Individual Experiments to Evaluate the Effects of Plant Population and Planting Date, Cultivar and Plant Growth Regulator Application, and Herbicide and Plant Growth Regulator Application on Cotton (*Gossypium hirsutum* L.) Growth and Development, Yield, and Fiber Quality

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) growth and development, lint yield, and fiber quality are influenced by many management decisions. Three field experiments examining the interaction of plant population and planting date, and cultivar or herbicide and plant growth regulator application on these parameters were conducted in Virginia during 2005 and 2006 and in North Carolina, South Carolina, and Louisiana during specific years.

Experiment I: Plant Population and Planting Date

Lint yields were highest with populations of 8.9 and 12.8 plants m^{-2} compared to 5.3 plants m^{-2} in Virginia and North Carolina, while in Louisiana the highest yields resulted from populations of 5.8 and 9.5 plants m^{-2} compared to 17.1 plants m^{-2}. Earlier planted (1 May) cotton produced higher yields relative to later planted (21 May) cotton in Louisiana, while yield was not influenced by planting date in Virginia and North Carolina. The impact of plant population and planting date on cotton appeared to be influenced significantly by heat unit accumulation.

Experiment II: Cultivar and Mepiquat Pentaborate Application

Mepiquat pentaborate (MPB) application consistently decreased plant height, HNR, and enhanced maturity for all cultivars, compared to untreated cotton. A trend of decreasing yield with increasing MPB application in Virginia was observed. These data suggests that cotton response to MPB application is influenced by cultivar maturity or fruiting interval.

Experiment III: Trifloxysulfuron-sodium and Mepiquat Chloride Application

Trifloxysulfuron-sodium (TFS) did not influence vegetative growth, maturity, or yield in comparison to untreated cotton. Mepiquat chloride (MC) application reduced vegetative growth and enhanced maturity in most years. The results of this experiment demonstrate that TFS application does not have the same effects on plant growth as MC application.

DEDICATION

I would like to dedicate this thesis to my family, especially my grandfather, as they have been my encouragement and support. Although my grandfather has not been here to see my accomplishments, I know he is proud and I hope to continue that. My entire family has believed in and supported me, and without them I would not have been able to continue through school away from home. I appreciate everyone who has helped and prayed for me along the way and I hope that I will be able to return my thanks in the future.

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Most importantly, I want to thank my family for all their support and encouragement as I continued with my education. They have made me into the person I am and pushed me to pursue everything that I have ever wanted. I especially want to thank my mom and dad for always believing in me and supporting everything I do. I also want to thank Lauren Bunch for being there for me through everything, as being away from home was never easy. I would also like to thank God, as he has given me the ability I have and continues to watch over me through every step of my life.

A special thanks also goes to the Virginia Cotton Board, Cotton Incorporated, Dow AgroSciences, and BASF Corporation for their financial support of my research.

ATTRIBUTION

Dr. Joel Faircloth, the Extension Cotton and Peanut specialist at the Tidewater Agricultural Research and Extension Center (TAREC) in Suffolk, Virginia, developed the cotton research experiments that I performed for the use of my thesis. Dr. Faircloth is my primary advisor and has supervised and assisted with the research of each these experiments, along with the preparation of each manuscript within this thesis. Dr. Ozzie Abaye, an Associate Professor in the Crop and Soil Environmental Sciences Department at Virginia Tech, and Dr. Ames Herbert, the Extension Entomologist at the TAREC are both graduate committee members that assisted in the preparation and review of my thesis and defense. Dr. Keith Edmisten, the Extension Cotton Specialist at North Carolina State University, and Guy Collins, a graduate student at North Carolina State University, performed the experiments and collected data associated with plant population and planting date, and trifloxysulfuron-sodium that was included in Chapters 2 and 4. Dr. Alexander Stewart, the Extension Cotton Specialist at the Louisiana State University AgCenter, Dean Lee Research Station in Alexandria, Louisiana performed and collected data associated with plant population and planting date experiment that was included in Chapter 2. Robert Haygood, a Production Technology Specialist for Dow AgroSciences provided funding for the plant population and planting date experiment that is included in Chapter 2. Dr. Michael Jones, the Extension Cotton Specialist at the Clemson University Pee Dee Research and Education Center in Florence, South Carolina, performed the cultivar and mepiquat pentaborate application experiment and collected data that was included in Chapter 3 of my thesis. Thomas McKemie, a Technical Service Representative for BASF Corporation provided funding that was used to perform the cultivar and mepiquat pentaborate experiment included in Chapter 3. Each of these co-authors provided significant contribution and without their help this research would not have been possible.

