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Response of Obsolete and Modern Cotton Genotypes to Varying Plant Densities

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) producers are interested in reduced seeding rates due to increasing seed costs. It is not clear whether diverse cotton genotypes respond differently to reduced plant densities. The objectives of this research were to evaluate the performance of obsolete and modern cotton genotypes grown under reduced and traditional plant population densities. The six genotypes representing five decades of release were grown at either five plants m^{-2} (low) or 10 plants m^{-2} (high) densities, during the years 2009 through 2012. Dry-matter partitioning, growth analysis, yield, yield component, and fiber quality data were collected. Genotypes did not interact with plant densities for any trait. Despite few consistent dry-matter partitioning or growth differences among the genotypes, large genotypic differences were detected in lint yield and fiber quality production. The obsolete genotypes had lower yields because of reduced lint percentage and lint index. The higher yielding genotypes produced more bolls per unit area to generate their higher yields. Increased light interception by the high density treatment was offset by the ability of the leaves of the low density canopy to more efficiently intercept and utilize sunlight. These counteracting traits resulted in no yield or fiber quality differences between the two densities. Yield success can be achieved with a reduced seeding rate if uniform seedling spacing is also achieved, possibly regardless of the cultivar planted.

Cotton (*Gossypium hirsutum* L.) production is a challenging prospect in the current sociological and economic climate. Population growth, changing dietary preferences, and a developing biofuels industry have caused a shifting of more hectares away from cotton to grain and oil seed production. Stagnant cotton prices coupled with increasing input costs have squeezed profit margins on these remaining hectares for U.S. cotton producers.

This reduced profit margin can be addressed from two angles: 1) increasing yields or 2) reducing inputs or using current inputs more efficiently. Although cotton breeders have continually achieved the broader goal of increased lint production, it is not always clear physiologically how these increases have been achieved (Meredith, 2000, 2006). In research conducted more than 25 years ago, Wells and Meredith (1984) were able to demonstrate that modern cultivars from that era partitioned more of their dry matter into reproductive growth rather than vegetative growth, leading to higher yields than the obsolete cultivars. Since that time numerous other cultivars have been commercialized; many containing transgenes conferring some type of insect or herbicide resistance. It is not clear how the growth, development, and yield production of these newer cultivars might compare to that of the obsolete cultivars.

Reducing the overall input amount or making more efficient use of current input levels would be another means of improving overall sustainability of cotton production. Increasingly, seed costs have become a larger percentage of the overall input costs for cotton production, largely because of the technology fees associated with the various transgenic traits, but also because of the more elaborate seed treatments being applied to help suppress seedling disease, early season insects, and/or nematodes. Producers are now expressing renewed interest in reduced seedling rates to offset this elevated seed cost. Multiple research projects over the years have been conducted to define the optimal population density for cotton under different growth scenarios (Bednarz et al., 2005; Buxton et al., 1977; Heitholt, 1994; Jadhao et al., 1993; Kerby et al., 1990a, b; Mohamad et al., 1982; Pettigrew and Johnson, 2005; Sawan et al., 1993; Smith et al., 1979). Many of these contained low population densities that compare

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favorably to some of the reduced seeding rates of interest to producers.

We know from previous research that dry-matter partitioning, lint yield, and fiber quality can vary depending upon the cultivar grown (Mohamad et al., 1982; Pettigrew and Meredith, 2012) or the plant population density obtained (Bednarz et al, 2005; Heitholt, 1994; Mohamad et al., 1982). It is not clear if cultivars bred in different eras would respond similarly to being planted in reduced population densities. Therefore, one objective of this research was to determine if the growth, development, lint yield, yield components, and fiber quality production differed among cotton genotypes bred during different periods. A second objective was to determine whether these genotypes responded differently to growth at two different plant population densities.

MATERIALS AND METHODS

Field studies were conducted at Stoneville, MS during the 2009 through 2012 growing seasons. During the 2009 and 2010 seasons the study was conducted on a Dubbs silt loam (fine-silty, mixed, active, thermic Typic Hapludalfs) soil. The study was then transferred to a Dundee silty clay loam (fine-silty, mixed, active, thermic Typic Endoaqualfs) for the 2011 and 2012 seasons. Six obsolete and modern cotton genotypes (Table 1) were grown at two different plant population densities in any one year throughout the duration of the study. The genotypes consisted of both conventional and transgenic genotypes released from 1962 through 2011. ‘ST 213’, ‘DP 50’, ‘MD 25’ (Meredith and Nokes, 2011), and ‘SG 747’ were the conventional genotypes. The transgenic genotypes were ‘PM 1218BR’, ‘FM 840B2RF’, and ‘DP 0935B2RF’ containing transgenic traits for resistance to both glyphosate herbicide and to certain lepidopteron insects. FM 840B2RF was an okra leaftype genotype, whereas the others were all normal leaftype lines. PM 1218BR was grown the first 2 yr of the study but was replaced by SG 747 (which had a similar year of release) during the last 2 yr of the study because the Environmental Protection Agency did not renew the label for the single gene *Bacillus thuringiensis* (Bt) Cry1Ac endotoxin insect resistance trait. The other transgenic genotypes in this study contained genes producing two different Bt endotoxin proteins.

