Genetic Variation for Yield and Fiber Quality Response to Supplemental Irrigation within the Pee Dee Upland Cotton Germplasm Collection

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ABSTRACT

Water availability is a major factor influencing cotton cultivar performance and sustainable cotton (*Gossypium hirsutum* L.) production in the southeastern USA. An increased understanding of the response of diverse cotton germplasm lines to supplemental irrigation could aid in future efforts to develop cultivars targeted to irrigated or dryland environments. In this study, 13 germplasm lines were selected from the Pee Dee (PD) germplasm collection and evaluated to measure the effect of supplemental irrigation on a number of agronomic and fiber quality traits important to cotton production systems. Most PD germplasm lines receiving supplemental irrigation had increased plant height and lint percent, while boll weight, seed index, fiber length, fiber strength, uniformity index, and micronaire decreased. Cultivars PD-2 and FM-966 did not show a significant response to supplemental irrigation for any of the traits measured. In contrast, PD5377 and PD93009 showed differential responses to supplemental irrigation for 5 out of the 12 traits measured. This study shows the importance of comparing individual genotype response to supplemental irrigation for agronomic and fiber quality traits to efficiently target genotypes for irrigated or dryland environments.

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Abbreviations: HVI, high-volume instrumentation; PD, Pee Dee.

The development of Upland cotton (*Gossypium hirsutum* L.) cultivars with improved lint yield potential, fiber quality potential, and regional adaptation is required for sustainable cotton production (Campbell and Jones, 2005). Within southeastern USA cotton production areas, a number of environmental variations, such as water availability, obstruct efforts to optimize cotton production systems and develop improved cultivars. Water availability has been identified as one of the major limiting factors impeding sustainable cotton production in the southeastern USA (Dumka et al., 2004). The importance of water availability is amplified because of endemic, intermittent drought events occurring in the region as a result of shallow, coarse-textured soils and irregular rainfall patterns. To minimize the deleterious effects of intermittent drought, cotton production systems frequently use irrigation to supplement rainfall (Camp et al., 1997; Pringle and Martin, 2003; Dumka et al., 2004; Pettigrew, 2004).

An important factor to consider in cotton production systems that use irrigation is the cultivar response to supplemental water. Overall, the effect of supplemental irrigation on cotton lint yield appears to vary according to the degree of water deficit present, with supplemental irrigation increasing lint yields in studies with greater water deficits (Bednarz et al., 2003; Pringle and Martin, 2003; Pettigrew, 2004). Pettigrew (2004) suggested studying the effects of supplemental irrigation and water deficits on yield component traits to provide better insight into the overall effect that supplemental irrigation has on the development of yield. In a study designed to measure the effects of water deficit on yield and yield components on eight cultivars in the Mississippi Delta,

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Table 1. Pedigree of genotypes evaluated in field trials over 2004 and 2005 in Florence, SC.

Genotype	Pedigree	Registration
AC241	Hybrid313/C6-5	Culp and Harrell, 1980
PD-1	PD4381/PD8623	Culp et al., 1985a
PD-2	FTA266/ATLAS// AC239/DIXIEKING	Culp et al., 1985b
PD-3	PD9363/PD9240	Culp et al., 1988
PD0259	TripHy108, 171, AHA6-1-4, Earli-staple, Sealand542, C6-5	Harrell and Culp, 1979
PD0878	TX-ORS-75C/Deltapine7146N	Culp et al., 1990
PD0948	TX-ORS-75C/PD875	Culp et al., 1990
PD5377	Delcott311/PD6171	Green et al., 1991b
PD5576	Deltapine41/PD3246	Green et al., 1991a
PD695	LAfrego2/2*PD8562	Culp, 1979
PD93009	PD5286/PD5485	May and Howle, 1997
PD94042	JIMIAN8/PD3	May, 1999
SC-1	Coker421/PD4398	Culp and Harrell, 1979
ST-474	Check	
FM-966	Check	

Pettigrew (2004) concluded that cultivars produced additional bolls at higher nodes and distal fruiting positions in response to supplemental irrigation. Hence, a great number of bolls per unit area resulted in increased lint yield. Previous studies measuring the effect of supplemental irrigation on fiber quality parameters are limited and generally indicate inconsistent results (Camp et al., 1997; Bradow and Davidonis, 2000; Pettigrew, 2004). In a study conducted in the southeastern USA, Bauer and Frederick (2005) documented that water deficit effects on fiber quality parameters differ depending on the timing of water stress during the flowering period.

Genetic variability for yield and fiber quality response to supplemental irrigation could allow cotton breeders to select specific genotypes in an effort to develop cultivars adapted to water-limited and/or water-sufficient growing environments. In two previous studies, Cook and El-Zik (1993) found no genotypic response differences for lint yield among six multiadversity resistance cultivars evaluated in Texas, while Pettigrew (2004) found no genotypic response differences for lint yield, yield components, and fiber quality parameters among eight cultivars evaluated in Mississippi. However, both of these studies tested the genotype × irrigation interaction only, which tests the overall difference among genotypes for trait response to irrigation. Preplanned tests between the irrigated and dryland mean values for a given genotype were not done.