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CHAPTER 1

Literature Review

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Abbreviations: PGR, plant growth regulator; MC, mepiquat chloride; MPB, mepiquat pentaborate; TFS, trifloxysulfuron-sodium; POST, postemergence; ALS, acetolactate synthase; WAT, week(s) after treatment

Numerous management decisions influence cotton (*Gossypium hirsutum* L.) growth and development including, but not limited to, plant population, planting date, cultivar selection, herbicide application, and plant growth regulator application. Cotton growth and development is also significantly impacted by environmental conditions, especially in the northern region of the cotton belt where limited heat unit accumulation leads to shorter growing seasons (i.e., Virginia) compared to the southern regions (Gwathmey and Craig, 2003). These agronomic and environmental factors individually and collectively affect cotton and plant growth regulation strategies of producers (Kerby, 1985; Kerby et al., 1986; Gwathmey and Craig, 2003).

Plant Population

As producers reduce seeding rate at planting to lower input costs, there may be negative effects associated with excessively low populations including delayed maturity, reduced lint yield, and poor fiber quality (Pettigrew and Johnson, 2005; Siebert et al., 2006; Siebert and Stewart, 2006). Virginia Cooperative Extension recommends a cotton seeding rate of 9.8-13.1 seed m^{-2}, with optimal yields achieved at 3.3-6.5 plants m^{-2} (Faircloth, 2007a). Previous research has reported optimal yields with as few as 2 plants m^{-2} (Jones and Wells, 1998) and as many as 21.5 plants m^{-2} (Bednarz et al., 2005). However, a yield reduction has occurred at plant populations of 3.4-7.0 plants m^{-2} (Bednarz et al., 2005; Pettigrew and Johnson, 2005; Siebert et al., 2006; Siebert and Stewart, 2006). Problems associated with dense populations include shading from excessive vegetative growth, which causes a greater potential for boll rot, fruit abscission, increased plant height, and delayed maturity, resulting in reduced yield and fiber quality (York, 1983; Bednarz et al., 2000; Bednarz et al., 2006; Siebert and Stewart, 2006).

Planting Date

The impact that plant population has on cotton growth and development may also be directly influenced by planting date as the potential for optimizing yield is related to heat unit accumulation (Guthrie, 1991; Porter et al., 1996; Pettigrew, 20002; Nuti et al., 2006). In the northern region of the cotton belt where heat unit accumulation is limited, earlier planting may benefit that region as the plants have more time to reach full maturity, enhancing the probability of harvesting before inclement fall weather (Faircloth, 2007a). However, there are risks associated with early planted cotton such as cool ambient temperatures, seedling disease, and insect pressure that can be detrimental to cotton growth and yield (Christianson and Thomas, 1969; Porter et al., 1996; Jones and Wells, 1997; Pettigrew, 2002). The Virginia Cooperative

Extension recommends planting cotton in Virginia from 20 April to 25 May when soil temperatures reach or exceed 15-18°C at three inches of depth by 10:00 a.m., while planting should be delayed when ambient temperatures below 10°C are expected within five days of planting (Faircloth, 2007a). Plantings during early-March to mid-April in Texas have produced optimum yields (Davidonis et al., 2004), while more northern regions of the cotton belt (i.e., North Carolina) have reported optimum yield with plantings that were delayed until early-May (Guthrie 1991; Nuti et al., 2006).

Cultivar Selection and Plant Growth Regulator Application

Since cotton is a perennial plant with an indeterminate fruiting pattern, cultivar selection and plant growth regulator (PGR) management practices are important factors when managing for earliness, especially in environments where heat unit accumulation is limited (Gwathmey and Craig, 2003). For this reason, most cultivars in Virginia are relatively determinate and early maturing to allow timely harvest (Faircloth, 2007c). In environments that accumulate more heat units relative to Virginia (i.e., South Carolina), more indeterminate, later maturing cultivars may be utilized as the growing season is extended.