Table 1. Cotton genotypes that were grown with two different plant population densities at Stoneville, MS from 2009 through 2012.

Genotype	Year of Release	Leaftype
ST 213	**1962**	**Normal**
DP 50	**1984**	**Normal**
PM 1218BR [z]	**1999**	**Normal**
FM 840B2RF	**2007**	**Okra**
DP 0935B2RF	**2009**	**Normal**
MD 25	**2011**	**Normal**
SG 747 [y]	**1998**	**Normal**

[z] PM 1218BR was grown only in 2009 and 2010

[y] SG 747 was grown only in 2011 and 2012

All the genotypes were grown at population densities of five plants m^{-2} (50,000 plants ha^{-1}) and at 10 plants m^{-2} (100,000 plants ha^{-1}). The plots were originally oversown and then hand-thinned to the desired population density. Plots consisted of six rows that were 9.1 m long with 1-m spacing between rows. The genotypes and population densities were arranged factorially in a randomized complete block design with six replicates in 2009 and 2010 and five replicates in 2011 and 2012.

The study was planted on 27 April, 2009; 15 April, 2010; 5 May, 2011; and 12 April, 2012. Each year the experimental area received 112 kg N ha^{-1} in a preplant application. Recommended insect and weed control measurements were employed each growing season as needed. All plots were furrow-irrigated once in 2009, two times in 2010 and 2011, and three times in 2012.

Above ground biomass was harvested from a 0.6-m section of a row five times during each growing season. The initial dry-matter harvest occurred during mid-to-late June, with subsequent harvests occurring every 2 wk until approximately mid-August. Harvested plants were collected from either row two or row five, avoiding the row ends. Height and the number of main stem nodes on each plant were determined. Plants were then separated into leaves, stems and petioles, squares, and blooms and bolls. Leaves were passed through a LI-3100 leaf area meter (LI-COR, Lincoln, NE) to determine leaf area index. Samples were dried for at least 48 h at 60°C, and dry weights were recorded. Harvest index was calculated as the reproductive dry weight/total dry weight. Crop growth rates (CGR), relative growth rates (RGR), and net assimilation rates (NAR) were also calculated from the various dry-matter components (Brown, 1984).

The percentage of incoming photosynthetic photon flux density (PPFD) intercepted by the cotton canopies was determined by the use of a LI 190SB point quantum sensor (LI-COR) positioned above the canopy and a 1-m-long LI 191SB line quantum sensor positioned on the ground perpendicular to, and centered on the row. Two measurements were taken on one of the inner plot rows, avoiding the ends of the row, during the same weeks as when the dry-matter harvests were collected. The mean of those measurements was used for later statistical analyses. Measurements were collected under generally clear skies between 1100 and 1500 CDT with the incoming PPFD levels at least 1600 µmol m^{-2} s^{-1}. Canopy PPFD extinction coefficients were estimated according to Beer's law as a function of measured leaf area index (LAI) and the canopy intercepted PPFD, as described previously (Constable, 1986; Pettigrew and Meredith, 2012; Sadras and Wilson, 1997).

When approximately 65% of the bolls on the latest maturing variety had opened, usually early-to-mid September, defoliation of the plots was initiated. At that time, a mixture of thidiazuron and diuron was applied to defoliate the crop and ethephon was applied to open the remaining unopened bolls. Approximately 2 wk after defoliation, the two center rows of each plot were mechanically spindle-picked and weighed. After defoliation, but before the mechanical harvest, a 50-boll sample was hand harvested from each plot for use in determination of yield components. Boll mass was determined by dividing the seed cotton weight of the 50-boll sample by the number of bolls harvested for each plot. These hand-harvested samples from each plot were then ginned on a 10-saw laboratory gin to determine the lint percentage of each plot, which was used to calculate the lint yield from the mechanically harvested seed cotton. Average seed mass was determined from 100 nondelinted seeds per sample and reported as weight per individual seed.

Lint from each ginned sample was sent to Starlab Inc. (Knoxville, TN) for fiber quality analyses. HVI instrumentation was used to quantify staple length, length uniformity, fiber strength, fiber elongation, and fiber micronaire. A second lint sample was also tested for various fiber quality traits using the Advanced Fiber Information System (AFIS) (Zellweger Uster Inc., Knoxville, TN).