The PD germplasm enhancement program is recognized as an important source of improved germplasm lines that have been used by cultivar development programs throughout the USA, primarily as a key source of fiber quality genes (Meredith, 1991; Bowman and Gutierrez, 2003). It is probable that extensive genetic variability exists within the PD germplasm collection, because the germplasm base was developed using a complex series of crosses and intercrosses involving race stocks, *G. barbadense* L., and the triple hybrid [(*G. arboreum* L. × *G. thurberi* Tod.) × *G. hirsutum* L.]. The objective of the current study was to measure the effect of supplemental irrigation on a number of agronomic and fiber quality traits important to cotton production systems among 13 PD germplasm lines. Because these PD germplasm lines were developed, selected, and tested under the highly variable, intermittent drought conditions present in testing locations in South Carolina, our hypothesis is that variability exists for germplasm line response to supplemental irrigation for yield, yield components, and fiber quality parameters.

MATERIALS AND METHODS

Plant Materials and Field Trials

Thirteen germplasm lines were selected from the USDA-ARS PD cotton germplasm collection for use in this study. These germplasm lines were selected based on diverse parentage to provide an indication of genetic variability for genotype response to supplemental irrigation within the PD germplasm collection. Two commercial cultivars, Fibermax 966 (FM-966) and Stoneville 474 (ST-474), were included to provide a comparison to modern cultivars. The 15 genotypes were evaluated at Florence, SC, in 2004 and 2005. Pedigrees and references for each of the 13 PD germplasm lines are provided in Table 1. PD0259 was excluded in the 2004 trial due to poor seed viability and germination.

The experimental design used in each of the two trials was a split-plot design with four replications and treatments assigned in a randomized complete block arrangement. The main plot factor, irrigation regime (irrigated, dryland), was assigned at random to each replication and then the split-plot factor and genotypes were randomly assigned within each main plot within each replication. Each genotype was grown in a two-row plot 10.7 m long with 96.5 cm spacing between rows. The trial was planted with a cone research planter on 7 May in 2004 and 13 May in 2005 and thinned to 10 plants m^{-1} following stand establishment. Fertilization, weed control, insect control, and defoliation measures were managed following established local practices.

Supplemental irrigation was applied using a surface drip irrigation system calibrated to apply water at a rate of 25.4 mm h^{-1}. A drip line was placed adjacent to plants on the inside of each of the two rows for the 15 split plots within an irrigation main plot. Four-row borders of cultivar PD-3 were planted between the main plot factors in each replication to limit the amount of irrigation overflow. Supplemental irrigation was applied beginning at the week of first flower and continuing through the seventh week of flowering, following the cotton irrigation schedule developed by the North Carolina Cooperative Extension Service (Edmisten et al., 1994). Natural rainfall amounts were recorded on a daily basis and supplemental irrigation applied considering the weekly recommended amount minus the amount of rainfall (Table 2).

A total of seven agronomic and five fiber quality traits were measured for each plot. Agronomic traits included plant height, seed cotton yield, lint percent, lint yield, boll weight, seed index, and bolls m^{-2}. Plant height was measured for each plot based on the average height of plants within a plot. Before harvest, 50 bolls were randomly harvested by hand from each plot to determine yield components, lint percent, and fiber quality properties. Each plot was subsequently harvested using a two-row mechanical spindle picker, and total seed cotton was weighed using an electronic, on-board weigh system. Plots were harvested on 12 October in 2004 and 1 November in 2005.

Seed cotton yield values were collected directly from the on-board weigh system and converted to kg ha^{-1} for each plot. The 50-boll sample was weighed before being ginned on a 10-saw laboratory gin used to separate fuzzy seeds from lint. The lint sample after ginning was weighed to determine lint percent by dividing the weight of the lint sample by the weight of the sample before ginning. Lint yield was calculated by multiplying seed cotton yield by lint percent/100 for each plot. Boll weight was determined by dividing the weight of the 50-boll sample before ginning by 50, and the seed index was calculated by weighing 100 fuzzy seeds after ginning. Bolls m^{-2} was calculated for each plot by dividing seed cotton yield by boll weight. A portion of the lint sample after ginning was sent to Cotton Incorporated (Cary, NC) to determine fiber quality traits using high-volume instrumentation (HVI) analyses. The fiber quality traits measured included fiber length, strength, elongation, uniformity index, and micronaire.

Statistical Analyses

Data for each trait were analyzed for normality by PROC UNIVARIATE (SAS Institute, 2002). An analysis of variance was conducted for each environment by PROC GLM coupled with the RANDOM statement to test significant differences among treatments, genotypes, and genotype × treatment interactions (SAS Institute, 2002). Replication was considered a random effect, while irrigation and genotypes were considered fixed effects. Homogeneity of variance tests were conducted to determine if data from 2004 and 2005 could be pooled. For the combined analysis of variance, year and replication within year were considered random effects, while irrigation and genotypes were considered fixed effects. To evaluate the response of individual genotypes to supplemental irrigation in each individual environment and combined across environments, the LSMEAN statement followed by PDIFF was used to test differences between all possible combinations of the least square means for each genotype. A significant difference among the irrigated and dryland least square means for an individual genotype indicated the genotype displayed a significant response to supplemental irrigation.

Table 2. Summary of weekly water amounts and weekly mean high and low temperatures (T) during the 7-wk flowering interval in 2004 and 2005.