In cotton production, PGR's are frequently applied to hasten maturity, especially in indeterminate cultivars, through a reduction of vegetative growth shifting plant resources to reproductive growth (Cathey and Meredith, 1988; Zhao and Oosterhuis, 2000; Gwathmey and Craig, 2003). Cotton response to PGR application includes decreased plant height, hastened maturity, and increased boll retention lower on the plant (Gwathmey and Craig, 2003; Nuti et al., 2006), along with inconsistent yield responses (Kerby, 1985; Cathey and Meredith, 1988; Zhao and Oosterhuis, 2000; Nuti et al., 2006). While numerous PGR's are commercially available, most are slight variations or additives to the mepiquat chloride (MC) molecule (1,1-dimethylpiperidinium chloride), including mepiquat pentaborate (MPB) (Pentia™, BASF, Research Triangle Park, NC) which utilizes five boron molecules with mepiquat (BASF Ag Products, 2007). Previous research on MPB application has reported similar results for vegetative and reproductive growth compared to MC (Coccaro et al., 2003; Coccaro et al., 2004; Gwathmey and Craig, 2003; Gwathmey and Craig, 2004).

While results between PGR products have been similar, cultivar response may differ to PGR application as there are distinct genetic characteristics associated with each cultivar. Single and multiple MC applications have resulted in a greater response with respect to maturity and plant height in indeterminate cultivars (Gwathmey and Craig, 2003). Gwathmey and Craig (2003) concluded that MC application benefited indeterminate cultivars through vegetative growth reduction and increased yield, while aggressive MC application reduced yield in earlier, more determinate cultivars.

Herbicide Application

Early season PGR application may be influenced by herbicide application as herbicides can effect cotton growth and development through chlorosis and stunting (Porterfield et al., 2002a; Porterfield et al., 2002b; Porterfield et al., 2003; Koger et al., 2005). Trifloxysulfuron-sodium (TFS) is an early season postemergence (POST) acetolactate synthase (ALS)-inhibiting herbicide that is applied to cotton prior to the 12-true leaf stage due to the significant control of numerous common and problematic broad-leaf weeds (Porterfield et al., 2002a; Richardson et al., 2003a; Branson et al., 2005; Richardson et al., 2007b).

Postemergence TFS application has resulted in injury that is typically associated with ALS-inhibiting herbicides in cotton, including chlorosis of the treated foliage, stunting, and occasional necrotic lesions (Richardson et al., 2004a; Richardson et al., 2004b; Koger et al., 2005; Thomas et al., 2006). The stunting associated with POST TFS application has been reported as a reduction in plant height at one to two weeks after treatment (WAT) (Hoffman and Cothren, 2002; Richardson et al., 2004a; Thomas et al., 2006; Collins et al., 2007), however, Richardson et al. (2004a) reported no difference in plant height relative to untreated cotton at eight WAT. This height reduction from TFS application may alter the necessity for early season PGR application, as similar reductions in vegetative growth have been noted with PGR application (Kerby, 1985; Cathey and Meredith, 1988; Gwathmey and Craig, 2003; Collins et al., 2007).

Due to the impact that plant population, planting date, cultivar, and herbicide application has on the growth and developmental characteristics of cotton, management decisions and the necessity for PGR application may be influenced. Published literature on the interactions between these agronomic factors and PGR application is limited. The objective of this research was to examine the interactions between PGR application and plant population and planting date, cultivar, and herbicide application on the growth and development, yield, and fiber quality of cotton.

CHAPTER 2

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

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Abbreviations: EP, early planting; LP, late planting

ABSTRACT

Limited data are published on the combined effects of plant population and planting date on cotton (*Gossypium hirsutum* L.) growth and development. The objective of this research was to examine the impact of plant population and planting date on cotton growth and development, lint yield, and fiber quality in three growing environments. 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, however actual populations were 5.3, 8.9, and 12.8 plants m^{-2} in Virginia and North Carolina, and 5.6, 9.5, 17.1 plants m^{-2} in Louisiana. In Virginia 2005 and 2006, the population of 5.3 plants m^{-2} 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}. Regardless of plant population, cotton planted early (1 May) in Louisiana yielded higher than the late planted (21 May); however, there was no yield advantage to planting early in Virginia and North Carolina. The lack of yield response in Virginia and North Carolina may have been due to a maximum of only 118 heat units accumulating between planting dates in Virginia and North Carolina, while 270 heat units accumulated in Louisiana. Fiber quality results were inconsistent. These results suggest that the impact of plant population and planting date on cotton growth and development is variable and may be influenced by heat unit accumulation.