Statistical analyses were performed by analysis of variance (Proc Mixed, SAS Institute, 1996). Because a slightly different set of genotypes was utilized in the last 2 yr of the study (2011-2012) compared to the first 2 yr (2009-2010), data from the years 2009 and 2010 (1st year set) were averaged together and data from 2011 and 2012 (2nd year set) were averaged together. These two groups were then statistically analyzed separately for each trait quantified. Genotype and treatment means for these two groupings were then separated by the use of a protected LSD at $P \leq 0.05$.

RESULTS

The 4 yr of this study were distinctive in their weather patterns (Table 2). Both 2009 and 2012 were relatively moist with milder temperatures, whereas 2010 and 2011 were hot and dry growing seasons. These diverse growing conditions across the years provided a good situation for conducting the research.

Table 2. Monthly weather summary for 2009 to 2012 at Stoneville, MS[z].

Month	2009	2010	2011	2012
		Precipitation (cm)		
April	7.54	6.0	16.0	10.6
May	34.3	13.4	7.0	5.2
June	0.7	3.1	4.0	16.2
July	22.2	4.8	5.0	11.6
August	3.6	0.6	6.1	10.9
September	12.9	5.4	10.1	8.3
October	39.4	4.5	2.7	14.7
		Thermal Units [y]		
April	92	124	159	137
May	203	273	224	293
June	363	401	404	316
July	342	412	436	409
August	340	458	425	370
September	265	315	228	264
October	64	129	101	68
		Solar Radiation (MJ m^{-2})		
April	602	-	626	638
May	547	681	748	688
June	759	743	743	751
July	663	710	723	700
August	656	667	689	634
September	442	609	530	528
October	317	566	523	462

[z] All observations made by NOAA, Mid-South Agric. Weather Service, and Delta Research and Extension Center Weather, Stoneville, MS.

[y] [(Max. temp + Min. temp.)/2] – 15.5

Analyses of variance indicate significance differences were detected among the main effects, genotype and plant density, for many of the traits quantified. However, there were no significant interactions between genotype and density for any of the traits. Although there were some minor interactions between the individual main effects and year, the f values for these interactions were small relative to that of the main effects and reflected changes in the magnitude rather than the direction of the effect. Therefore, genotype means were averaged across plant densities and year. Plant density means were also averaged across genotypes and year.

Inconsistent genotypic differences were observed in canopy leaf development and light interception throughout the course of this research (Table 3). Genotypic differences in LAI were only detected during the 1st year set of the study, 2009 and 2010. On the second dry-matter harvest of that period, PM 1218BR had greater LAI than any of the other genotypes. By the final dry-matter harvest, LAI of the other genotypes had exceeded that of PM 1218BR, with ST 213 having a greater LAI than any of the other genotypes. The only differences in light interception for that period was during the third dry-matter harvest where the okra leaftype genotype FM 840B2RF intercepted the least amount of sunlight. FM 840BR also had the lowest canopy light interception during the first four dry-matter harvests for the 2nd year set, 2011 and 2012, as well. No genotypic differences were detected in canopy extinction coefficients with the exception of the third dry-matter harvest during the 2nd year set. The lower extinction coefficient for FM 840B2RF at that time indicated that its LAI was less efficient in intercepting the sunlight than that of either MD 25 or ST 213.

The higher plant density (10 plants m^{-2}) consistently produced a greater LAI than the lower plant density (5 plants m^{-2}) throughout both periods, with the exception of the final dry-matter harvest during the 1st year set (Table 4). Despite these LAI differences, the higher plant density canopies only intercepted significantly more sunlight on the first and second dry-matter harvest during the 2nd year set. These two phenomenon resulted in greater extinction coefficients for the lower density compared to the higher plant density, with the exception of the last two dry-matter harvests for the 1st year set. These higher extinction coefficients indicate that canopies of the lower plant densities were more efficient in intercepting sunlight per unit LAI than the higher density canopies.

Table 3. Leaf area index, canopy light interception, and extinction coefficients for various genotypes and five (first–fifth) sequential dry-matter harvests averaged across two plant population densities when grown at Stoneville, MS during two year sets (2009-2010) and (2011-2012).

