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Cotton Genotype Response to Early-Season Cold Temperatures

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ABSTRACT

Identifying cotton (*Gossypium hirsutum* L.) genotypes that are less sensitive to cool temperatures may improve productivity in areas where late-spring cold fronts are common. Our objectives were to compare commercially available genotypes for relative cold tolerance and to determine whether seedling growth response to cool temperature in a controlled environment was a valid predictor of field performance. Four genotypes, 'DPL 20' (early maturity), 'DPL 50' (mid), 'DPL 5690' (late), and 'DPL Acala 90' (late), were studied. Cotyledon area, root and shoot length, and root and shoot fresh weight were measured after 4-d-old seedlings were exposed to temperatures of 15, 20, 25, and 30°C for 6 d. The four genotypes were also evaluated in the field in 1991 and 1992 by planting in mid-April, early-May, and mid-May near Florence, SC. Root length was the only seedling trait for which the temperature response was genotype dependent. Root length of DPL 5690 and DPL Acala 90 was the same at all assay temperatures (mean = 4.3 cm). For DPL 20, root length was 9.3 cm at 15 and 20°C, 11.8 cm at 25°C, and 14.3 cm at 30°C. DPL 50 root length was 8.7 cm at 30°C and averaged 6.4 cm at the other three temperature treatments. In the field, when DPL 20 emerged faster than the two late-maturity genotypes at planting dates that were followed by cold temperatures, it had lower lint yield. The results suggest that measuring the amount of seedling root length inhibition (rather than relative growth differences) caused by suboptimal temperatures may be useful for determining cold sensitivity in cotton.

COTTON is a cold-sensitive crop species of tropical origin that is commercially produced in many temperate regions. Cold temperature stress can decrease plant productivity and grower returns, especially in the northern areas of the U.S. Cotton Belt. One of the most damaging effects of cold temperature stress is to reduce cotton stands (Gipson, 1986). Since cotton seedling growth ceases at temperatures of <16°C (Munro, 1987), production guides frequently recommend monitoring soil temperature and weather forecasts to determine when to plant to ensure adequate stands.

Nonfreezing cold stress that occurs during the germination process can also adversely impact growth and development of surviving plants (Christiansen and Thomas, 1969). Kittock et al. (1987) reported that reduced stand explained only part of the yield reduction from low temperature stress on young cotton. They suggested that morphological and physiological effects can affect final lint yield as much as stand does. Less is known about how cold temperatures impact cotton seedlings once plant stands have been established. When emerged seedlings are exposed to temperatures below 20°C, growth, water relations (Bradow, 1990; 1991), nighttime starch utilization, and photosynthetic activity (Warner and Burke, 1993) are adversely impacted.

Genotypic differences in tolerance to chilling temperatures have been reported (Bradow, 1991; Krieg and Carroll, 1978; Steiner and Jacobsen, 1992). Genotype selection appears to be one tactic for overcoming yield reductions due to cold stress in cotton. Identification of easily measured traits that correlate with cold resistance may aid in the development of cultivars that can withstand suboptimal temperatures. Since early-maturing genotypes are adapted to more northern U.S. cotton growing areas where heat unit accumulations are lower, they may be more tolerant of cold temperatures than full-season genotypes. Bradow (1991) recently proposed a controlled environment assay for determining genotypic differences in cold tolerance after seedlings have emerged and are photosynthetically active.

Our objectives were to compare the cold tolerance of four genotypes that differed in maturity and to determine whether seedling growth responses of genotypes to cool temperature in a controlled environment are valid predictors of yield under field conditions.

MATERIALS AND METHODS

Plant Materials

The cultivars used for all experiments were Deltapine (DPL) 20, DPL 50, DPL 5690, and DPL Acala 90. These genotypes were chosen because they represent a range in relative maturity and in geographical areas of commercial production. DPL 20 and DPL 50 are earlier maturing genotypes that are more widely grown in shorter-season environments than the other two genotypes.

Seed from commercial sources were used in all experiments. Seed treatments used by Delta and Pine Land Company for all planting seed those 2 yr were either carboxin-PCNB (5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxanilide, Pentachloronitrobenzene) plus metalaxyl [*N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl) alanine methyl ester] or chloroneb (1,4-dichloro-2,5-dimethoxybenzene) plus metalaxyl (B. Savoy, 1996, personal communication). Seed weight of each genotype was determined on four randomly selected samples of 100 seeds each. Seed density (by liquid displacement) was determined on five randomly selected samples of 10 seeds each.

