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AGRONOMY AND SOILS

Plant Population and Planting Date Effects on Cotton (*Gossypium hirsutum* L.) Growth and Yield

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ABSTRACT

To reduce seed costs, cotton (*Gossypium hirsutum* L.) producers aim to reduce plant populations without sacrificing yields. Field experiments examining the impact of plant population and planting date on cotton growth, fruiting, lint yield, and fiber quality were conducted in Virginia and North Carolina in 2005 and 2006, and in Louisiana during 2005. Plant populations of 4.9, 9.8, and 16.4 plants m^{-2} and two planting dates ranging from 24 April to 5 May and 15 to 25 May were targeted. Actual plant populations achieved were 5.2, 9.2, and 11.2 plants m^{-2} (Virginia 2005); 5.2, 9.2, and 15.4 plants m^{-2} (North Carolina 2005); 5.6, 9.5, and 17.1 plants m^{-2} (Louisiana 2005); 4.9, 6.6, and 12.8 plants m^{-2} (Virginia 2006); 5.9, 8.9, and 12.8 plants m^{-2} (North Carolina 2006). In Virginia in 2005 and 2006, the 5.3 plants m^{-2} population had more apical main-stem nodes than 8.9 and 12.8 plants m^{-2}, and in 2005 had more monopodial and outer position bolls regardless of planting date. Lint yields were highest with populations of 8.9 and 12.8 plants m^{-2} in Virginia and North Carolina compared to 5.3 plants m^{-2}, while in Louisiana the highest yields resulted from 5.8 and 9.5 plants m^{-2} compared to 17.1 plants m^{-2}. In Virginia and North Carolina a maximum of 118 heat units accumulated between planting dates, while 270 heat units accumulated in Louisiana. Regardless of plant population, cotton planted early (1 May) in Louisiana yielded higher than the late planted (21 May). However, there were no yield differences due to planting date in Virginia and North Carolina. In regions where few heats units accumulate early in the season, earlier planting appears to be of little benefit, while earlier planting may increase yields when a significantly larger amount of heat units accumulate near planting.

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Cotton (*Gossypium hirsutum* L.) growth and development are influenced by environmental conditions, as well as seasonal management practices. Hastening maturity is critical in the northern region of the cotton belt, which frequently experiences relatively cool, wet springs, and accumulates fewer heat units relative to the southern region of the cotton belt (Edmisten, 2007; Faircloth, 2007). Plant population and planting date can influence maturity (Edmisten, 2007; Faircloth, 2007). With increases in cotton seed prices following the introductions of various transgenic and seed treatment technologies, determining optimal plant populations is increasingly important (Bednarz et al., 2006; Pettigrew and Johnson, 2005; Siebert and Stewart, 2006; Siebert et al., 2006). While reducing seeding rate at planting may lower input costs, maturity, lint yield, and fiber quality may be negatively impacted at excessively low plant populations (Pettigrew and Johnson, 2005; Siebert and Stewart, 2006; Siebert et al., 2006).

Past research has examined the effects of variable cotton populations on yield and fiber quality and have reported that the optimal plant population can vary across environments (Bednarz et al., 2005; Pettigrew and Johnson, 2005; Siebert and Stewart, 2006; Siebert et al., 2006). Virginia Cooperative Extension recommends a cotton seeding rate of 9.8-13.1 seed m^{-2} (Faircloth, 2007). Recent research has reported optimal yields in plant populations ranging from 9.0-21.5 plants m^{-2} in Georgia (Bednarz et al., 2005), 3.4-15.3 plants m^{-2} in Louisiana (Siebert et al., 2006), 9-13 plants m^{-2} in Mississippi (Pettigrew and Johnson, 2005), and 2-12 plants m^{-2} in North Carolina (Jones and Wells, 1998). Yield reduction can occur at plant populations of 3.4-7 plants m^{-2} (Bednarz et al., 2005; Pettigrew and Johnson, 2005; Siebert and Stewart, 2006; Siebert et al., 2006), and may be magnified by early season stress caused by seedling diseases, sand blasting, hail, and soil crusting prior to emergence (Gannaway et al., 1995). Low plant populations may also result in delayed maturity (Jones and Wells, 1997; Siebert and Stewart, 2006; Siebert et al., 2006) and reduced harvesting efficiency due to increased branching (Gannaway et al., 1995).