Year	Genotype	Leaf Area Index					Canopy Light Interception					Canopy Extinction Coefficient				
		1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
									%							
2009-10	DP 0935B2RF	0.83	1.87	3.08	3.67	3.96	37.6	60.2	90.8	95.6	94.4	0.79	0.58	0.89	1.04	0.82
	DP 50	0.83	1.86	3.22	3.59	3.70	35.4	58.3	90.3	95.9	88.3	0.82	0.53	0.86	1.11	0.60
	FM 840B2RF	0.62	1.62	3.06	3.73	3.82	32.0	55.9	85.8	92.8	90.3	0.87	0.56	0.73	0.84	0.57
	MD 25	0.90	1.88	3.22	4.13	4.11	37.7	62.8	92.8	96.8	94.5	0.94	0.64	1.03	0.95	0.73
	PM 1218BR	1.02	2.27	3.46	3.70	3.61	40.5	66.9	92.6	94.9	93.2	0.68	0.54	0.85	0.96	0.66
	ST 213	0.84	1.86	3.55	4.45	4.91	35.4	59.8	91.2	96.0	94.5	0.98	0.57	0.90	0.88	0.63
	LSD 0.05	0.31	0.25 *	0.64	0.70	0.90 *	6.9	9.6	3.9 *	2.7	3.9	0.45	0.11	0.16 *	0.26	0.19
2011-12	DP 0935B2RF	0.52	1.50	2.68	3.45	3.81	33.9	62.5	85.0	92.0	94.1	0.96	0.75	0.88	0.95	0.97
	DP 50	0.72	1.86	3.04	4.13	3.63	37.1	67.7	87.2	93.8	94.6	0.75	0.71	0.90	0.97	1.10
	FM 840B2RF	0.52	1.48	2.33	3.32	3.75	30.8	55.0	80.3	88.8	93.7	0.84	0.61	0.87	0.78	0.86
	MD 25	0.74	1.88	2.90	2.99	3.16	37.6	66.1	85.9	91.4	92.1	0.76	0.68	0.90	1.15	1.04
	SG 747	0.62	1.72	2.48	3.03	3.07	36.6	66.1	87.2	93.0	92.4	0.83	0.70	1.02	1.09	0.98
	ST 213	0.70	1.84	3.09	3.82	3.78	37.0	64.2	86.5	93.8	94.3	0.78	0.64	0.79	1.01	0.95
	LSD 0.05	0.26	0.36	0.70	1.15	1.22	4.5 *	3.4 *	2.7 *	3.3 *	2.1 *	0.19	0.11	0.16	0.25	0.30

***= significantly different at the $P \leq 0.05$ level, other LSD values are not significantly different.**

Table 4. Leaf area index, canopy light interception, and extinction coefficients for two plant population densities and five (first–fifth) sequential dry-matter harvests averaged across six genotypes when grown at Stoneville, MS during two year sets (2009-2010) and (2011-2012).

Year	Density	Leaf Area Index					Canopy Light Interception					Canopy Extinction Coefficient				
		1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
									%							
2009-10	5 plants m^{-2}	0.70	1.63	2.92	3.59	3.88	34.8	58.9	90.1	94.9	91.7	1.04	0.64	0.96	1.02	0.69
	10 plants m^{-2}	0.98	2.17	3.61	4.17	4.16	38.1	62.4	91.1	95.8	93.3	0.65	0.50	0.79	0.91	0.65
	LSD 0.05	0.18	0.14	0.37	0.41	0.52 ns[z]	4.0 ns	5.6 ns	2.3 ns	1.5 ns	2.3 ns	0.26	0.06	0.10	0.15 ns	0.11 ns
2011-12	5 plants m^{-2}	0.48	1.37	2.21	2.86	3.03	33.5	61.4	85.2	91.6	93.4	0.97	0.78	1.07	1.12	1.12
	10 plants m^{-2}	0.79	2.05	3.30	4.06	4.03	37.5	65.8	85.5	92.7	93.7	0.68	0.58	0.72	0.86	0.85
	LSD 0.05	0.15	0.21	0.41	0.67	0.70	2.6	2.0	1.6 ns	1.9 ns	1.2 ns	0.11	0.06	0.09	0.15	0.17

[z] ns = not significantly different at the $P \le 0.05$ level.

Table 5. Plant height, specific leaf weight, and harvest index for various genotypes and five (first–fifth) sequential dry-matter harvests averaged across two plant population densities when grown at Stoneville, MS during two year sets (2009-2010) and (2011-2012).