Abbreviations: EP, early planting; LP, late planting; HNR, height-to-node ratio

Cotton growth and development is influenced by not only environmental conditions, but also management practices. Plant population and planting date can influence maturity (Edmisten, 2007; Faircloth, 2007). 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). With increases in cotton seed prices following the introductions of various transgenic and seed treatment technologies, determining optimal plant populations is increasingly important (Pettigrew and Johnson, 2005; Bednarz et al., 2006; Siebert et al., 2006; Siebert and Stewart, 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 et al., 2006; Siebert and Stewart, 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 (Pettigrew and Johnson, 2005; Bednarz et al., 2005; Siebert et al., 2006; Siebert and Stewart, 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), 9.0-13.0 plants m^{-2} in Mississippi (Pettigrew and Johnson, 2005), and 2.0-12.0 plants m^{-2} in North Carolina (Jones and Wells, 1998). Yield reduction can occur at plant populations of 3.4-7.0 plants m^{-2} (Bednarz et al., 2005; Pettigrew and Johnson, 2005; Siebert et al., 2006; Siebert and Stewart, 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 et al., 2006; Siebert and Stewart, 2006) and reduced harvest efficiency due to increased branching (Gannaway et al., 1995).

In dense plant populations (> 10.0 plants m^{-2}), shading caused by excessive vegetative growth may result in a greater potential for boll rot, fruit abscission, increased plant height, and delayed maturity, leading to reduced yield and fiber quality (York, 1983; Bednarz et al., 2000; Bednarz et al., 2006; Siebert and Stewart, 2006). Reduced micronaire and fiber fineness have 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 $plant^{-1}$ (Jones and Wells, 1998; Bednarz et al., 2000; Siebert et al., 2006; Siebert and Stewart, 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 $plant^{-1}$ (Jones and Wells, 1998; Bednarz et al., 2000; Siebert et al., 2006; Siebert and Stewart, 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 (Jones and Wells, 1998; Bednarz et al. 2005; Bednarz et al., 2006).

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; Porter et al., 1996; Pettigrew, 2002; Nuti et al., 2006). In environments where heat units accumulation is limited, 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, wet weather, physical resistance (soil impedance, sand blasting, etc.), seedling disease, and insect pressure. These risks individually or collectively can be detrimental to cotton emergence, growth, and yield (Christiansen and Thomas, 1969; Porter et al., 1996; Jones and Wells, 1997; Pettigrew, 2002).

Planting recommendations in several cotton producing states are based on date and soil temperatures reaching or exceeding 15-18°C at three inches of depth by 10:00 a.m. (Pettigrew, 2002; Faircloth, 2007). Planting is usually delayed when ambient temperatures below 10°C are expected within five days following planting (Pettigrew, 2002; Faircloth, 2007). Virginia Cooperative Extension recommends planting cotton in Virginia from 20 April to 25 May, depending on environmental conditions (Faircloth, 2007). In previous planting date research, 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 (Porter et al., 1996; Bauer et al., 1998). However, in some cases, reduced fiber strength, fiber elongation, and fiber length was 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 and development, 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) during 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) during 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) during 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) during 2005 on a Norwood silt loam soil (fine-silty loam, mixed calcareous, thermic Typic Udifluvent).

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 four rows [91.4-cm centers (Virginia and North Carolina) or 96.5-cm centers (Louisiana)] wide and 12.2-m long. Cotton cultivars Phytogen 475 WRF and Phytogen 485 WRF were planted on two dates 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 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, and are reported as 5.3, 8.9, and 12.8 plants m^{-2} for Virginia and North Carolina, and 5.6, 9.5, 17.1 plants m^{-2} for Louisiana. Decisions on fertility, weed control, insect control, and plant growth regulator application methods were followed according to respective state cooperative extension recommendations (Stewart, 2005; Edmisten et al., 2007; Faircloth et al., 2007).

Plant mapping data were collected at the end of the season in Virginia during 2005 and 2006, and in North Carolina during 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). 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.

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 location and/or year when a significant trial × main effect interactions 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, Figures 1 and 2).

RESULTS AND DISCUSSION

Environmental Conditions

The Virginia and North Carolina early growing 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 (Figures 1 and 2). 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 may have occurred in Virginia and North Carolina, resulting in less variation between these locations. Louisiana was warmer than North Carolina and Virginia from May to October 2005, accumulating 2104 total heat units compared to 1436 and 1316 total heat units, respectively (Table 3). In 2006, the Virginia location received twice as much precipitation as North Carolina, while heat unit accumulation remained similar. The trial × main effect interactions observed in this experiment may have been influenced by variations in environmental conditions at each location 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 and trials. 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 this location.