In dense plant populations (> 10 plants m^{-2}), shading caused by excessive vegetative growth may result in a greater potential for boll rot (York, 1983a), fruit abscission (Bednarz et al., 2000; Guinn, 1974), increased plant height (Siebert et al., 2006), and delayed maturity (Cathey and Meredith, 1988; York, 1983a, York, 1983b), leading to reduced yield (Cathey and Meredith, 1988; Gwathmey and Craig, 2003; Siebert and Stewart, 2006; York, 1983b) and fiber quality (Bednarz et al., 2006; York, 1983b). Reduced micronaire and fiber fineness has been reported in lint produced by cotton in dense plant populations (12.6-21.5 plants m^{-2}) (Bednarz et al., 2000; Bednarz et al., 2005; Bednarz et al., 2006). Bednarz et al. (2006) reported an increase in fiber length at lower plant populations (3.6-9.0 plants m^{-2}), but an increase in the percentage of immature fibers at higher plant populations (9.0-21.5 plants m^{-2}) when measured across fruiting positions. Past research has also indicated that in higher plant populations (> 15.3 plants m^{-2}), cotton plants typically produce fewer apical main-stem nodes and monopodial branches plant^{-1} (Bednarz et al., 2000; Jones and Wells, 1998; Siebert and Stewart, 2006; Siebert et al., 2006).

Lower plant populations (2.0-5.1 plants m^{-2}) typically demonstrate greater fruit retention and produce more apical main-stem nodes plant^{-1}, bolls on monopodial branches plant^{-1}, and bolls on distal sympodial branch fruiting positions plant^{-1} (Bednarz et al., 2000; Jones and Wells, 1998; Siebert and Stewart, 2006; Siebert et al., 2006). Bolls produced on monopodial branches and sympodial branch fruiting positions past the second position are reported to be of lower quality than those on sympodial branches and closer to the main-stem (Bednarz et al., 2005; Bednarz et al., 2006; Jones and Wells, 1998).

The impact of plant population on cotton growth and development may be influenced by planting date, as the potential for optimizing yield is directly affected by the accumulation of heat units (Guthrie, 1991; Nuti et al., 2006; Pettigrew, 2002; Porter et al., 1996). In environments where fewer heat units accumulate, earlier planting is beneficial as it allows plants to mature and increases the probability of harvesting prior to inclement fall weather. Risks associated with early planted cotton include cool ambient and soil temperatures (Christiansen and Thomas, 1969; Pettigrew, 2002), wet weather (Guthrie, 1991), physical resistance (soil impedance, sand blasting, etc.) (Guthrie, 1991), seedling disease (Guthrie, 1991; Pettigrew, 2002), and insect pressure (Pettigrew, 2002). These risks individually or collectively can be detrimental to cotton emergence, growth, and yield.

Planting recommendations in several cotton producing states are based on date and soil temperatures reaching or exceeding 15-18°C at 7.6 cm of depth by 10:00 a.m. (Edmisten, 2007; Faircloth, 2007). However, planting is usually delayed when ambient temperatures below 10°C are expected within five days following planting as cotton seedling growth is delayed at these low temperatures (Christiansen and Thomas, 1969; Pettigrew, 2002). Virginia Cooperative Extension recommends planting cotton in Virginia from 20 April to 25 May, depending on environmental conditions (Faircloth, 2007). Optimum yield has been associated with early-March to mid-April plantings for Texas (Davidonis et al., 2004), early to mid-April plantings for Mississippi (Cathey and Meredith, 1988; Pettigrew and Adamczyk, 2006), early-May plantings in North Carolina (Guthrie, 1991; Nuti et al., 2006) and mid to late-April plantings in South Carolina (Bauer et al., 1998; Porter et al., 1996). However, in some cases, reduced fiber strength, fiber elongation, and fiber length were reported for early to mid-April plantings (Pettigrew, 2002; Pettigrew and Adamczyk, 2006).