Year	Genotype	Plant Height					Specific Leaf Weight					Harvest Index [z]			
		1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	2nd	3rd	4th	5th
		cm					$g\ m^{-2}$								
2009-10	DP 0935B2RF	39	73	93	102	109	60.0	58.1	50.9	49.5	44.3	0.065	0.151	0.276	0.390
	DP 50	36	65	90	97	106	56.0	56.3	49.6	46.1	47.5	0.088	0.183	0.298	0.408
	FM 840B2RF	34	69	90	107	112	61.8	58.2	47.1	44.2	43.5	0.062	0.137	0.278	0.395
	MD 25	43	78	103	123	133	58.3	58.5	51.0	47.4	45.3	0.063	0.136	0.233	0.322
	PM 1218BR	46	81	100	105	112	56.1	56.7	52.1	50.9	49.5	0.096	0.199	0.353	0.460
	ST 213	36	66	93	111	117	56.1	54.9	46.3	44.1	39.4	0.050	0.103	0.194	0.300
	LSD 0.05	7	10	10 ns[y]	9	7	2.8	2.4	2.2	4.2	8.6 ns	0.019	0.032	0.041	0.044
2011-12	DP 0935B2RF	30	60	88	104	110	64.3	60.4	58.0	50.8	53.5	0.038	0.142	0.279	0.409
	DP 50	33	65	89	103	107	61.5	57.3	55.8	47.2	53.7	0.068	0.208	0.339	0.450
	FM 840B2RF	29	57	84	102	108	67.4	60.5	60.3	49.9	51.7	0.065	0.157	0.268	0.416
	MD 25	40	73	102	114	121	65.2	59.5	58.9	53.0	55.9	0.070	0.213	0.360	0.463
	SG 747	33	68	93	104	107	64.6	61.1	62.2	54.6	58.6	0.062	0.240	0.397	0.496
	ST 213	32	64	92	107	113	60.0	58.2	58.6	48.7	52.1	0.057	0.149	0.274	0.380
	LSD 0.05	5	6	5	8 ns	13 ns	2.7	2.7	5.0 ns	4.8	5.5 ns	0.028 ns	0.042	0.076	0.089 ns

[z] Harvest index = reproductive weight / total weight. It was not collected on first harvest due to insufficient reproductive growth.

[y] ns = not significantly different at the $P \le 0.05$ level.

Other growth traits also exhibited differences among the genotypes (Table 5). MD 25 was consistently one of the tallest varieties across all dry-matter harvests and both year sets. Earlier in the growing season, ST 213 (an obsolete genotype) was one of the shorter genotypes before accelerating its growth to become one of the taller genotypes during the later dry-matter harvests. Both PM 1218BR and SG 747 exhibited some of the highest specific leaf weights (SLW) across all the dry-matter harvests. Conversely, FM 840B2RF produced higher SLW during the first couple of dry-matter harvests for both year sets before declining to one of the lower SLW during the later dry-matter harvests. PM 128BR and SG 747 tended to have the greater harvest indexes for the 1st and 2nd year sets respectively. In contrast, the harvest index of ST 213 was consistently one of the lower harvest indexes.

Plant density did not impact plant height except for the last two dry harvests when plants in the lower density started to grow taller than plants in the higher density (Table 6). With the exception of the last two dry-matter harvests, leaves from the lower density plants consistently had a greater SLW than leaves from the higher density. Varying the plant population did not have any impact on the harvest index for any of the dry-matter harvest during either of the two-year sets.

Despite genotypic differences in many of the dry-matter partitioning traits, essentially no differences were detected among the genotypes for any of the growth analyses traits (crop growth rate, relative growth rate, or net assimilation rate) (data not shown). The exception to this generalization is the significantly higher net assimilation exhibited by SG 747 (5.75 g m^{-2} d^{-1}) for the third net assimilation rate during the 2nd year set. ST 213 exhibited the lowest net assimilation rate of 2.83 g m^{-2} d^{-1} during that period.

Conversely, varying the plant population density did impact many of these growth analyses traits (Table 7). Early in the growing season during the 2nd year set, the high plant density produced a greater crop growth rate than the low plant density. However, during four of the eight determinations of relative growth rate across both year sets, the low plant density exhibited a higher RGR than the high plant density. No differences were observed for the other RGR measurements. Similar to the RGR, the lower plant density produced a higher net assimilation rate during four of the eight determinations. No differences were detected between the plant densities for the other NAR measurements.

Table 6. Plant height, specific leaf weight, and harvest index for two plant population densities and five (first–fifth) sequential dry-matter harvests averaged across six genotypes when grown at Stoneville, MS during two year sets (2009-2010) and (2011-2012).

Year	Density	Plant Height					Specific Leaf Weight					Harvest Index [z]			
		1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	2nd	3rd	4th	5th
		cm					g m^{-2}								
2009-10	5 plants m^{-2}	39	73	96	110	117	59.4	59.9	51.2	47.5	46.2	0.071	0.147	0.275	0.384
	10 plants m^{-2}	39	71	93	106	112	56.7	54.3	47.8	46.5	43.6	0.070	0.157	0.269	0.375
	LSD 0.05	4 ns [y]	6 ns	6 ns	5 ns	4	1.6	1.4	1.3	2.4 ns	4.9 ns	0.011 ns	0.019 ns	0.024 ns	0.025 ns
2011-12	5 plants m^{-2}	32	65	92	108	115	65.9	61.7	61.3	52.3	55.6	0.066	0.179	0.323	0.434
	10 plants m^{-2}	34	65	90	103	107	61.8	57.3	56.6	49.0	52.9	0.053	0.191	0.316	0.437
	LSD 0.05	3 ns	3 ns	3 ns	5	8	1.5	1.6	2.9	2.7	3.2 ns	0.016 ns	0.024 ns	0.044 ns	0.052 ns

[z] Harvest index = reproductive weight / total weight. It was not collected on first harvest due to insufficient reproductive growth.