Controlled Environment Experiment

The controlled environment seedling-growth system used was described earlier (Bradow, 1990; Bradow, 1991). Briefly, seeds were soaked for 1 h in deionized water at room tempera-

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ture and then placed in wetted paper scrolls for 48 h at 31°C in the dark. Twenty uniform, damage- and disease-free seedlings of each cultivar for each temperature treatment were selected and re-scrolled, five seedlings per scroll, and returned to the 31°C environmental chamber for 24 h. The scrolls were then placed for 6 d in environmental chambers that were set at 15, 20, 25, and 30°C. The chambers were lighted (14 h d^{-1}) with cool-white fluorescent tubes that delivered 39 W m^{-2} to the tops of the seedlings. Relative humidity in the chamber was 60%. At the end of the 6-d experimental period, the seedlings were removed and cotyledon area, root and shoot fresh weight, and root and shoot length were measured.

Field Experiment

A field experiment was conducted at Clemson University's Pee Dee Research and Education Center near Florence, SC, in 1991 and 1992 on Typic Kandiudult soils. Daily high and low temperature and rainfall data were collected with a weather station located at the Center. Each year, the entire experimental area was disked, harrowed, in-row subsoiled, and bedded (beds rose about 15 cm above the midrows) before planting. An in-furrow application of pentachloronitrobenzene (0.78 kg a.i. ha^{-1}) plus metalaxyl (0.08 kg a.i. ha^{-1}) was used to suppress seedling diseases. Plant nutrients were applied based on soil test results and Clemson University Extension recommendations for nonirrigated cotton. Weed control was accomplished with a combination of herbicides, mechanical cultivation, and handweeding. Insects were controlled with organophosphate and pyrethroid insecticides as needed.

The four cultivars were planted in mid-April (17 April 1991, 15 April 1992), early-May (1 May 1991, 29 April 1992), and mid-May (15 May 1991, 14 May 1992). These planting dates were chosen to provide a range in temperatures following planting and still be considered full-season plantings for the area. The plots were seeded with a planter that was equipped with cone hoppers. Seeding rate was approximately 17 seeds m^{-1} of row. The experimental design was a randomized complete block in a split-plot arrangement with four replicates. Main plots were planting date and subplots were cultivars. Subplot size was two rows (10.64 by 0.97 m) each year.

In 1991, emerged plants were counted periodically in all subplots. Counts were made up to 41 d after planting for the mid-April planting date, 27 d after planting for the early-May planting date, and 13 d after planting for the mid-May planting date. In 1992, stand counts were made daily from 5 to 16 d after planting in the mid-April and early-May planting dates and from 5 to 9 d after planting for the mid-May planting date. Seedlings were counted as emerged if any part of the plant (including hypocotyl) was above the soil surface.

When more than 80% of the bolls for all genotypes within a planting date were open, the cotton in that planting date was chemically defoliated each year. Defoliants were applied on 7 September, 17 September, and 1 October to the mid-April, early-May, and mid-May planting dates, respectively, in 1991. In 1992, defoliants were applied on 28 September, 19 October, and 30 October.

Both rows of each subplot were harvested twice with a spindle picker each year. First-harvest dates for the three planting dates in 1991 were 17 September, 23 September, and 10 October. A second picking of all plots was made on 21 October. In 1992, the first-harvest dates were 28 September, 19 October, and 30 October. The second picking for all planting dates was 17 November. Lint percent was determined after saw-ginning a subsample from the harvest bags at each first-harvest date.

Data Analysis

All data were subjected to analysis of variance. For the controlled environment data, linear and quadratic single degree of freedom contrasts were computed for the temperature main effect means if interactions between temperature and genotype were not significant ($P > 0.05$). Genotype means in the controlled environment experiment were separated by calculating a least significant difference (LSD) ($P = 0.05$) when F values for genotype or interactions that included genotype were significant ($P \leq 0.05$). Because stand counts were made at different times for each planting date in the field experiment, an analysis of variance, that included days after planting when appropriate, was computed for each planting date in each year. For final plant stands and yield, years were combined for the analysis of variance. Treatment means in the field experiment were separated with a LSD ($P = 0.05$) when F values from the analysis of variance were significant ($P \leq 0.05$).

