10.08	6.68	-3.33	-1.38	18.71
	100%	10.08	8.79	-3.01	-1.38	20.50
2018	Dryland	6.34	4.69	-2.74	0.00	13.77
	33%	6.34	9.22	-2.74	0.00	18.29
	66%	6.34	12.76	-2.05	0.00	21.15
	100%	6.34	16.63	-2.10	0.00	25.07

Table 3. Mean lint yield, boll numbers, and boll size by irrigation level and pooled across cultivars for 2016 and 2018. Analysis of variance (ANOVA) results show the level of probability for main effects and the interaction. Means comparisons are based on the Tukey or Tukey- Kramer adjusted confidence limits.

Year	Irrigation Level	Plant Density	Lint Yield	Open Bolls	Unopen Bolls	Total Bolls	Boll Size
		plants ft^{-2}	lb $acre^{-1}$	bolls ft^{-1}	bolls ft^{-1}	bolls ft^{-1}	g lint $boll^{-1}$
2016	Dryland	1.01	974	4.92	2.74 a*	7.63 a	2.08
	33%	1.09	1015	4.81	3.67 ab	8.49 ab	2.19
	66%	0.99	955	4.72	4.57 bc	9.30 b	2.12
	100%	1.09	917	4.58	4.86 c	9.46 b	2.04
ANOVA			----------------------- *P > F* ------------------------				
Block			0.445	0.322	0.078	0.489	0.218
Irrigation			0.717	0.929	0.001	0.017	0.183
Cultivar			<0.001	<0.001	<0.001	<0.001	<0.001
Irrigation×Cultivar			0.137	0.017	0.271	0.084	0.211
2018	Dryland	1.05	557 a	2.70 a	0.10 a	2.80 a	2.14 a
	33%	1.03	890 b	3.77 b	0.28 a	4.11 b	2.49 b
	66%	0.99	1136 c	4.89 c	0.58 b	5.55 c	2.45 b
	100%	1.05	1572 d	6.59 d	0.89 c	7.56 d	2.51 b
ANOVA			----------------------- *P > F* ------------------------				
Block			0.098	0.033	0.382	0.039	0.205
Irrigation			<0.001	<0.001	<0.001	<0.001	<0.001
Cultivar			<0.001	<0.001	<0.001	<0.001	<0.001
Irrigation×Cultivar			0.023	<0.001	<0.001	<0.001	0.403

*Means followed by the same letter do not differ significantly at the 0.05 level of probability.

Both irrigation level and cultivar significantly influenced the majority of fiber quality properties in both years of the study (Table 4). Micronaire response to irrigation differed strongly with year with lower micronaire in 2016 (≤4.5 units) compared with 2018 (≥4.2 units). Low micronaire in 2016 is likely a result of the presence of immature fibers. Fiber length significantly increased with irrigation in 2016 for all cultivars except for DP1219 B2RF and FM2011 GT (Figure 3). In this year, medium maturity cultivars exhibited significantly greater (P<0.001) fiber lengths compared with medium-early and early cultivars across all irrigation rates. In 2018, fiber length significantly increased with irrigation except for the PHY333 WRF cultivar. As in 2016, medium-early to medium maturity cultivars tended to exhibit greater fiber lengths compared with the early maturing cultivars (Figure 3), however in this year the cultivar effect depended on irrigation level (Table 4). Fiber length uniformity was significantly influenced by irrigation level and cultivar in both study years. In 2016, there was a small but significant increase in length uniformity with increasing irrigation up to the 66% level. In this year, ST4747 GLB2 had a significantly lower length uniformity compared with most other cultivars across irrigation rates. Length uniformity also significantly increased with increasing irrigation level for all cultivars in 2018. Differences in length uniformity exhibited by each of the cultivars narrowed with increasing irrigation (Figure 3). Fiber strength was dominated by significant cultivar effects with the ST4747 GLB2 cultivar exhibiting a lower strength across all irrigation levels compared to all others in both years. In 2018, fiber strength significantly increased with increasing irrigation level. Fiber elongation was also dominated by significant cultivar effects with DP1212 and DP1216 exhibiting significantly greater elongation percentages across irrigation rates compared with all other cultivars in 2016 and 2018. The effect of irrigation on fiber elongation was inconsistent with respect to the growing season, decreasing with increasing irrigation in 2016 and increasing with increasing irrigation in 2018.