[y] ns = not significantly different at the $P \leq 0.05$ level.

Table 7. Crop growth rate, relative growth rate, and net assimilation rate for two plant population densities and sequential growth analysis periods averaged across six genotypes when grown at Stoneville, MS during two year sets (2009-2010) and (2011-2012).

Year	Density	Crop Growth Rate				Relative Growth Rate				Net Assimilation Rate			
		1st [z]	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
		g m^{-2} d^{-1}				g g^{-1} d^{-1}				g m^{-2} d^{-1}			
2009-10	5 plants m^{-2}	9.4	11.6	13.2	14.4	0.103	0.046	0.030	0.023	11.25	5.71	4.24	4.30
	10 plants m^{-2}	10.4	13.5	14.3	9.4	0.086	0.042	0.027	0.014	8.80	5.00	3.69	2.25
	LSD 0.05	1.6 ns [y]	2.1 ns	4.7 ns	5.5 ns	0.015	0.006 ns	0.009 ns	0.008	1.40	0.80 ns	1.35	1.71
2011-12	5 plants m^{-2}	8.5	12.9	11.7	12.8	0.093	0.053	0.028	0.022	10.74	7.51	4.89	4.34
	10 plants m^{-2}	11.6	18.0	9.5	18.6	0.086	0.052	0.018	0.024	9.49	7.02	2.94	4.67
	LSD 0.05	1.1	3.5	3.7 ns	6.1 ns	0.007	0.010 ns	0.007	0.007 ns	0.84	1.44 ns	1.16	1.33 ns

[z] 1st growth analysis period is between first and second dry-matter harvest; 2nd (second and third harvests); 3rd (third and fourth harvests); 4th (fourth and fifth harvests).

[y] ns = not significantly different at the $P \leq 0.05$ level.

Genotypic differences were detected in lint yield production and in the individual yield components for both year sets (2009-2010 and 2011-2012) (Table 8). The older obsolete genotypes DPL 50 and ST 213 produced two of the lowest lint yields during this study. Reduced lint percentage and lint index both contributed to the lower yields for both these genotypes. A small boll mass was an additional source of DP 50's reduced yield, whereas the low yield of ST 213 was partially due to the production on a smaller number of bolls. The yield leaders PM 1218BR and SG 747 from the first and second periods respectively, attained their higher yields primarily through the production of more bolls. These genotypes also have a moderate boll mass, and a moderate lint percentage. Although one of the higher yielding genotypes, MD 25, did not produce a large number of bolls, it did produce the largest boll mass and a high lint percentage to generate its yield.

Despite the growth differences exhibited between the varying plant densities, no significant lint yield or yield component differences were detected between the plant population densities (data not shown). Furthermore, varying the plant density also did not alter any of the fiber quality traits (data not shown). An exception to this generalization is that the lower plant density (7.6%) produced a significantly greater short fiber content than the high density (7.0%) during the 1st year set, but not the 2nd year set. Over the range of plant densities utilized in this study, varying the plant density did not alter reproductive growth sufficiently to alter either the quantity or quality of lint produced.

Considerable genotypic variability was detected for many of the HVI (Table 9) and AFIS (Table 10) fiber quality traits. FM 840B2RF and MD 25 consistently produced fiber that was longer, stronger, and with a higher length uniformity than the other genotypes (Table 9). Both of the high lint yielding genotypes (PM 1218BR and SG 747) had the highest micronaire value, which contributed to their higher yields. MD 25 also produced the fewest fiber neps and had the lowest percentage short fiber content of any of the genotypes (Table 10). The higher fiber maturity ratio of MD 25 also indicated a more complete filling of the fiber secondary cell wall through cellulose deposition. The greater fiber fineness values for PM 1218BR and SG 747 are reflective of the higher micronaire values of these genotypes. With the exception of the superior fiber quality produced by FM 840B2RF and MD 25, the quality of the fiber produced by the obsolete genotypes DP 50 and ST 213 was not that different from some of the newer genotypes.

Table 8. Lint yield and yield components for various genotypes averaged across two plant population densities when grown at Stoneville, MS during two year sets (2009-2010) and (2011-2012).