Flowering interval		Rainfall	Irrigation	Total water	Suggested water	Mean high T	Mean low T
Week	Date	mm	mm	mm	mm	°C	°C
			2004				
1	June 27–July 3	64.26	0	64.26	38.10	30.6	20.9
2	July 4–10	15.75	27.43	43.18	38.10	35.0	22.1
3	July 11–17	22.35	42.67	65.02	63.50	33.5	21.3
4	July 18–24	30.99	57.91	88.90	63.50	32.6	20.1
5	July 25–31	71.37	42.67	114.04	63.50	32.8	21.7
6	Aug. 1–7	109.22	0	109.22	50.80	32.4	20.5
7	Aug. 8–14	88.39	0	88.39	50.80	29.8	17.8
Total		402.33	170.68	573.01	368.30		
			2005				
1	July 3–9	35.60	0	35.60	38.10	33.3	22.2
2	July 10–16	6.30	6.10	12.40	38.10	32.3	22.7
3	July 17–23	8.40	25.40	33.80	63.50	34.6	22.9
4	July 24–30	67.10	38.10	105.20	63.50	35.1	22.8
5	July 31–Aug. 6	57.70	0	57.70	63.50	30.9	21.3
6	Aug. 7–13	66.80	0	66.80	50.80	32.6	22.1
7	Aug. 14–20	52.60	0	52.60	50.80	33.4	23.4
Total		294.50	69.60	364.10	368.30		

RESULTS AND DISCUSSION

Analysis of Variance

A summary of individual analysis of variance in 2004 and 2005 is provided in Tables 3 and 4. Significant irrigation differences were identified in 2004 for seed cotton yield, plant height, lint yield, boll weight, seed index, bolls m^{-2}, fiber strength, fiber elongation, and micronaire; while in 2005 significant irrigation differences were identified only for seed index and micronaire. Irrigation differences were more prevalent in 2004 due to greater differences in total water amount between the dryland and irrigated treatments during the 7-wk flowering period as compared to 2005 (Table 2). Significant genotypic differences among the PD germplasm lines were identified in 2004 for all traits except plant height, uniformity index, and micronaire; while in 2005 PD germplasm lines differed for all traits except seed cotton yield, lint yield, boll weight, bolls m^{-2}, and uniformity index. PD line × irrigation interactions were detected for fiber length and uniformity index in 2004 but not in 2005. No other PD line × irrigation interactions were significant at $P < 0.05$. These results indicate that variation exists among the PD germplasm lines for their response to supplemental irrigation for fiber length and uniformity index. The irrigated and dryland mean values for the PD germplasm lines in 2004 show that supplemental irrigation decreased fiber length and uniformity index overall. However, comparing the irrigated and dryland mean values for individual PD germplasm lines in 2004 shows that PD-3, PD5377,

Table 3. Summary of the analysis of variance and mean values of seven agronomic traits for cotton genotypes grown under dryland (Dry) and irrigated (Irr) conditions at Florence, SC, in 2004 and 2005.

	Seed cotton yield kg ha^{-1}		Plant height cm		Lint percent %		Lint yield kg ha^{-1}		Boll weight g		Seed index g		Bolls m^{-2}	
	P > F		*P > F*		*P > F*		*P > F*		*P > F*		*P > F*		*P > F*	
Source	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Irrigation (I)	0.01**	0.83	0.01**	0.67	0.08	0.37	0.01**	0.90	0.00**	0.08	0.00**	0.00**	0.00**	0.89
Genotype (G)	0.05*	0.39	0.01**	0.00**	0.00**	0.00**	0.00**	0.04*	0.00**	0.62	0.00**	0.00**	0.01**	0.42
PD line (L)	0.02*	0.20	0.26	0.01**	0.00**	0.00**	0.00**	0.13	0.01**	0.69	0.01**	0.00**	0.01**	0.22
Check (C)	0.62	0.31	0.70	0.06	0.03*	0.03*	0.41	0.20	0.16	0.50	0.23	0.05*	0.34	0.21
L vs. C	0.44	0.67	0.01**	0.00**	0.00**	0.00**	0.20	0.29	0.90	0.43	0.39	0.33	0.48	0.83
G × I	0.82	0.72	0.29	0.75	0.77	0.77	0.80	0.68	0.56	0.44	0.06	0.94	0.73	0.78
L × I	0.87	0.72	0.21	0.62	0.63	0.63	0.83	0.68	0.61	0.45	0.07	0.96	0.90	0.71
C × I	0.35	0.84	0.34	0.81	0.88	0.88	0.35	0.76	0.20	0.29	0.16	0.80	0.15	0.79
L vs. C × I	0.26	0.19	0.95	0.99	0.94	0.94	0.30	0.20	0.36	0.30	0.22	0.19	0.17	0.38
Mean PD line (Dry)	2627	2686	89.6	97.9	41.4	39.6	1092	1066	6.10	5.31	11.09	10.56	43.1	50.9
Mean PD line (Irr)	2835	2563	104.4	99.7	41.9	39.6	1189	1019	5.75	5.17	10.24	10.10	49.4	49.3
Mean check (Dry)	2898	2613	84.4	91.0	44.7	43.4	1295	1135	6.04	5.35	10.74	10.07	48.2	49.2
Mean check (Irr)	2859	2846	99.4	92.7	45.1	43.7	1293	1243	5.84	5.46	10.17	9.95	49.5	52.2

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

Table 4. Summary of the analysis of variance of five fiber quality traits for cotton genotypes grown under dryland (Dry) and irrigated (Irr) conditions at Florence, SC, in 2004 and 2005.