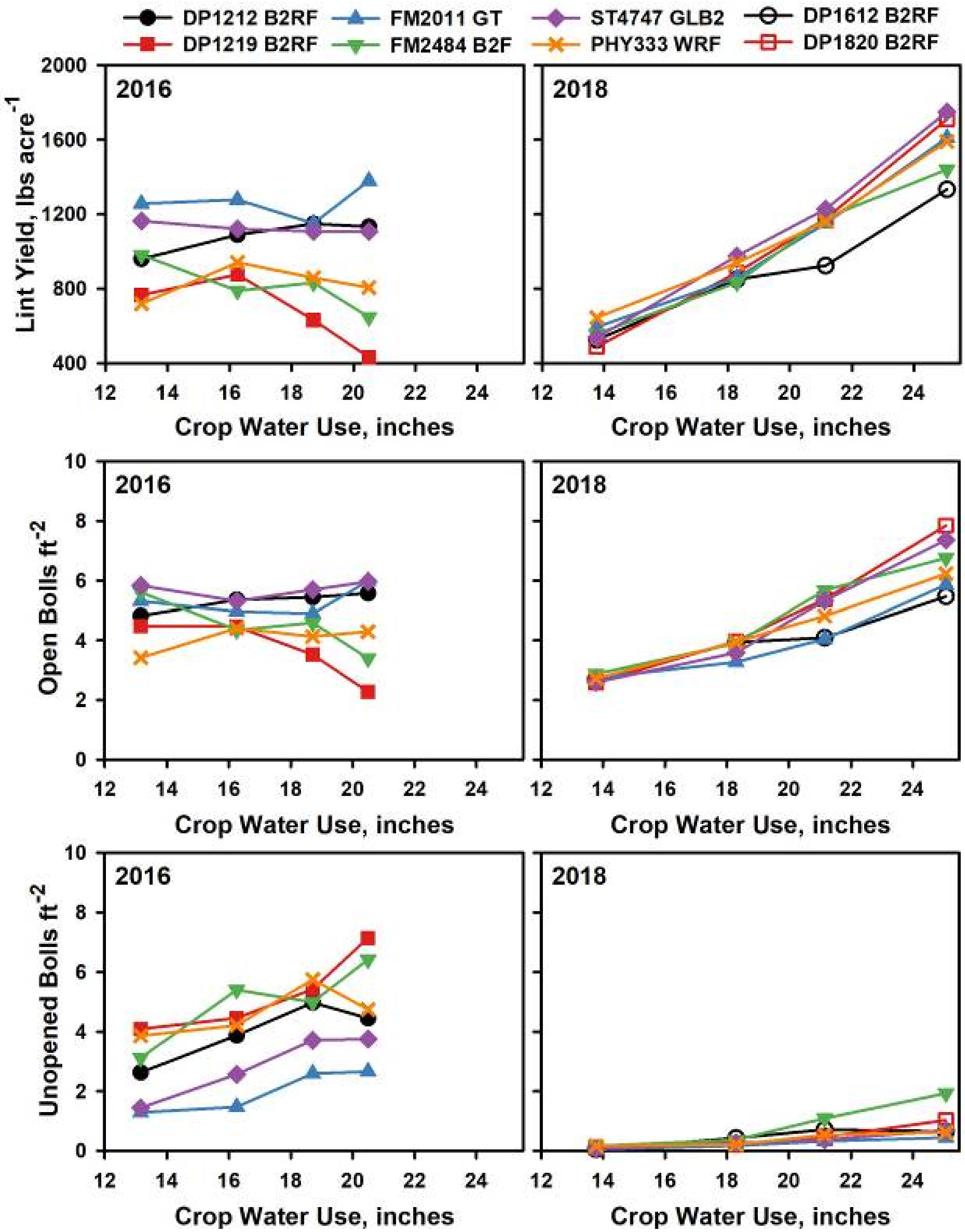

Figure 2. Response of lint yield, open bolls, and unopened bolls to mean crop water use in 2016 and 2018.