Years	Genotype	Lint Yield	Boll Number	Boll Mass	Lint Percentage	Seed Mass	Seed Number	Lint Index
		kg ha^{-1}	bolls m^{-2}	g boll^{-1}	%	mg seed^{-1}	seed boll^{-1}	mg seed^{-1}
2009-10	DP 0935B2RF	1582	84	4.41	43.1	94	26.6	71
	DP 50	1406	87	4.28	38.1	99	26.9	61
	FM 840B2RF	1496	88	4.39	39.2	98	27.3	63
	MD 25	1579	80	4.94	40.4	105	28.0	71
	PM 1218BR	1683	92	4.53	40.9	109	24.5	76
	ST 213	1272	76	4.43	37.7	102	27.2	62
	LSD 0.05	218	8	0.18	1.4	3	1.0	4
2011-12	DP 0935B2RF	1125	64	4.18	41.1	94	26.1	66
	DP 50	1101	74	4.02	36.5	95	26.7	55
	FM 840B2RF	991	59	4.46	37.0	102	27.5	60
	MD 25	1230	68	4.52	38.3	101	27.5	63
	SG 747	1400	80	4.30	40.4	95	26.8	65
	ST 213	811	53	4.16	36.0	100	26.5	56
	LSD 0.05	204	12	0.25	0.7	4	1.3 ns [z]	2

[z] ns = not significantly different at the $P \leq 0.05$ level.

Table 9. HVI fiber quality traits for various genotypes averaged across two plant population densities when grown at Stoneville, MS during two year sets (2009-2010) and (2011-2012).

Years	Genotype	Fiber Strength	Fiber Length	Length Uniformity	Fiber Elongation	Fiber Micronaire	Rd	+b
		cN tex^{-1}	cm	%	%			
2009-10	DP 0935B2RF	25.8	2.77	83.0	6.6	4.7	71.2	8.4
	DP 50	25.8	2.86	83.6	6.8	4.6	71.5	7.8
	FM 840B2RF	28.8	3.08	84.8	6.7	4.3	72.2	7.3
	MD 25	31.6	3.06	85.4	6.8	4.5	72.3	7.9
	PM 1218BR	26.0	2.69	83.3	6.8	5.1	70.7	8.1
	ST 213	26.1	2.81	83.0	6.6	4.6	71.7	8.4
	LSD 0.05	1.0	0.06	0.5	0.2 ns [z]	0.3	1.7 ns	0.3
2011-12	DP 0935B2RF	29.6	2.83	83.1	6.1	4.4	75.8	8.0
	DP 50	29.9	2.88	83.7	6.5	4.4	74.8	7.4
	FM 840B2RF	34.0	3.04	84.5	6.4	4.5	74.0	7.3
	MD 25	35.8	3.00	85.0	6.3	4.5	73.8	7.7
	SG 747	27.3	2.83	84.0	6.4	4.8	73.2	8.2
	ST 213	29.5	2.85	83.1	6.0	4.3	74.3	8.0
	LSD 0.05	1.3	0.06	0.5	0.2	0.2	1.5	0.5

[z] ns = not significantly different at the $P \leq 0.05$ level.

Table 10. Advanced Fiber Information System fiber quality traits for various genotypes averaged across two plant population densities when grown at Stoneville, MS during two year sets (2009-2010) and (2011).

Years	Genotype	Fiber Neps	Seed Coat Fragments	Short Fiber Content	Fiber Fineness	Fiber Maturity Ratio
		number g^{-1}	number g^{-1}	% weight	millitex	
2009-10	DP 0935B2RF	121	3.5	9.6	177	0.91
	DP 50	138	2.7	7.6	181	0.91
	FM 840B2RF	132	3.4	7.0	167	0.93
	MD 25	93	3.3	5.1	178	0.96
	PM 1218BR	117	3.8	7.0	189	0.93
	ST 213	124	4.0	7.6	182	0.91
	LSD 0.05	24	1.3 ns [z]	0.8	7	0.02
2011	DP 0935B2RF	117	3.9	8.1	171	0.93
	DP 50	125	3.4	6.2	175	0.93
	FM 840B2RF	129	3.4	5.5	166	0.95
	MD 25	96	2.0	4.2	176	0.97
	SG 747	104	2.7	5.8	178	0.94
	ST 213	94	3.3	6.1	179	0.93
	LSD 0.05	21	1.5 ns	0.9	5	0.02

[z] ns = not significantly different at the $P \leq 0.05$ level.