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 reported to be directly related to plant population (Siebert and Stewart, 2006), while the impact of planting date has been inconsistent (Pettigrew, 2002; Nuti et al. 2006). Planting date had no influence on HNR in Virginia or North Carolina in 2005 and 2006, which has been reported in previous research by Pettigrew and Adamczyk (2006).

The location × 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. Plant population has been reported to inversely impact the number of apical main-stem nodes on cotton plants (Bednarz et al., 2000; Bednarz et al., 2006; Siebert et al., 2006; Siebert and Stewart, 2006). Similar to findings reported by Nuti et al. (2006), in this experiment 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 location × treatment interaction. Plant population did not influence either the number of first or second position sympodial bolls plant^{-1}, at either location (Table 4). Similar to plant population, the number of first and second position sympodial bolls were not influenced by planting in North Carolina (2006), 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 year and location were analyzed separately for Virginia (2005 and 2006) and North Carolina (2006). As reported in previous research (Bednarz et al., 2000; Bednarz et al., 2006; Siebert et al., 2006; Siebert and Stewart, 2006), in this experiment a higher number of monopodial bolls plant^{-1} (1.4, 3.1, and 5.8 bolls) were produced in Virginia 2005 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 12.8 plant m^{-2} population produced significantly more outer position bolls plant^{-1} (1.0 boll) compared to the 8.9 and 5.3 plants m^{-2} populations (0.3 and 0.2 bolls) in 2005. A similar trend was observed in Virginia and North Carolina in 2006 for both monopodial bolls and outer position bolls; however the differences in these parameters were not significant for any plant population. Planting date had no influence on the number of monopodial bolls or outer position bolls at either location.

Lint Percentage and Yield

Despite differences in boll location, lint percentage (Table 5) was not effected by plant population or planting date at any location or year. 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}. Lint percentage has also been reported to increase with EP cotton (Cathey and Meredith, 1988; Porter et al., 1996; Pettigrew, 2002).

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}. At the Louisiana location, 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. Although the growth parameters were not measured in Louisiana, this yield reduction may have occurred due to excessive vegetative growth in the higher population. Similarly, in previous research in Louisiana, Siebert and Stewart (2006) reported a yield reduction with a plant population of 15.3 plants m^{-2} versus 5.1-10.2 plants m^{-2}, when increased vegetative growth occurred in the highest population. 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 from previous research may be attributed to variable environmental conditions associated with each experiment (Siebert et al., 2006; Siebert and Stewart, 2006).

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. As previously mentioned, only 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 (Table 3). 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. The yield reduction associated with the early cool weather in Mississippi may help explain the equivalent yields that resulted for the early and late plantings in Virginia and North Carolina, as heat unit accumulation was also limited in Mississippi (38 heat units accumulated during April 1997).

Fiber Quality

Fiber strength was not influenced by plant population or planting date at any location or year (data not shown). Pettigrew and Johnson (2005) and Siebert et al. (2006) have reported similar results for varying plant populations, while Bednarz et al. (2005) reported a reduction in fiber strength with a plant population of 3.6 plants m^{-2} compared to 9.0-21.5 plants m^{-2}. Porter et al. (1996), Bauer et al. (1998), and Pettigrew (2002) reported inconsistent results for fiber strength due to planting date. The results for all other fiber quality parameters are reported by location and year due to interactions with treatment (Table 6).

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

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

Bednarz et al. (2005), Pettigrew and Johnson (2005), and Siebert et al. (2006) reported that plant population had no effect on fiber length uniformity. These results were similar at all locations and years in this research except in the highest plant population of 12.8 plants m^{-2} in North Carolina 2006, where length uniformity was 82.90%, significantly less than length uniformity in the lower populations of 5.3 and 8.9 plants m^{-2} (83.73% and 83.73%, respectively). Fiber length uniformity values were numerically higher in all locations and years for the LP, although only North Carolina 2006 LP resulted in a significant difference in length uniformity (84.41%) when compared to the EP (82.50%). Porter et al. (1996) also reported that delayed planting produced higher fiber length uniformity values.

CONCLUSIONS

This research suggests when a low amount of heat units (< 120) 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. 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 similar to Louisiana in 2005, it may be more likely that yield is enhanced by early planting.