In summary, the impact of plant population and planting date may vary depending on growing conditions. As rising seed costs encourage a reduction in seeding rate, earlier plantings may become critical to allow for yield compensation. The objective of this research was to examine cotton growth, fruiting, lint yield, and fiber quality response in different environments to various plant populations and planting dates.

MATERIALS AND METHODS

Field experiments were conducted at the Virginia Tech, Tidewater Agricultural Research and Extension Center in Suffolk, VA (36°41' N, 76°46' W) in 2005 on an Uchee loamy sand soil (loamy, kaolinitic, thermic Arenic Kanhapludults), and in 2006 on an Emporia loamy fine sand soil (fine-loamy, siliceous, subactive, thermic Typic Hapludults). The experiment was also conducted at the North Carolina State University, Upper Coastal Plain Research Station near Rocky Mount, NC (35°54' N, 77°43' W) in 2005 on a Rains loamy sand soil (fine-loamy, siliceous, semiactive, thermic Typic Paleaquults), the Central Crops Research Station in Clayton, NC (35°40' N, 78°30' W) in 2006 on a Johns fine sandy loam soil (fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludults), and the LSU AgCenter, Dean Lee Research Station in Alexandria, LA (31°10' N, 92°24' W) in 2005 on a Norwood silt loam soil (fine-silty loam, mixed calcareous, thermic Typic Udifluvent). Throughout the results, each location and year is referred to individually as a trial.

Six treatment combinations were tested in a split-plot design with four replicates, where planting date was the main-plot factor and plant population was the sub-plot factor. Plots were non-irrigated and four rows [91.4-cm centers (Virginia and North Carolina) or 96.5-cm centers (Louisiana)] wide by 12.2-m long. Cotton cultivars 'Phytogen 475 WRF' and 'Phytogen 485 WRF' were planted in 2005 and 2006, respectively. Two separate planting dates were utilized to represent an early planting (EP) (24 April to 5 May) and a late planting (LP) (15 May to 25 May), with a targeted minimum of 21 days between plantings (Table 1). In North Carolina in 2006, wet weather delayed planting so there were only 14 days between plantings. Three plant populations were targeted at planting (4.9, 9.8, and 16.4 plants m^{-2}). Plots were hand-thinned 21 days after emergence to achieve desired plant populations. Actual populations achieved by location and year are provided in Table 1. Decisions on fertility, weed control, insect control, and plant growth regulator application methods were followed according to respective state cooperative extension recommendations (Edmisten et al., 2005; Faircloth et al., 2005; Stewart, 2005).

Plant mapping data were collected at the end of the growing season from six randomly selected plants within each treatment in Virginia (2005 and 2006), and in North Carolina (2006) to determine the height-to-node ratio (HNR), number of apical main-stem nodes, total first and second position sympodial bolls, monopodial bolls, and outer position bolls (bolls on fruiting positions greater than the second position) (Bourland and Watson, 1990). Plant mapping data were not collected for Louisiana.

When necessary, harvest aid applications and harvest were performed separately by planting date. Harvest aid applications were based on the maturity of each planting date reaching an average of 60% open bolls. Two weeks after defoliation, the center two rows of each plot were harvested using a two-row commercial spindle cotton harvester. Seed-cotton samples from each plot were retained and ginned on a 10-saw gin to determine lint yield. A 150 g sub-sample was sent to the USDA classing office in Florence, SC to determine physical fiber properties using high volume instrument analysis.

Table 1. Planting date, target populations, and actual plant populations for Virginia and North Carolina (2005 and 2006), and Louisiana (2005).

	2005			2006	
	Virginia	**North Carolina**	**Louisiana**	**Virginia**	**North Carolina**[y]
Planting date[z]	**27 April**	**3 May**	**1 May**	**24 April**	**11 May**
	18 May	**24 May**	**21 May**	**15 May**	**25 May**
Target population	**Actual population**				
plants m^{-2}	**plants m^{-2}**				
4.9	**5.2**	**5.2**	**5.6**	**4.9**	**5.9**
9.8	**9.2**	**9.2**	**9.5**	**6.6**	**8.9**
16.4	**11.2**	**15.4**	**17.1**	**12.8**	**12.8**

[z] **Actual planting dates for Virginia and North Carolina (2005 and 2006), and Louisiana (2005).**

[y] **Only 14 days between planting dates due to wet weather.**

Data were analyzed using PROC GLM (SAS Institute, 2000). Means were separated using Fisher's Protected LSD test and statistical significance was evaluated at P = 0.05. Initially all data were combined, but due to significant trial × main effect interactions, Louisiana data were analyzed independent of Virginia and North Carolina (Table 2). Virginia and North Carolina data were combined when applicable, or analyzed by trial when a significant trial × main effect interaction occurred. Monthly cumulative heat units (calculated as the sum of the average of the maximum and minimum daily temperatures minus 15.5 °C for each month) and precipitation were recorded each year at all locations (Table 3).