	Fiber length mm		Fiber strength kN m kg^{-1}		Fiber elongation %		Uniformity index %		Micronaire units	
	P > F		*P > F*		*P > F*		*P > F*		*P > F*	
Source	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Irrigation (I)	0.46	0.40	0.02*	0.08	0.02*	0.72	0.27	0.77	0.03*	0.01**
Genotype (G)	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.07	0.00**	0.00**
PD line (L)	0.04*	0.01**	0.00**	0.00**	0.00**	0.01**	0.11	0.06	0.06	0.00**
Check (C)	0.03*	0.26	0.02*	0.04*	0.04*	0.06	0.28	0.10	0.18	0.03*
L vs. C	0.17	0.12	0.05*	0.70	0.64	0.61	0.00**	0.20	0.07	0.04*
G × I	0.02*	0.61	0.96	0.54	0.59	0.39	0.09	0.84	0.20	0.66
L × I	0.02*	0.64	0.91	0.49	0.75	0.61	0.05*	0.74	0.22	0.53
C × I	0.80	0.29	0.70	0.54	0.41	0.51	0.58	0.88	0.13	0.89
L vs. C × I	0.15	0.28	0.93	0.33	0.08	0.03*	0.99	0.70	0.44	0.59
Mean PD line (Dry)	28.9	28.9	295	291	5.20	4.93	83.4	82.7	4.8	4.6
Mean PD line (Irr)	28.6	28.9	285	286	5.59	4.92	83.1	82.8	4.5	4.5
Mean check (Dry)	27.6	28.2	299	291	5.65	4.95	84.3	83.0	5.3	5.1
Mean check (Irr)	27.9	27.8	288	289	5.49	4.55	84.0	82.9	4.9	4.9

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

and PD93009 responded to supplemental irrigation with decreased fiber length, while PD0878 responded with increased fiber length. Similarly, PD0878 responded to supplemental irrigation with decreased uniformity index, and PD5576 responded with increased uniformity index.

Homogeneity of variance tests indicated homogeneous error variance for each trait in 2004 and 2005 and allowed for a pooled analysis of variance. Table 5 provides the combined analysis of variance for agronomic traits, and Table 6 provides the combined analysis of variance for fiber quality traits. Overall, irrigation differences were present for lint percent only, while year × irrigation effects were significant for plant height, boll weight, seed index, fiber elongation, and micronaire. Irrigation differences were minimized in the combined analysis due to smaller differences in total water amount between the dryland and irrigated treatments during the 7-wk flowering period in 2005 (Table 2). Genotypic differences among PD germplasm lines were identified for all of the traits measured except plant height, boll weight, and fiber elongation; while a significant PD line × year interaction was identified for fiber elongation (Tables 5 and 6). Hence, genetic variation exists among the PD germplasm

Table 5. Combined analysis of variance of seven agronomic traits for cotton genotypes grown under dryland (Dry) and irrigated (Irr) conditions at Florence, SC, in 2004 and 2005.

		Seed cotton yield kg ha^{-1}	Plant height cm	Lint %	Lint yield kg ha^{-1}	Boll weight g	Seed index g	Bolls m^{-2}
Source	df	MS	MS	MS	MS	MS	MS	MS
Year (Y)	1	946819	240.3	210.8*	63035	24.95*	7.84	601.3
Rep (Y)	6	1966775	764.1	2.3	265301	0.34*	0.11	420.0
Irrigation (I)	1	123446	3912.2	7.9*	52731	2.67	23.8	290.8
Y × I	1	882656	2457.9*	0.0	140555	0.60**	1.70**	573.3
I × Rep (Y)	6	1705200**	274.8**	2.0	312074**	0.03	0.17	582.2**
Genotype (G)	14	494234**	301.1*	54.1**	183660**	0.13	2.83**	155.2*
PD Line (L)	12	531149**	240.8	29.1**	153607**	0.31	2.54**	150.6*
Check (C)	1	105181	325.1	31.5	88353*	1.80	6.94	283.9
L vs. C	1	389681	962.8	382.7*	629034	0.18	2.51	64.6
Y × G	13	73147	99.1	1.6	17663	1.19	0.21	48.8
Y × L	11	85983	97.9	1.5	20860	0.16	0.24	52.7
Y × C	1	1810	171.1	0.3	142.8	0.42	0.07	36.3
Y × L vs. C	1	3284	48.0	3.1	12.4	0.18	0.04	18.3
Rep (Y) × G	81	252164	62.9	1.2	43297	0.17	0.23	73.6
Rep (Y) × L	6	1358467**	40.0	1.7	42565	0.26	0.19	72.9
Rep (Y) × C	69	260865*	66.4	1.3	44346	0.16	0.25	75.1
Rep (Y) × L vs. C	6	165756	45.6	0.2	31956	0.17	0.07	57.4
G × I	14	99284	52.6	0.8	17162	0.13	0.18	22.0
L × I	12	104047	58.0	0.9	17473	0.12	0.12	23.6
C × I	1	118539	40.5	0.1	26434	0.01	0.30	24.9
L vs. C × I	1	22834	0.0	0.0	4399	0.26	0.87	0.1
Pooled error	94	181944	59.5	1.0	32952	0.13	0.30	67.5
CV		16	7.9	2.5	16	6.46	5.21	16.9
Mean PD line (Dry)		2670	93.8	40.21	1076	5.68	10.88	47.4
Mean PD line (Irr)		2700	101.7	40.60	1099	5.45	10.19	49.5
Mean check (Dry)		2755	87.7	44.09	1215	5.70	10.41	48.7
Mean check (Irr)		2852	96.1	44.41	1268	5.65	10.06	50.9

*Significant at the 95% probability level.

**Significant at the 99% probability level.

lines for the majority of traits measured except plant height, boll weight, and fiber elongation. PD germplasm lines performed similarly across years for all of the traits measured except fiber elongation.