Plant population appears to be a critical factor in optimizing yield, especially in environments similar to Virginia and North Carolina where heat unit accumulation is limited during 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 relative to Virginia and North Carolina, yields were maximized at lower populations of 5.6 to 9.5 plants m^{-2} and 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 be influenced by 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 at that location. While generally not significant, decreases in fiber length and fiber length uniformity due to earlier planting may be associated with early season stunting due to cool and/or wet weather and limited heat unit accumulation.

Due to the lack of main effect interactions, 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. In conclusion, the impact of plant population and planting date on cotton growth and development appears to be very dependent upon the heat unit accumulation during the growing season.

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

	2005			2006	
	Virginia‡	North Carolina	Louisiana	Virginia	North Carolina§
Planting date†	27 April	3 May	1 May	24 April	11 May
	18 May	24 May	21 May	15 May	25 May
Target pop.	Actual pop.				
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
LSD (0.05)*	0.6	1.5	0.9	0.7	0.8

† Actual planting dates for Virginia and North Carolina in 2005 and 2006, and Louisiana in 2005.

‡ Virginia and North Carolina plant populations combined for 2005 and 2006: 5.3, 8.9, and 12.8 plants m^{-2}; LSD (0.05) = 0.9.

§ Only 14 days between planting dates due to wet weather.

* Significant at the 0.05 probability level.

Table 2. Analysis of variance for main effects and main effect interactions on plant stand, lint percentage (Lint %), lint yield (Yield), micronaire (Mic.), length (Len.), length uniformity (Uni.), strength (Str.), height-to-node ratio (HNR), apical main-stem nodes (Nodes), first (1) position sympodial bolls, second (2) position sympodial bolls, outer position sympodial bolls, and monopodial (Mono) bolls for Virginia and North Carolina in 2005 and 2006 and Louisiana in 2005.

										Sympodial positions			
Source	**Plant stand**	**Lint %**	**Yield**	**Mic.**	**Len.**	**Uni.**	**Str.**	**HNR**	**Nodes**	**1**	**2**	**Outer**	**Mono**
						Virginia and North Carolina (2005 and 2006)							
Trial†	***	***	***	***	***	***	NS	**	***	***	***	***	***
PDATE	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	–	–	–	–	–	–

† Trial represents the Year × Location interaction

*** Significant at the 0.05 probability level.**

**** Significant at the 0.01 probability level.**

***** Significant at the 0.001 probability level.**

NS denotes no significance

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

2005						
	Suffolk, VA		Rocky Mount, NC		Alexandria, LA	
Month	HU†	Precip. ‡	HU	Precip.	HU	Precip.
	°C	cm	°C	cm	°C	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	HU	Precip.	HU	Precip.
	°C	cm	°C	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

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

‡ Monthly average precipitation.

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

Location	Population§	HNR	AMS nodes	Sympodial		
				1	2	Total
	plants m $^{-2}$	cm node $^{-1}$	no.	— bolls plant $^{-1}$ –		
VA†	5.3	4.93	17.4	8.1	4.6	12.7
	8.9	5.04	17.2	7.4	4.4	11.8
	12.8	5.08	16.7	7.0	3.3	10.2
LSD (0.05)*		0.06	0.1	NS	NS	
NC‡	5.3	4.46	13.8	4.5	1.2	5.7
	8.9	4.31	14.1	4.6	1.2	5.9
	12.8	4.30	14.2	5.2	1.0	6.2
LSD (0.05)		NS	NS	NS	NS	
	Planting date¶					
VA	EP	4.83	17.8	8.4	4.6	13.0
	LP	5.21	16.5	6.5	3.6	10.1
LSD (0.05)		NS	0.5	0.6	0.4	
NC	EP	4.30	13.8	4.8	1.3	6.2
	LP	4.41	14.2	4.7	1.0	5.7
LSD (0.05)		NS	NS	NS	NS	

† Virginia mapping data combined for 2005 and 2006.

‡ North Carolina mapping data for Clayton, NC 2006.

§ Pooled plant population data for Virginia and North Carolina.

¶ Target planting dates of early planting (EP) (24 April to 5 May) and late planting (LP) (15 May to 25 May).

NS, * denotes level of significance for no significance and P = 0.05 level respectively.