RESULTS AND DISCUSSION

Environmental Conditions: The Virginia and North Carolina early season was characterized both years by relatively cool (76 to 118 heat units) and wet (7.8 to 11.5 cm precipitation) weather in May. In contrast, Louisiana was warmer (270 heat units) and drier (2.7 cm precipitation). Pettigrew (2002) has reported that early season stunting from cool weather can affect the growth and development of cotton, which likely occurred in Virginia and North Carolina, causing less variation in the results between these trials. Louisiana was also warmer than North Carolina and Virginia from May to October 2005, with each state accumulating 2104, 1436, and 1316 total heat units, respectively (Table 3). In 2006, the Virginia trial received twice as much precipitation as North Carolina, while heat units remained similar. The trial × main effect interactions observed in this experiment were most likely influenced by variations in environmental conditions at each trial during the 2005 and 2006 growing seasons.

Plant Population: Actual plant populations achieved were 5.3, 9.2, 11.2 (Virginia); 5.3, 9.2, 15.4 (North Carolina); 5.6, 9.5, 17.1 (Louisiana) plants m^{-2} in 2005, and 4.9, 6.7, 12.8 (Virginia); and 5.9, 8.9, 12.8 (North Carolina) plants row m^{-2} in 2006 (Table 1). No interactions were observed between Virginia and North Carolina plant populations. Therefore, plant populations were combined across years for those two states, resulting in mean populations of 5.3, 8.9, and 12.8 plants m^{-2}. Due to the higher plant populations (5.6, 9.5, 17.1 plants m^{-2}) in Louisiana, a trial × treatment interaction was observed and all data were analyzed separately for that trial. There were no planting date by plant population interactions observed in this experiment.

Table 2. Analysis of variance for main effects and main effect interactions on plant stand, lint percentage, lint yield, micronaire, fiber length, fiber length uniformity, fiber strength, height-to-node ratio, apical main-stem nodes, first position sympodial bolls, second position sympodial bolls, outer position sympodial bolls, and monopodial bolls for Virginia and North Carolina (2005 and 2006), and Louisiana (2005).

Source	Plant stand	Lint %	Lint yield	Micronaire	Fiber length	Fiber length uniformity	Fiber strength	Height-to-node ratio	Main-stem nodes	Sympodial positions 1st	Sympodial positions 2nd	Sympodial positions Outer	Sympodial positions Mono.
Virginia and North Carolina (2005 and 2006)													
Trial[z]	***	***	***	***	***	***	NS	**	***	***	***	***	***
PDATE [y]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Trial × PDATE	***	NS	NS	***	*	***	NS	***	***	***	**	NS	*
PPOP	***	NS	*	NS	NS	NS	NS	NS	***	*	*	NS	NS
Trial × PPOP	***	NS	NS	NS	NS	NS	NS	NS	NS	**	*	**	***
PDATE × PPOP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Trial × PDATE × PPOP	***	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Louisiana (2005)													
PDATE	NS	NS	*	NS	NS	NS	NS	–	–	–	–	–	–
PPOP	***	NS	*	*	NS	NS	NS	–	–	–	–	–	–
PDATE × PPOP	NS	NS	NS	NS	NS	NS	NS	–	–	–	–	–	–

[z] Trial represents Year × Location.

[y] Abbreviations: NS (not significant); PDATE (planting date); PPOP (plant population).

*, **, *** denotes level of significance at the 0.05, 0.01, and 0.001 probability level, respectively.

Table 3. Monthly and total cumulative heat units and precipitation recorded at Suffolk, VA (2005 and 2006), Rocky Mount, NC (2005), Clayton, NC (2006), and Alexandria, LA (2005).