RESULTS

Controlled Environment Experiment

No interactions between temperature and genotypes occurred, except for seedling root length. Averaged across all four genotypes, cotton seedling root weight, shoot weight, and shoot length increased linearly with increasing temperature across the range of treatment temperatures (Table 1). A quadratic response occurred for cotyledon area (Table 1).

The earlier maturing genotypes produced larger seedlings. For root and shoot weight, DPL 20 was heaviest, DPL 50 second, and there was no difference between DPL 5690 and DPL Acala 90 (Table 1). Similarly, shoot length and cotyledon area were greater for the earlier maturity genotypes, although DPL 5690 and DPL Acala 90 differed in shoot length and DPL 50 had the same cotyledon area as the two later-maturing genotypes.

Root length was the only seedling parameter where the response to temperature varied among genotypes. Compared to root length at 30°C, cool temperatures reduced root extension of DPL 20 more than that of the

Table 1. Temperature and genotype effects on growth of 10-d-old cotton seedlings. Temperature treatments were imposed for six days (from 4–10 d after seeding).

Temperature	Root weight	Shoot weight	Shoot length	Cotyledon area
°C	mg	mg	cm	cm^2
15	90	330	3.7	11.8
20	100	360	4.5	13.9
25	110	380	4.8	15.1
30	120	400	5.7	15.6
Contrast†	L**	L**	L**	L**, Q**
Genotype				
DPL 20	130	460	5.8	17.0
DPL 50	110	380	5.3	13.9
DPL 5690	100	340	4.7	13.8
DPL Acala 90	100	340	4.1	13.7
LSD (0.05)	10	20	0.4	0.8

** Significant at $P = 0.01$.
† Polynomial contrasts that were significant; L = linear, Q = quadratic.

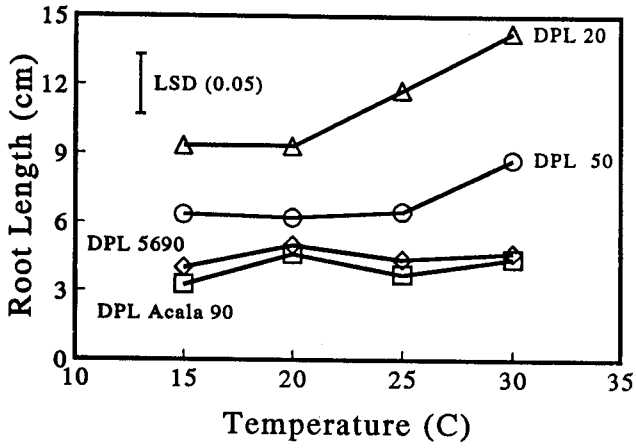

Fig. 1. Temperature and genotype effects on root length of 10-d-old cotton seedlings. Temperature treatments were imposed for 6 d (from 4–10 d after seeding). LSD value (2.6 cm) is for comparing root length means within a genotype.

other cultivars (Fig. 1). For DPL 50, root length at 15, 20, and 25°C was less than at 30°C. Root length of both DPL 5690 and DPL Acala 90 was the same at all temperatures.

Field Experiment

Weather conditions differed greatly between the 2 yr of the field experiment. Early-spring daily maximum and minimum temperatures for the 2 yr of the experiment are given in Fig. 2. In 1991, rainfall and temperature throughout the season were good for cotton production, and excellent yields were obtained at all three planting dates. Monthly rainfall totals in 1991 were 7.7 cm in May, 8.6 cm in June, 15.2 cm in July, 14.6 cm in August, and 4.2 cm in September. In 1992, cool spring temperatures (Fig. 2) and an extended drought during July limited yield. Rainfall totals in that year were 9.4 cm in May, 15.3 cm in June, 2.6 cm in July, 35.7 cm in August, and 5.5 cm in September.