The results from this study indicate that the growth and structure of the cotton canopy will be affected by the choice of genotype planted and by the density at which the seed was planted. Although Schwartz and Smith (2008) reported greatest genetic gain when current and obsolete cotton cultivars were planted at the commercial seeding rate (1 x 0.3-m spacing) compared to lower spacings (3 x 3 m, 2 x 2 m, and 1 by 1 m), we did not see this interaction in our study. The difference might be due to the more drastic range of plant population densities and older cultivars utilized by Schwartz and Smith (2008) compared to our study. One of the highest yielding genotypes in our study, PM 1218BR, produced superior early season growth and leaf production. This extra leaf production allowed it to intercept more of the early season sunlight and might have contributed to its higher yield. These results confirm an earlier report for this genotype (Pettigrew and Meredith, 2012). In contrast, the oldest genotype, ST 213, lagged in early season growth but maintained a high level of vegetative growth late in the season. This extended vegetative growth came at the expense of reproductive growth, as indicated in its lower final harvest index value, and possibly contributed to the lower yield of ST 213. In addition, another modern relatively high yielding genotype, MD 25, exhibited both strong vegetative and strong reproduction growth when the reproductive phase kicked in throughout the growing seasons. The higher SLW exhibited by PM 1218BR and SG 747 often has been positively correlated with superior leaf photosynthetic performance (Pettigrew and Meredith, 2012). Elevated photosynthesis during the boll filling period was strongly associated with higher yields (Pettigrew and Meredith, 1994); therefore the greater SLW of PM 1218BR and SG 747 could have provided for more photosynthesis and contributed to their higher yields. Similar to the findings of Wells and Meredith (1984), the greater harvest index of PM 1218BR and SG 747 indicate more of their total dry matter produced was partitioned into reproductive growth.

The strong yield improvements seen with the modern genotypes also were accompanied with improved fiber quality, though these quality improvements were more modest in nature. FM 840BR and MD 25 produced the best fiber quality of the genotypes, with MD 25 producing the stronger fiber and FM 840BR producing the longer fiber. Of the two high fiber quality genotypes, MD 25 (the most modern) had the higher yield and therefore presented the best package of yield potential and fiber quality. The results from this study support the premise that although the primary objective of cotton breeders is yield increases, there also have been incremental fiber quality improvements made by breeders over the years (Meredith, 2000, 2006).

The most profound effect on canopy growth and architecture came from varying the plant population density, and this response was consistent regardless of the genotype grown. The extra plants in the high plant density increased the LAI throughout the growing season and further allowed this plant density to intercept more early season light than the low plant density. Despite these apparent advantages for the high plant density, higher extinction coefficients for the low plant density indicate that those canopies were more efficient in intercepting sunlight per unit LAI than the higher density canopies. These higher canopy extinction coefficients for the low plant density are similar to the main stem leaf extinction coefficient response to varying within row plant density reported by Constable (1986). However, our canopy extinction coefficient response to varying within row plant densities contrasts with the results of Brodrick et al. (2013), who reported higher extinction coefficients for the higher plant densities generated by a ultra narrow row planting when compared to the lower density in a wide row planting configuration. Apparently the alteration in canopy architecture produced by varying the within row plant density is different from alteration produced from varying plant density by changing the row width. In addition, the greater specific leaf weight of the low plant density canopies (often positively correlated with leaf photosynthetic rates, [Pettigrew and Meredith, 2012]) indicate that these low plant density canopies would more efficiently utilize the sunlight that had been intercepted. The greater net assimilation rates for these low plant density canopies reinforce the notion of these canopies exhibiting superior leaf photosynthesis. Therefore, the increased leaf area production and sunlight intercepting ability of the high plant density canopies was offset by the more efficient interception and utilization of the sunlight by canopy leaves in the low plant density treatment, resulting in no yield differences between the two plant population densities.

The results from this study indicate that a uniformly spaced low plant density (5 plants m^{-2}) could yield similarly as a uniformly spaced higher more traditional plant density (10 plants m^{-2}). However, that does not mean that all producers should convert all their fields to the lower seedling rate. The challenge for cotton producers wanting to go with a lower plant density is achieving the relative uniform plant spacing. Getting that uniform plant spacing is dependent upon a seedling emerging and surviving at that uniform spacing. To increase the odds of having a surviving cotton seedling at that uniform spacing, producers should start by planting a good quality seed that has been treated with a seed treatment package for protection against soil borne pathogens and insects. The next step is uniformly delivering the seed at the proper depth and placement, and planting with a favorable weather forecast for the next few days to achieve the desired stand establishment. A soil crusting event caused by heavy thunderstorms shortly after planting can severely limit stand establishment. It is incumbent on the seed companies to provide good quality seeds, just as it is the responsibility of chemical companies to provide improved seed treatments. Perhaps improvements can be made in planting equipment to increase the uniformity and consistency of seed depth and placement. Until producers gain enough confidence in the overall planting process for consistently and reliably delivering the desired uniform plant density, it might be wiser for producers to still plant a slightly higher seeding rate to achieve the desired final surviving plant population density.

DISCLAIMER

Trade names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product or service, and the use of the name by USDA implies no approval of the product or service to the exclusion of others that might also be suitable.

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