2005						
	Suffolk, VA		Rocky Mount, NC		Alexandria, LA	
Month	Heat units[z]	Precipitation[y]	Heat units	Precipitation	Heat units	Precipitation
		cm		cm		cm
May	76	9.7	98	11.5	270	2.7
June	247	5.2	252	13.6	385	2.1
July	351	11.6	369	6.6	428	10.9
August	330	5.9	352	6.8	446	1.3
September	231	6.6	260	4.4	397	17.5
October	81	16.3	105	9.3	178	1.1
Total	1316	55.3	1436	52.2	2104	35.6

2006				
	Suffolk, VA		Clayton, NC	
Month	Heat units	Precipitation	Heat units	Precipitation
		cm		cm
May	97	7.8	118	9.4
June	226	23.2	239	1.4
July	314	6.9	338	4.7
August	315	6.0	331	8.8
September	143	19.9	163	8.7
October	43	18.9	55	7.6
Total	1138	82.7	1244	40.6

[z] Cumulative heat units , base 15.5°C. Heat units = ([Max. temperature + Min. temperature]/2) – 15.5.

[y] Monthly average precipitation.

Growth Characteristics and Boll Distribution: Height-to-node ratio was decreased at a plant population of 5.3 plants m^{-2} for Virginia in 2005 and 2006, but was not influenced by plant population for North Carolina in 2006 (Table 4). Height-to-node ratio has been previously reported to be directly related to plant population (Siebert and Stewart, 2006). Planting date had no influence on HNR in Virginia or North Carolina in 2005 and 2006, which Pettigrew and Adamczyk (2006) previously reported.

The trial × treatment interaction was significant for number of apical main-stem nodes plant^{-1}; therefore, Virginia (2005 and 2006) and North Carolina (2006) data are reported separately. Neither plant population nor planting date influenced the number of apical main-stem nodes plant^{-1} (Table 4) in North Carolina. In Virginia, more apical main-stem nodes (16.7, 17.2, and 17.4 nodes plant^{-1}) were observed as plant population decreased from 12.8, 8.9, and 5.3 plants m^{-2}, respectively. Several researchers (Bednarz et al., 2000; Bednarz et al., 2006; Siebert and Stewart, 2006; Siebert et al., 2006) have reported that plant population can inversely impact the number of apical main-stem nodes on cotton plants. Similar to findings reported by Nuti et al. (2006), EP cotton displayed a higher number of apical main-stem nodes than LP (17.8 nodes plant^{-1}) in Virginia.

Results of first and second position sympodial bolls plant^{-1} are reported by location due to a significant trial × treatment interaction. Plant population did not influence either the number of first or second position sympodial bolls plant^{-1} in those trials (Table 4). In North Carolina (2006), the number of first and second position sympodial bolls was also not influenced by planting date, although both were numerically higher in EP cotton (4.8 and

1.3 first and second position sympodial bolls plant^{-1}, respectively). In Virginia (2005 and 2006), the EP cotton produced more first (8.4 bolls plant^{-1}) and second (4.6 bolls plant^{-1}) position sympodial bolls compared to the LP cotton (6.5 bolls plant $^{-1}$ and 3.6 bolls plant^{-1}, respectively).

Due to significant trial × treatment interactions, each trial was analyzed separately for monopodial and outer position bolls plant^{-1} in Virginia (2005 and 2006) and North Carolina (2006). In Virginia in 2005, a significantly higher number of monopodial bolls plant^{-1} (1.4, 3.1, and 5.8 bolls plant^{-1}, LSD = 1.3; not shown) were produced as plant population decreased from 12.8, 8.9, and 5.3 plants m^{-2}. Similar to findings of Bednarz et al. (2000) and Siebert and Stewart (2006), the 5.3 plant m^{-2} population produced significantly more outer position bolls plant^{-1} (1.0 boll plant^{-1}, LSD = 0.3; not shown) compared to the 12.8 and 8.9 plants m^{-2} populations (0.3 and 0.2 bolls plant^{-1}, respectively, LSD = 0.3; not shown) in 2005. As previously noted in other research, sparse cotton plant populations tend to produce more monopodial and outer position bolls than cotton in dense populations (Bednarz et al., 2000; Bednarz et al., 2006; Siebert and Stewart, 2006; Siebert et al., 2006). A similar trend was observed in Virginia and North Carolina in 2006 for both monopodial bolls and outer position bolls; however, there were no differences at any plant population. Planting date had no influence on the number of monopodial bolls or outer position bolls in those trials.