Cotton planted in mid-May of 1992 was exposed to more cool temperatures than cotton planted in mid-April of 1991. In 1991, low temperatures less than 15°C occurred on 14 nights following the mid-April planting date, with ten of these occurring during the first 10 nights following planting (Fig. 2). Only one night after the mid-April planting date (Day 123) did temperatures reach as low 10°C. In 1992, there were 32 nights with temperatures less than 15°C following the mid-April planting date (Fig. 2), with eight of these occurring after the mid-May planting date. Following emergence of the mid-May planting date in 1992, there were three occasions (Days 142, 143, and 147) when temperatures were 10°C or less (Fig. 2). All three main effects (year, planting date, and genotype) and the year × genotype interaction were significant ($P \leq 0.01$) for final plant stands. Though significant, stand differences caused by the treatments did not appear to influence cotton yield. Final stands for each genotype at each planting date were at or above recommended levels for optimum cotton production on Coastal Plain soils (Table 2).

Emergence rates differed among genotypes. In both years and at most planting dates, DPL 20 emerged quicker than the other cultivars, especially the two late-maturing cultivars (Table 3). An exception was the mid-May planting date in 1991 where all cultivars were established by 5 d after planting. This was the only planting date in the 2 yr of the experiment that was relatively free of cold stress (Fig. 2).

Differences in emergence rate and final stand did not seem be related to seed weight or density. DPL 50 had the lowest seed weight (8.8 g per 100 seed) and DPL Acala 90 had the highest (9.4 g per 100 seed). Seed weights of DPL 20 and DPL 5690 were both 9.3 g per 100 seed. Seed density differences were small, ranging from 0.96 g mL^{-1} for DPL 50 to 1.09 g mL^{-1} for DPL 20. DPL 5690 and DPL Acala 90 had intermediate seed densities of 1.01 and 1.02 g mL^{-1}, respectively.

Emergence rate in the field and plant size after 10 d in the controlled environment experiment were not good indicators of relative cultivar yield performance in our study. In 1991, the fastest emerging cultivar, DPL 20, had lower lint yield than the slower emerging cultivars, DPL 5690 and DPL Acala 90, when planted in mid-April or early May. At the mid-May planting in 1991, which was the only planting date where no cold stress occurred, yield among these cultivars was equal (Table 2).

The year × planting date × genotype interaction was significant for lint yield. In 1992, yields did not differ

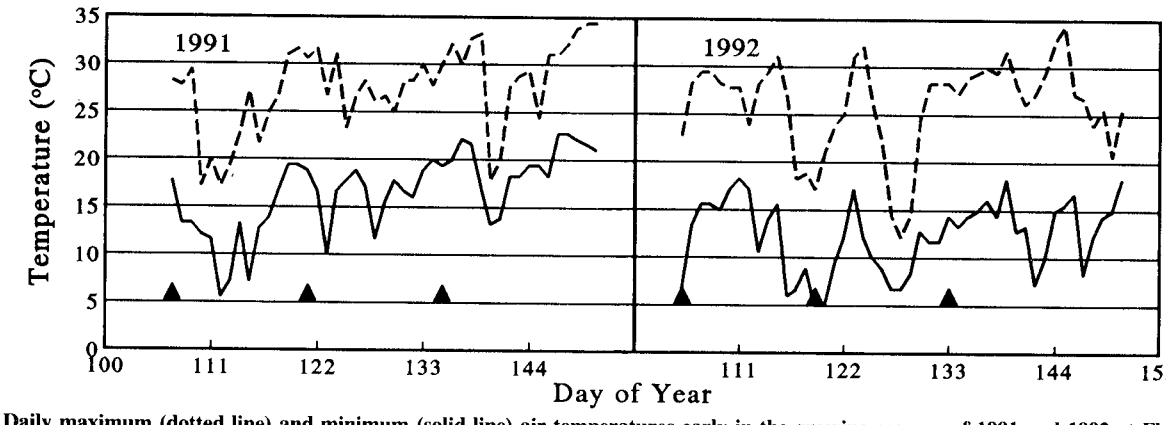

Fig. 2. Daily maximum (dotted line) and minimum (solid line) air temperatures early in the growing seasons of 1991 and 1992 at Florence, SC. Data are from the calendar dates of 15 April to 31 May in 1991 and 14 April to 30 May in 1992. Triangles indicate cotton planting dates.

Table 2. Effect of planting date and genotype on cotton plant stands and yield at Florence, SC.