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

Location	Population§	Lint percentage	Lint yield
	plants m^{-2}	%	kg ha^{-1}
VA/NC†	5.3	42.98	916
	8.9	42.90	971
	12.8	42.98	1048
LSD (0.05)*		NS	90
LA‡	5.8	41.06	1832
	9.5	41.05	1840
	17.1	41.18	1663
LSD (0.05)		NS	162
	Planting date¶		
VA/NC	EP	42.93	973
	LP	42.98	987
LSD (0.05)		NS	NS
LA	EP	41.23	2061
	LP	40.96	1495
LSD (0.05)		NS	397

† Virginia and North Carolina data combined for 2005 and 2006.

‡ Louisiana data reported individually for 2005.

§ Pooled plant population data for Virginia and North Carolina, with Louisiana reported individually.

¶ Target planting dates of early planting (EP) (24 April to 5 May) and late planting (LP) (15 May to 25 May).

NS, * denotes level of significance for no significance and P = 0.05 level respectively.

Table 6. Location-year and plant population effect on physical fiber properties at Suffolk, VA in 2005 and 2006; Rocky Mount, NC in 2005 and Clayton, NC in 2006; and Alexandria, LA in 2005.

Location	Population‡	Micronaire	UHM¶	Uniformity
	plants m^{-2}	units	cm	%
VA 2005†	5.3	4.31	2.91	84.28
	8.9	4.35	2.91	84.68
	12.8	4.38	2.92	84.26
LSD (0.05)*		NS	NS	NS
VA 2006	5.3	4.70	2.87	84.05
	8.9	4.66	2.86	84.20
	12.8	4.76	2.86	83.86
LSD (0.05)		NS	NS	NS
NC 2005	5.3	4.94	2.67	82.34
	8.9	5.00	2.69	82.66
	12.8	4.84	2.69	82.72
LSD (0.05)		0.12	NS	NS
NC 2006	5.3	5.30	2.73	83.73
	8.9	5.31	2.73	83.73
	12.8	5.39	2.71	82.90
LSD (0.05)		NS	NS	0.56
LA 2005	5.8	4.74	2.82	83.46
	9.5	4.75	2.82	83.34
	17.1	4.59	2.83	83.26
LSD (0.05)		0.13	NS	NS
	Planting date§			
VA 2005	EP	4.42	2.89	84.25
	LP	4.27	2.92	84.56
LSD (0.05)		NS	NS	NS
VA 2006	EP	4.72	2.85	84.01
	LP	4.55	2.88	84.06
LSD (0.05)		NS	NS	NS
NC 2005	EP	5.02	2.67	82.45
	LP	4.83	2.69	82.73
LSD (0.05)		NS	NS	NS
NC 2006	EP	5.02	2.68	82.50
	LP	5.47	2.77	84.41
LSD (0.05)		0.06	0.04	0.56
LA 2005	EP	4.76	2.80	83.35
	LP	4.62	2.84	83.36
LSD (0.05)		NS	NS	NS

† Virginia, North Carolina, and Louisiana data reported individually for 2005 and 2006.

‡ Pooled plant population data for Virginia and North Carolina, with Louisiana reported individually.

§ Target planting dates of early planting (EP) (24 April to 5 May) and late planting (LP) (15 May to 25 May).

¶ Upper half mean staple length.

NS, * denotes level of significance for no significance and P = 0.05 level respectively.

Figure 1. Monthly heat unit accumulation recorded at Suffolk, VA, Rocky Mount, NC, Clayton, NC, and Alexandria, LA.