Lint Percentage and Yield: In this experiment, despite differences in boll location, lint percentage (Table 5) was not affected by plant population or planting date in any trial. Conversely, Bednarz et al. (2005) reported that lint percentage increased with a plant population of 3.6 plants m^{-2} compared to 9.0-21.5 plants m^{-2}, while lint percentage has also been reported to increase with EP cotton (Cathey and Meredith, 1988; Pettigrew, 2002; Porter et al., 1996).

Table 4. Location, plant population, and planting date effect on the height-to-node ratio, number of apical main-stem nodes, number of first position sympodial bolls, and number of second position sympodial bolls plant $^{-1}$ at Suffolk, VA (2005 and 2006), and in Clayton, NC (2006).

Location	Population[x]	Height-to-node ratio	Main-stem nodes	Sympodial position		
				1	2	Total
	plants m $^{-2}$	cm	no.	– bolls plant $^{-1}$ –		
VA[z]	5.3	4.9	17.4	8.1	4.6	12.7
	8.9	5.1	17.2	7.4	4.4	11.8
	12.8	5.1	16.7	7.0	3.3	10.2
	LSD (0.05)	0.1	0.1	NS	NS	
NC[y]	5.3	4.5	13.8	4.5	1.2	5.7
	8.9	4.3	14.1	4.6	1.2	5.9
	12.8	4.3	14.2	5.2	1.0	6.2
	LSD (0.05)	NS	NS	NS	NS	
	Planting date[w]					
VA	EP[v]	4.8	17.8	8.4	4.6	13.0
	LP	5.2	16.5	6.5	3.6	10.1
	LSD (0.05)	NS	0.5	0.6	0.4	
NC	EP	4.3	13.8	4.8	1.3	6.2
	LP	4.4	14.2	4.7	1.0	5.7
	LSD (0.05)	NS	NS	NS	NS	

[z] Virginia mapping data combined for 2005 and 2006.

[y] North Carolina mapping data for Clayton, NC (2006).

[x] Pooled plant population data for Virginia and North Carolina.

[w] Target planting dates of early planting (24 April to 5 May) and late planting (15 May to 25 May).

[v] Abbreviations: EP (early planting); LP (late planting); NS (not significant).

Table 5. Location, plant population and planting date effect on lint percentage and lint yield at Suffolk, VA (2005 and 2006); Rocky Mount, NC (2005) and Clayton, NC (2006); and Alexandria, LA (2005).

Location	Population [x]	Lint percentage	Lint yield
	plants m $^{-2}$	%	kg ha $^{-1}$
VA/NC [z]	5.3	43.0	916
	8.9	42.9	971
	12.8	43.0	1048
	LSD (0.05)	NS	90
LA [y]	5.8	41.1	1832
	9.5	41.1	1840
	17.1	41.2	1663
	LSD (0.05)	NS	162
	Planting date [w]		
VA/NC	EP [v]	42.9	973
	LP	43.0	987
	LSD (0.05)	NS	NS
LA	EP	41.2	2061
	LP	41.0	1495
	LSD (0.05)	NS	397

[z] Virginia and North Carolina data combined for 2005 and 2006.

[y] Louisiana data reported individually for 2005.

[x] Pooled plant population data for Virginia and North Carolina, with Louisiana reported individually.

[w] Target planting dates of early planting (24 April to 5 May) and late planting (15 May to 25 May).

[v] Abbreviations: EP (early planting); LP (late planting); NS (not significant).