A direct comparison of the PD germplasm lines vs. the check cultivars (PD line vs. check) identified significant differences for lint percent, fiber length, and micronaire (Tables 5 and 6). On average, PD germplasm lines produced lower lint percent and micronaire than the two check cultivars, while producing longer fibers. No PD line × irrigation interactions were significant for any of the traits measured; however, the (PD line vs. check) × irrigation interaction was significant for fiber elongation. Interestingly, the PD germplasm lines responded to supplemental irrigation with increased fiber elongation (0.20), while the check cultivars responded to supplemental irrigation with decreased fiber elongation (–0.28). Perhaps this finding illustrates a higher level of adaptation for the PD germplasm lines, since their development was likely subject to environmental conditions similar to those present in the current study.

Individual PD Germplasm Line Analyses

Estimating and testing the trait variation among PD germplasm lines and their interactions with irrigation offer a basis for assessing the potential of exploiting genotype differences for response to supplemental irrigation. However, it is also useful to evaluate individual PD germplasm lines for their response to supplemental irrigation. Table 7 shows a summary of the results of *t* tests comparing irrigated and dryland least square means for the PD germplasm lines in 2004, 2005, and combined over 2004 and 2005. Based on the combined data, 6 PD germplasm lines showed a significant response to supplemental irrigation for plant height, 3 for lint percent, 6 for boll weight, 11 for seed index, 2 for fiber length, 3 for fiber strength,

Table 6. Combined analysis of variance of five fiber quality traits evaluating using high-volume instrumentation for cotton genotypes grown under dryland (Dry) and irrigated (Irr) conditions at Florence, SC, in 2004 and 2005.

Source	df	Fiber length mm	Fiber strength kN m kg^{-1}	Fiber elongation %	Uniformity index %	Micronaire units
		MS	MS	MS	MS	MS
Year (Y)	1	0.019	1.70	15.54	19.9	0.29
Rep (Y)	6	0.005	7.65*	0.74*	1.0	0.23*
Irrigation (I)	1	0.006	38.49	1.20	1.2	1.71
Y × I	1	0.000	2.22	1.58**	1.7	0.39*
I × Rep (Y)	6	0.007	1.76	0.11	1.0	0.05
Genotype (G)	14	0.058**	24.66**	4.05*	3.7**	0.71**
PD line (L)	12	0.036**	12.36**	1.07	3.6**	0.27**
Check (C)	1	0.136	195.00	43.94	0.0	1.40
L vs. C	1	0.248*	1.50	0.00	9.1	5.34*
Y × G	13	0.007	1.65*	1.48**	0.9	0.07
Y × L	11	0.006	1.53	0.93**	0.7	0.06
Y × C	1	0.025**	4.35*	8.30**	1.6	0.26*
Y × L vs. C	1	0.001	0.29	0.79	2.9	0.01
Rep (Y) × G	81	0.007	0.92	0.26	0.7	0.04
Rep (Y) × L	6	0.005	1.77	0.44	0.4	0.14
Rep (Y) × C	69	0.004	0.89	0.26	0.8	0.04
Rep (Y) × L vs. C	6	0.001	0.41	0.12	0.3	0.04
G × I	14	0.006	0.80	0.28	1.0	0.05
L × I	12	0.007	0.86	0.19	1.2	0.05
C × I	1	0.003	0.50	0.02	0.2	0.05
L vs. C × I	1	0.000	0.25	1.67**	0.0	0.03
Pooled error	94	0.005	1.10	0.20	0.7	0.04
CV		2.371	1.03	8.75	3.5	4.35
Mean PD line (Dry)		28.4	294	5.02	83.0	4.68
Mean PD line (Irr)		28.8	286	5.22	82.9	4.52
Mean check (Dry)		27.9	295	5.30	83.7	5.16
Mean check (Irr)		27.9	289	5.02	83.5	4.93

*Significant at the 95% probability level.

**Significant at the 99% probability level.

3 for uniformity index, and 5 for micronaire. These PD germplasm lines responded to supplemental irrigation with increased plant height and lint percent, while boll weight, seed index, fiber length, fiber strength, and micronaire were decreased (Figs. 1 and 2). For uniformity index, PD-1 and PD94042 responded to supplemental irrigation with a lower uniformity index, while PD5576 responded with an increase in uniformity index. None of the PD germplasm lines showed a response to supplemental irrigation for seed cotton yield, lint yield, bolls m^{-2}, and fiber elongation. ST-474 showed a response to supplemental irrigation for seed index and micronaire, while FM-966 did not show a response for any of the traits measured. The only PD germplasm line combined over both years not showing a response to supplemental irrigation for any of the traits measured was PD-2.

CONCLUSIONS

Considering the agronomic traits measured in this study, significant ($P < 0.05$) irrigation differences were detected in 2004 and followed the same trend in 2005, but were not significant at $P < 0.05$. Overall, supplemental water increased seed cotton yield, plant height, lint percent, lint yield, and bolls m^{-2}; while boll weight and seed index were decreased. In terms of the yield component traits, these results correspond to those reported by Pettigrew (2004), indicating the number of bolls per unit area increase in response to supplemental irrigation, resulting in higher overall yield. At the same time, boll weight and seed index decreased in response to the increased number of bolls produced. In 2004, irrigation resulted in differences ($P < 0.05$) for fiber strength, fiber elongation, and micronaire. Irrigation differences followed the same trend in 2005, but significant differences ($P < 0.05$) were detected only for micronaire.