Table 4. Mean fiber quality parameters by irrigation level and pooled across cultivar for 2016 and 2018. Analysis of variance (ANOVA) results show the level of probability for main effects and the interaction. Means comparisons are based on the Tukey or Tukey-Kramer adjusted confidence limits.

Year	Irrigation Level	Micronaire	Length	Uniformity	Strength	Elongation
		units	inches	%	g/tex	%
2016	Dryland	4.02 ab	1.18 a	83.27 a	30.81	6.91 a
	33%	4.05 b	1.19 ab	83.46 a	30.90	6.85 a
	66%	3.77 ac	1.21 b	84.25 b	31.10	6.81 ab
	100%	3.54 c	1.21 b	83.62 a	30.52	6.48 b
ANOVA		-----------------------		*P* > *F*	-----------------------	
Block		0.042	0.457	0.289	0.938	0.221
Irrigation		<0.001	0.011	0.007	0.082	0.020
Cultivar		<0.001	<0.001	<0.001	<0.001	<0.001
Irrigation×Cultivar		0.101	0.860	0.654	0.618	0.484
2018	Dryland	4.41 a	1.06 a	80.73 a	28.42 a	6.55 a
	33%	4.69 b	1.07 ab	81.70 ab	29.49 ab	6.63 ab
	66%	4.81 b	1.08 b	82.07 bc	30.19 b	6.87 bc
	100%	4.65 b	1.12 c	83.40 c	30.65 b	7.00 c
ANOVA		-------------------------		*P* > *F*	--------------------------	
Block		0.654	0.315	0.401	0.280	0.060
Irrigation		0.001	<0.001	0.001	0.008	0.004
Cultivar		<0.001	<0.001	<0.001	<0.001	<0.001
Irrigation×Cultivar		0.405	0.002	0.059	0.158	0.147

*Means followed by the same letter do not differ significantly at the 0.05 level of probability.