In Virginia and North Carolina, populations of 8.9 and 12.8 plants m $^{-2}$ resulted in higher yields compared to 5.3 plants m $^{-2}$ (Table 5). Bednarz et al. (2005), Pettigrew and Johnson (2005), and Siebert et al. (2006) reported that yield can be reduced at plant populations of 3.4-7.0 plants m $^{-2}$ compared to populations of 9.0-21.5 plants m $^{-2}$. In the Louisiana trial, lint yield was reduced with a plant population of 17.1 plants m $^{-2}$, while the yields of 5.8 and 9.5 plants m $^{-2}$ were not different from each other. Similarly, in previous research in Louisiana, Siebert and Stewart (2006) reported a yield reduction where plant population was 15.3 plants m $^{-2}$ versus 5.1-10.2 plants m $^{-2}$. Research in several cotton producing states has shown that optimal yields can be produced at plant populations from 3.4 plants m $^{-2}$ (Siebert et al., 2006) to 25.1 plants m $^{-2}$ (Bednarz et al., 2000). This wide range in optimal plant populations may be attributed to several factors, including but not limited to differences in location, environment, and the ability of cotton to compensate for different populations during the growth and development stages.

Differences in lint yield (Table 5) between early versus late planted cotton may be related to variations in early season heat unit accumulation in Louisiana (Table 3). As previously mentioned, relatively few heat units (78-118 heat units) accumulated between planting dates in Virginia and North Carolina in each year, while greater than two times the number of heat units (270 heat units) were accumulated in Louisiana. Planting date did not influence lint yield in Virginia and North Carolina despite differences in the number of first and second position sympodial bolls. However, in Louisiana yields were increased with the EP cotton (2061 kg ha $^{-1}$), compared to the LP cotton (1495 kg ha $^{-1}$). Pettigrew and Adamczyk (2006) reported a 10% yield increase with earlier planting (early-April versus early-May) in Mississippi. Pettigrew (2002) also reported a yield increase in earlier plantings in four out of five years. In the year where yields were not different between plantings, Pettigrew (2002) attributed this to cool weather and stunting in the early season. Yield reduction from this early cool weather may help explain the equivalent yields that resulted for the early and late plantings of Virginia and North Carolina, as heat unit accumulation was comparable to that particular year in Mississippi (38 heat units accumulated during April 1997).

Fiber Quality: In this experiment, fiber strength was not influenced by plant population or planting date in any trial (Table 2). Pettigrew and Johnson (2005) and Siebert et al. (2006) have reported similar results for varying plant populations, while Bauer et al. (1998), Pettigrew (2002), and Porter et al. (1996) reported inconsistent results for fiber strength due to planting date. The results for all other fiber quality parameters are reported by trial due to trial × treatment interactions (Table 6).

In North Carolina and Louisiana in 2005, lower micronaire values (4.84 and 4.59 units) were observed in the highest populations (12.8 and 17.1 plants m $^{-2}$, respectively) (Table 6). Micronaire was not significantly impacted by plant population in any other trial. Micronaire reduction associated with increasing plant populations has been reported in previous research (Gannaway et al., 1995; Jones and Wells, 1998; Pettigrew and Johnson, 2005; York, 1983b). Only the EP for North Carolina in 2006 resulted in differences in micronaire values when compared to the LP (5.02 and 5.47 units, respectively). Although not significant, in the remaining four trials micronaire values were reduced numerically in the LP, which has been previously noted (Bauer et al., 1998; Cathey and Meredith, 1988; Pettigrew and Adamczyk, 2006; Porter, 1996).

Plant population had no influence on fiber length for any trial. For all trials there was a trend toward longer fiber length in the LP cotton (Table 6), being significantly different only in North Carolina in 2006. Similarly, Bauer et al. (1998), Davidonis et al. (2004), Pettigrew (2002), and Pettigrew and Adamczyk (2006) reported increases in fiber length with delayed planting.

In this experiment plant population had no effect on fiber length uniformity in all trials, except in North Carolina in 2006 for the 12.8 plants m^{-2} population, where length uniformity was 82.9%, significantly less than length uniformity in the lower populations of 5.3 and 8.9 plants m^{-2} (83.7% and 83.7%, respectively). Bednarz et al. (2005), Pettigrew and Johnson (2005), and Siebert et al. (2006) reported that plant population had no affect on fiber length uniformity. Fiber length uniformity values were numerically higher in all trials for the LP, although only North Carolina in 2006 LP resulted in a significant difference in length uniformity (84.4%) when compared to the EP (82.5%). Porter et al. (1996) also reported that delayed planting produced higher fiber length uniformity values.