The results of this experiment indicate that significant variation exists among the 13 PD germplasm lines evaluated for seed cotton yield, lint percent, lint yield, seed index, bolls m^{-2}, micronaire, fiber length, fiber strength, and fiber uniformity. Significant differences among the PD germplasm lines were detected under dryland and irrigated conditions separately for all of the above traits, with the exception of seed cotton yield and lint yield differences detected under irrigated conditions only (data not shown). When examining the genotype × irrigation interaction and considering all genotypes combined, significant differences among the genotypes for their response to supplemental irrigation could not be detected for any of the traits measured using the combined data set. These results are consistent with the conclusions of previous studies by Pettigrew (2004) and Cook and El-Zik (1993). However, we were able to detect significant genotype responses to supplemental irrigation for many of the traits measured in this study by testing for differences between irrigated and dryland least square means for each genotype. Based on the comparison of the combined least square mean values, 6 PD germplasm lines showed a response to supplemental irrigation for plant height, 3 for lint percent, 6 for boll weight, 11 for seed index, 2 for fiber length, 3 for fiber strength, 3 for uniformity index, and 5 for micronaire.

The response to supplemental irrigation of these PD germplasm lines resulted in increased plant height and lint percent, while resulting in decreased boll weight, seed index, fiber length, fiber strength, and micronaire (Figs. 1 and 2). The absence of a significant genotypic response to supplemental irrigation for lint yield is likely the consequence of selection for yield stability under the episodic drought conditions present in the southeastern USA during the development of these genotypes or the failure to produce sufficient water deficit under natural conditions in 2004 and 2005. Interestingly, PD-2 and FM-966 did not show a significant response to supplemental irrigation for any of the traits measured, based on our comparison. This finding indicates that PD-2 and FM-966 may contain genes that provide increased stability to differential water availability, or it could indicate that these lines are simply not responsive to supplemental irrigation. In contrast, based on

Table 7. Comparison of irrigated and dryland least square mean values for plant height (PHT), seed cotton yield (SYLD), lint percent (LP), lint yield (LYLD), boll weight (BWT), seed index (SDI), bolls m^{-2} (BMSQ), fiber length (FL), fiber strength (FS), fiber elongation (FE), uniformity index (UI), and micronaire (MIC) involving 15 cotton genotypes evaluated in Florence, SC, from 2004 to 2005. Traits with significant differences (*P* < 0.05) among least square mean values for each line are given.

Genotype	Year 2004	2005	Combined
AC241	PHT, SDI	–	PHT, SDI
PD-1	BWT, SDI, MIC	MIC	BWT, SDI, UI, MIC
PD-2	PHT, FL	LP	–
PD-3	SDI, BMSQ	SYLD, LP	LP, BWT, SDI
PD0259†	–	MIC	–
PD0878	PHT, SYLD, LYLD, SDI, BMSQ, FL, UI, MIC	PHT	PHT, SDI, MIC
PD0948	PHT, BWT, BMSQ, MIC	LP, SDI	PHT, LP, SDI, MIC
PD5377	PHT, BWT, SDI, FL, FS, FE, MIC	–	BWT, SDI, FL, FS, MIC
PD5576	PHT, BWT, SDI, UI	–	BWT, SDI, UI
PD695	PHT, FS	BWT, SDI, FS	PHT, BWT, SDI, FS
PD93009	PHT, LP, BWT, SDI, FL	FS	PHT, LP, BWT, SDI, FL
PD94042	PHT, SDI	FS	PHT, SDI, UI
SC-1	PHT, SDI	FS	FS
ST-474	PHT, BWT, SDI, MIC	–	SDI, MIC
FM966	PHT	–	–

†PD0259 was not evaluated in 2004 due to poor seed viability.