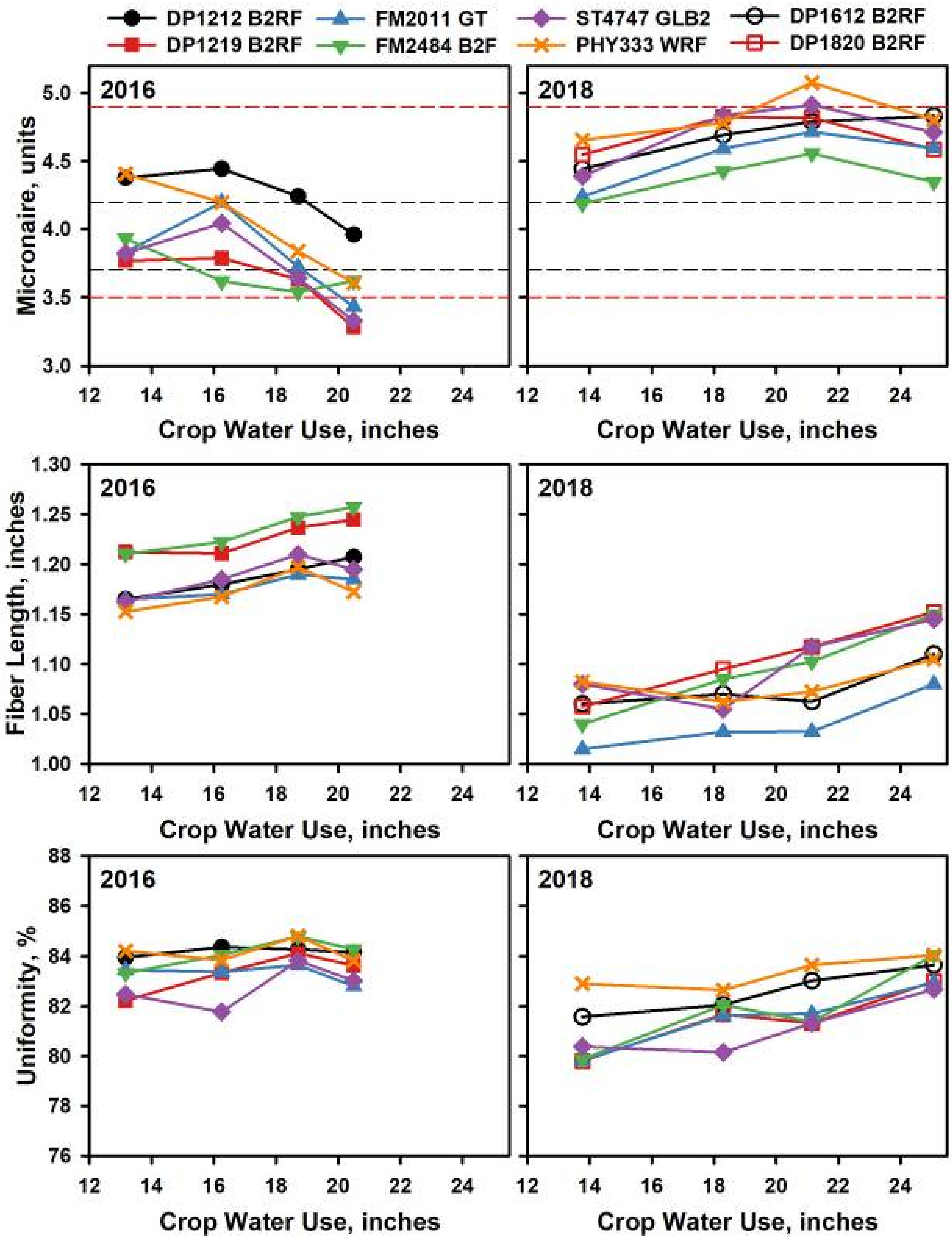

Figure 3. Response of selected fiber quality parameters to mean crop water use in 2016 and 2018.

Summary

The results of this study suggest that available thermal energy, precipitation, and irrigation induced differences in physiological growth patterns that ultimately influenced lint yield and fiber quality of cultivars. Compared with mean lint yield across cultivars under the 100% irrigation level in 2016, lint yield in 2018 was 71% greater despite both years having similar heat unit accumulations. In 2016, heat unit accumulation was slower during the vegetative and early reproductive stages of development thereby delaying maturity. In addition, cool weather and rainfall just prior to cutout in 2016 likely contributed to delayed maturity and a greater boll accumulation compared with 2018. As a consequence, lint yield and open bolls were not significantly influenced by irrigation in 2016. Cultivar significantly influenced lint yield and all yield components in both years of the study. Seasonal water use and inferred rooting depth were similar among the cultivars in both years. Early and early-medium maturity cultivars exhibited the greatest lint yields compared with the medium maturity cultivars. In 2018, however, cultivar effect on lint yield was only important at the higher irrigation rates. Heat unit accumulation required to achieve the high yields associated with medium maturity cultivars likely occurs infrequently in the North Texas High Plains.

Fiber quality was strongly influenced by cultivar in both study years. Irrigation level also significantly influenced most fiber quality properties in both study years, with micronaire and fiber length exhibiting the greatest response to irrigation. Micronaire declined with increasing irrigation in 2016 whereas in 2018 micronaire increased with increasing irrigation. The negative response and low micronaire in 2016 is likely due to the presence of immature fibers which increased at greater irrigation levels. Fiber length usually exhibited a significant increase in length with increasing irrigation in both study years, however, this response was absent or less pronounced in some cultivars.

In general, irrigation increased lint yield and improved most fiber quality properties of the six commercial upland cotton cultivars examined in this study. Lint yields exceeding 1500 lbs. acre^{-1} are attainable at full irrigation in this environment, although accumulation of the required thermal energy during the growing season to support this yield will usually be lacking. Because both irrigation and cultivar were responsible for delayed maturity during crop growth stages with limited thermal energy, it may be possible to manage irrigation as well as cultivar selection to match accumulated thermal energy and thereby increase crop water productivity.

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[1]The use of trade, firm, or corporation names in this article is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the United States Department of Agriculture or the Agricultural Research Service of any product or service to the exclusion of others that may be suitable.

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