CONCLUSIONS

This research suggests that when few heat units accumulate early in the growing season (late-April to mid-May), there is little to no benefit to planting cotton in late-April to early-May versus late-May. In this experiment, measurements of monopodial bolls and outer position bolls taken in Virginia and North Carolina in 2005 and 2006 confirmed that early planting did not enhance the plant's ability to compensate for sparse populations. In environments where a greater number of heat units accumulate in May, yield may be more likely to be enhanced by early planting as observed in Louisiana in 2005.

Plant population appears to be a critical factor in optimizing yield, especially in environments where fewer heat units accumulate throughout the season. Although plant compensation through monopodial bolls and outer position bolls was seen in some cases in Virginia and North Carolina, at a plant population of 5.3 plants m^{-2} yields were reduced. In Louisiana, where more heat units accumulated throughout the season, yields were optimal in lower populations of 5.6 to 9.5 plants m^{-2} and were decreased when plant populations reached 17.1 plants m^{-2}.

Overall fiber quality results in previous plant population and planting date research have been inconsistent, suggesting that seasonal environmental conditions may impact fiber quality. The influence that plant population has on micronaire may also involve the increase in monopodial and outer position bolls found in lower plant populations. Although monopodial and outer position bolls were not measured specifically in Louisiana, lower populations resulted in higher micronaire values in that trial. While generally not significant, decreases in fiber length and fiber length uniformity in the earlier planted cotton may be associated with lower heat unit accumulation during flowering compared to the later planted cotton.

This experiment did not indicate that the impact of plant population on the parameters measured was influenced by the planting dates examined. These findings are limited to the years and locations utilized and further research should be conducted in multiple environments with cultivars ranging in maturity to better understand these relationships.

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Table 6. Trial and plant population effect on physical fiber properties at Suffolk, VA (2005 and 2006); Rocky Mount, NC (2005) and Clayton, NC (2006); and Alexandria, LA (2005).

Location	Population[y]	Micronaire	Fiber length	Fiber length uniformity
	plants m $^{-2}$	units	cm	%
VA 2005[z]	5.3	4.31	2.91	84.3
	8.9	4.35	2.91	84.7
	12.8	4.38	2.92	84.3
	LSD (0.05)	NS	NS	NS
VA 2006	5.3	4.70	2.87	84.1
	8.9	4.66	2.86	84.2
	12.8	4.76	2.86	83.9
	LSD (0.05)	NS	NS	NS
NC 2005	5.3	4.94	2.67	82.3
	8.9	5.00	2.69	82.7
	12.8	4.84	2.69	82.7
	LSD (0.05)	0.12	NS	NS
NC 2006	5.3	5.30	2.73	83.7
	8.9	5.31	2.73	83.7
	12.8	5.39	2.71	82.9
	LSD (0.05)	NS	NS	0.56
LA 2005	5.8	4.74	2.82	83.5
	9.5	4.75	2.82	83.3
	17.1	4.59	2.83	83.3
	LSD (0.05)	0.13	NS	NS
	Planting date[x]			
VA 2005	EP[w]	4.42	2.89	84.3
	LP	4.27	2.92	84.6
	LSD (0.05)	NS	NS	NS
VA 2006	EP	4.72	2.85	84.0
	LP	4.55	2.88	84.1
	LSD (0.05)	NS	NS	NS
NC 2005	EP	5.02	2.67	82.5
	LP	4.83	2.69	82.7
	LSD (0.05)	NS	NS	NS
NC 2006	EP	5.02	2.68	82.5
	LP	5.47	2.77	84.4
	LSD (0.05)	0.06	0.04	0.56
LA 2005	EP	4.76	2.80	83.4
	LP	4.62	2.84	83.4
	LSD (0.05)	NS	NS	NS

[z] Virginia and North Carolina data combined for 2005 and 2006.

[y] Pooled plant population data for Virginia and North Carolina, with Louisiana reported individually.

[x] Target planting dates of early planting (24 April to 5 May) and late planting (15 May to 25 May).

[w] Abbreviations: EP (early planting); LP (late planting); NS (not significant).

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