	Genotype							
	Plant stands				Yield			
Planting date	DPL 20	DPL 50	DPL 5690	DPL Acala 90	DPL 20	DPL 50	DPL 5690	DPL Acala 90
	plants m^{-1}				kg ha^{-1}			
				1991				
Mid-April	11.6	12.8	15.7	12.9	1204	1214	1372	1529
Early-May	12.8	13.6	16.7	13.1	1207	1308	1437	1391
Mid-May	14.3	12.9	15.9	14.2	1415	1394	1467	1493
				1992				
Mid-April	9.7	11.1	14.6	10.1	500	527	496	490
Early-May	11.3	12.1	14.8	10.5	527	526	584	730
Mid-May	12.0	13.4	17.3	12.7	480	576	707	764
LSD (0.05)			ns†				148	

† LSD value is for comparing genotype means within a planting date and year. NS indicates the year × planting date × genotype interaction was not significant ($P \leq 0.05$).

among cultivars at the mid-April planting date (Table 2). Lack of precipitation in July and the extremely cool temperatures in late spring that year may have limited yield of all four cultivars. In the early-May and mid-May planting dates, yield of DPL Acala 90 was greater than both DPL 20 and DPL 50. Yield of DPL 5690 did not differ from DPL 50 in either of the last two planting dates in 1992, but was greater than DPL 20 at the mid-May planting date (Table 2).

DISCUSSION

Plant stands in all planting dates were not reduced to yield limiting levels (Table 2). This is important to emphasize since Kittock et al. (1987) reported that up to 100% of the yield reduction in cotton caused by cool temperatures could be attributed to stand reductions in some instances.

The early-maturing genotypes were more sensitive to chilling stress in the controlled environment root length assay than the late-maturing genotypes. Lint yield of the early-maturing genotypes was also affected more in the field experiment when seedlings were exposed to chilling temperatures than the late-maturing cultivars. Although more genotypes need to be evaluated, this suggests that screening for genetic traits that promote earliness, other than fast early-season growth rate, may be useful in developing cultivars for areas of the Cotton Belt where late-spring cold fronts are common.

Factors other than seedling cool temperature tolerance may have influenced the relative yield response of the cultivars to our planting date treatments in both years of the field experiment. Bird (1982) reported that reduced germination and radicle elongation rate at 13.3°C was associated with resistance to some seedling diseases and insect pests. Although cotton is an indeterminate crop, the two early-maturing cultivars (DPL 20 and DPL 50) used in this study have a more determinate growth habit than either DPL 5690 and DPL Acala 90. Since season length was not a limiting factor in the field experiment, it is possible that the late-maturing cultivars were better able to initiate growth and produce more bolls after intermittent stresses than the earlier-maturing cultivars. Nonetheless, our data do not support previous work (Wanjura et al., 1969; Steiner and Jacobsen, 1992) that suggested that genotypes that emerge rapidly should be planted when early-season cool temperature stress is expected.

Chilling of seedlings results in desiccation by reducing root water uptake (Christiansen and Rowland, 1986). In our controlled environment experiment, we noticed that the longer roots of DPL 20 at 15°C and 20°C were finer and less branched than the shorter roots of DPL 5690 and DPL Acala 90. Perhaps the slower growth, or the difference in root morphology, of the late-maturing cultivars allowed them to maintain better water relations and sustain less long-term desiccation damage. A closer examination of root area may be a possible starting point for further verification and refinement of the root length assay for cotton improvement programs.

Table 3. Effect of planting date and genotype on stand establishment rate at Florence, SC. Final plant stands are given in Table 2.

Year	Planting date	Days after planting	Genotype			
			DPL 20	DPL 50	DPL 5690	DPL Acala 90
			% of final stand			
1991	Mid-April	7	34	26	14	20
		10	94	88	98	82
	LSD (0.05)†			9.1		
	Early-May	5	59	50	41	37
		7	81	77	69	58
	LSD (0.05)			11.3		
	Mid-May	5	92	96	98	96
	LSD (0.05)			ns‡		
1992	Mid-April	8	21	16	15	10
		12	84	83	83	76
	LSD (0.05)			ns		
	Early-May	6	18	4	3	1
		10	83	72	69	54
	LSD (0.05)			11.6		
	Mid-May	5	59	36	42	26
		7	94	94	94	91
	LSD (0.05)			7.4		

† LSD value for comparing genotype means within a planting date. LSD values were only calculated if genotype (mid-May 1992) or genotype × days after planting interaction (all other planting dates) were significant ($P \leq 0.05$).

‡ ns indicates genotypes had equal percent of final stand at each day after planting.

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