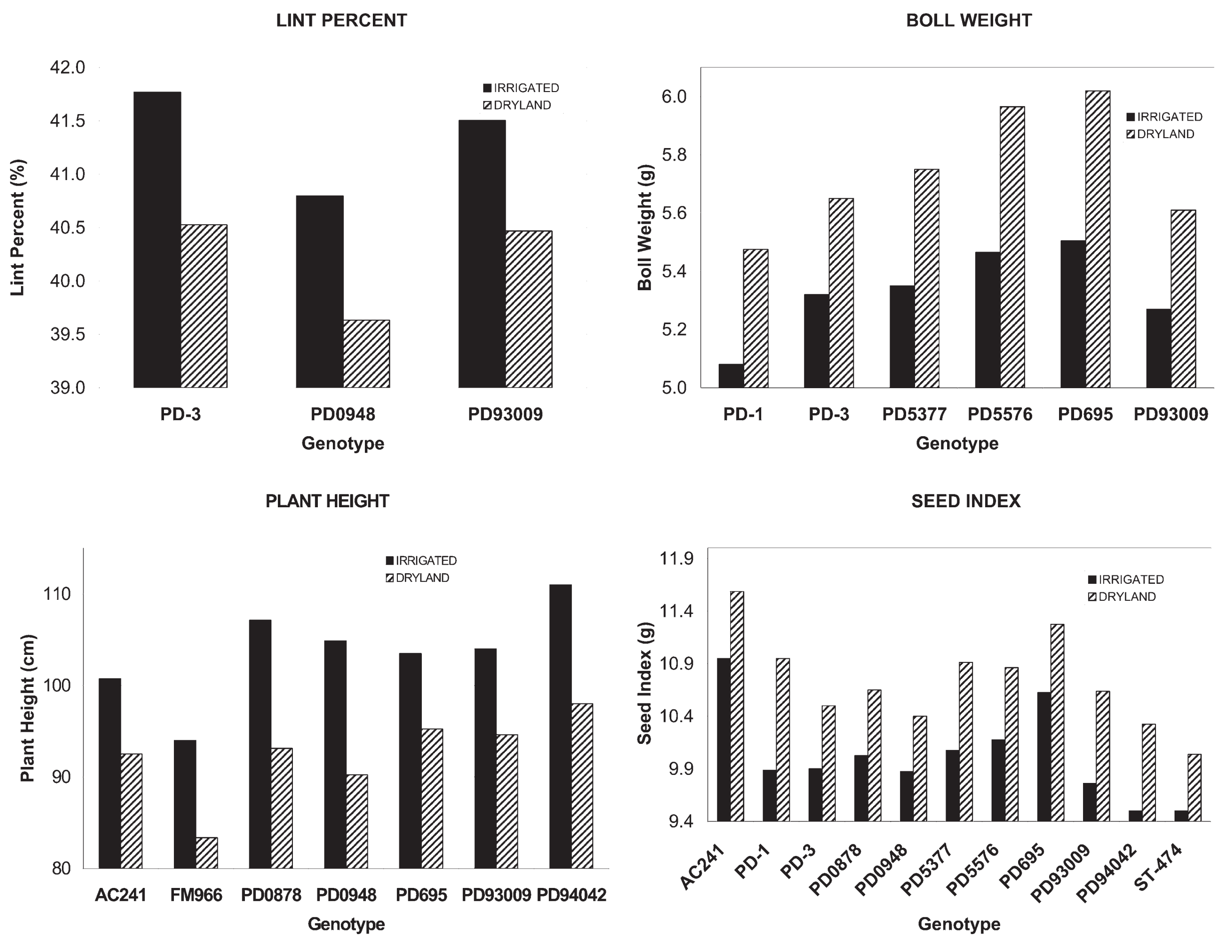

Figure 1. Irrigated and nonirrigated least square means for genotypes with a significant (*P* < 0.05) response to supplemental irrigation for lint percent, plant height, boll weight, and seed index.

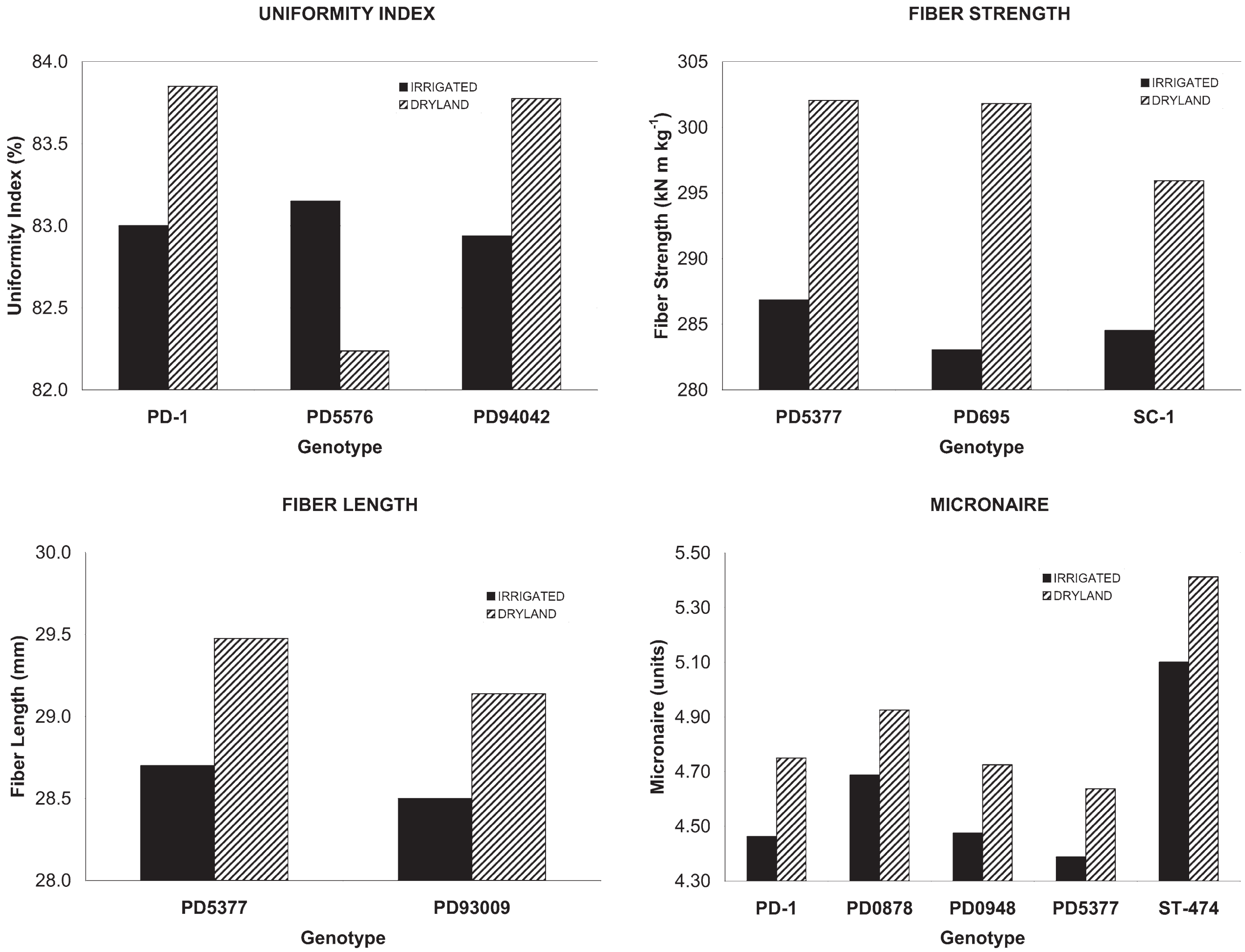

Figure 2. Irrigated and nonirrigated least square means for genotypes with a significant ($P < 0.05$) response to supplemental irrigation for uniformity index, fiber length, fiber strength, and micronaire.

the comparison of combined least square mean values, PD5377 and PD93009 showed differential responses to supplemental irrigation for 5 out of the 12 traits measured. This finding indicates that PD5377 and PD93009 may contain genes with expression sensitivity to differential water availability. Overall, this research highlights the importance of understanding specific genotype responses to differential water availability so that specific genotypes can be selected as parental lines to develop cultivars targeted to irrigated and/or nonirrigated environments. Perhaps PD-2 and FM-966 may be desirable parental lines in crosses designed to develop cultivars with stability to differential water availability. Future research should address the physiological mechanisms associated with the dissimilar PD germplasm line response to supplemental irrigation for yield and fiber quality traits.

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References

Bauer, P.J., and J.R. Frederick. 2005. Tillage effects on canopy position specific cotton fiber properties on two soils. Crop Sci. 45:698–703.

Bednarz, C.W., J. Hook, R. Yager, S. Cromer, D. Cook, and I. Griner. 2003. Cotton crop water use and irrigation scheduling. *In* A.S. Culpepper (ed.) 2002 Cotton Research-Extension Report. UGA/CPES Research-Extension Publication No. 4.

Bowman, D.T., and O.A. Gutierrez. 2003. Sources of fiber strength in the U.S. upland cotton crop from 1980–2000. J. Cotton Sci. 7:164–169.

Bradow, J.M., and G.H. Davidonis. 2000. Quantitation of fiber quality and the cotton production-processing interface: A physiologist's perspective. J. Cotton Sci. 4:34–64.

Camp, C.R., P.J. Bauer, and P.G. Hunt. 1997. Subsurface drip irrigation lateral spacing and management for cotton in the southeastern coastal plain. Trans. ASAE 40:993–999.

Campbell, B.T., and M.A. Jones. 2005. Assessment of genotype × environment interactions for yield and fiber quality in cotton performance trials. Euphytica 144:69–78.

Cook, C.G., and K.M. El-Zik. 1993. Fruiting and lint yield of cotton cultivars under irrigated and nonirrigated conditions. Field Crops Res. 33:411–421.

Culp, T.W. 1979. Registration of Pee Dee 695 and Pee Dee 875 germplasm lines of cotton. Crop Sci. 19:751.

Culp, T.W., C.C. Green, and B.U. Kittrell. 1990. Registration of five cotton germplasm lines with resistance to bollworm, tobacco budworm, and boll weevil. Crop Sci. 30:235–236.

Culp, T.W., and D.C. Harrell. 1979. Registration of SC-1 cotton. Crop Sci. 19:410.

Culp, T.W., and D.C. Harrell. 1980. Registration of medium staple cotton germplasm. Crop Sci. 20:290.

Culp, T.W., R.F. Moore, L.H. Harvey, and J.B. Pitner. 1988. Registration of 'PD-3' cotton. Crop Sci. 28:190.

Culp, T.W., R.F. Moore, and J.B. Pitner. 1985a. Registration of PD-1 cotton. Crop Sci. 25:198.

Culp, T.W., R.F. Moore, and J.B. Pitner. 1985b. Registration of PD-2 cotton. Crop Sci. 25:198–199.

Dumka, D., C.W. Bednarz, and B.W. Maw. 2004. Delayed initiation of fruiting as a mechanism of improved drought avoidance in cotton. Crop Sci. 44:528–534.

Edmisten, K., J. Crawford, and M. Bader. 1994. Drought management for cotton production [Online]. Available at www.ces.ncsu.edu/disaster/drought/dro-17.html; verified 3 Aug. 2006. North Carolina Cooperative Extension Service.

Green, C.C., T.W. Culp, and B.U. Kittrell. 1991a. Registration of four germplasm lines of upland cotton with early maturity and high fiber quality. Crop Sci. 31:854.

Green, C.C., T.W. Culp, and B.U. Kittrell. 1991b. Registration of five germplasm lines of upland cotton with high yield potential and fiber quality. Crop Sci. 31:854–855.

Harrell, D.C., and T.W. Culp. 1979. Registration of Pee Dee 0259 and Pee Dee 2165 germplasm lines of cotton. Crop Sci. 19:418.

May, O.L. 1999. Registration of PD 94042 germplasm line of upland cotton with high yield and fiber maturity. Crop Sci. 39:597–598.

May, O.L., and D.S. Howle. 1997. Registration of six germplasm lines of upland cotton: PD 93009, PD 93019, PD 93021, PD 93030, PD 93034, and PD 93057. Crop Sci. 37:1030–1031.

Meredith, W.R. 1991. Contributions of introductions to cotton improvement. p. 127–146. *In* H.L. Shands and L.E. Weisner (ed.) Use of plant introductions in cultivar improvement: Part 1. CSSA, Madison, WI.

Pettigrew, W.T. 2004. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96:377–383.

Pringle, H.C., and S.W. Martin. 2003. Cotton yield response and economic implications to in-row subsoil tillage and sprinkler irrigation. J. Cotton Sci. 7:185–193.

SAS Institute. 2002. The SAS system for windows, release 9.1. SAS Institute, Cary, NC.