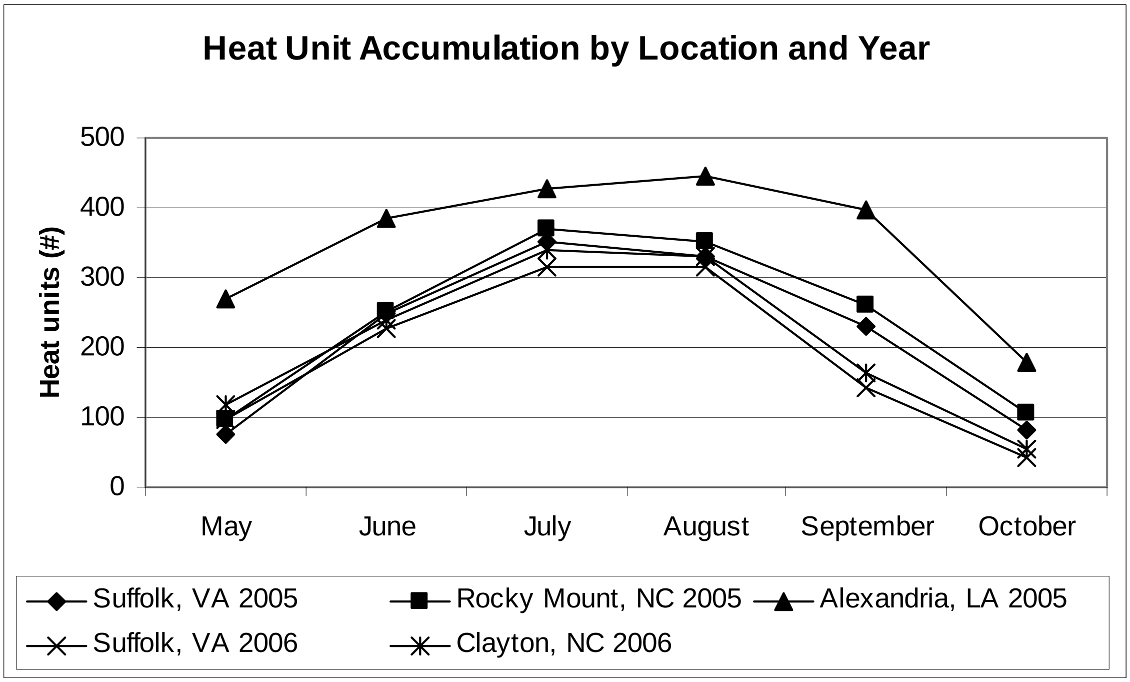
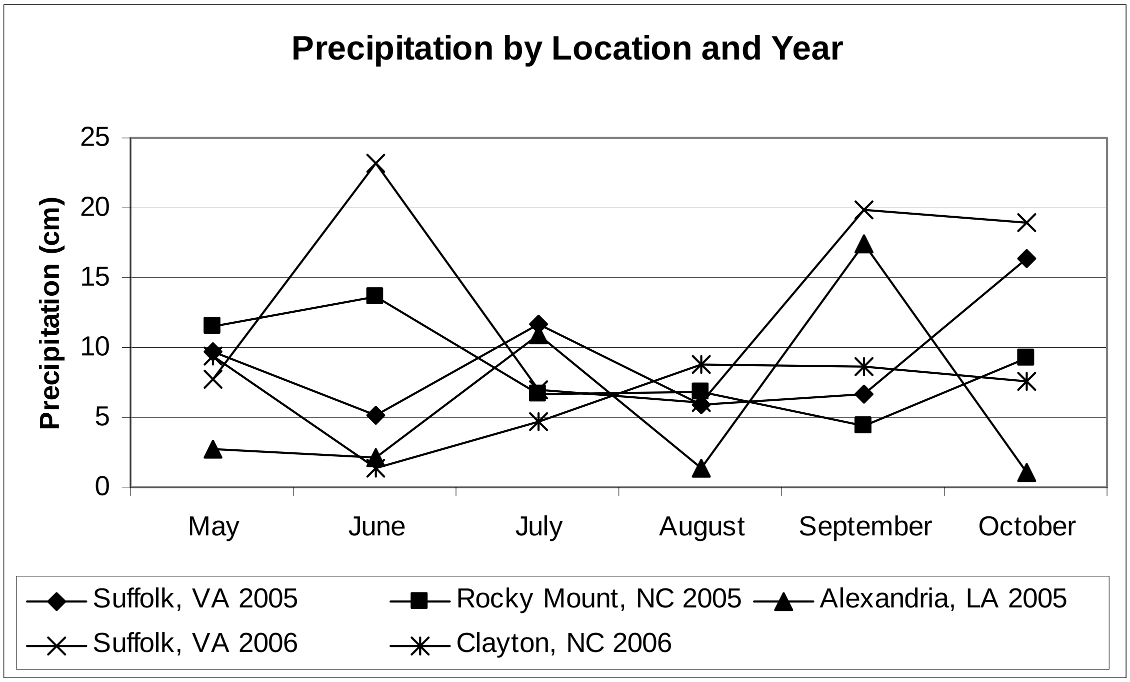


Figure 2. Monthly precipitation recorded at Suffolk, VA, Rocky Mount, NC, Clayton, NC, and Alexandria, LA.



CHAPTER 3

Cotton (*Gossypium hirsutum* L.) Cultivar Response to Mepiquat Pentaborate

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Abbreviations: AMS, apical main-stem; HNR, height-to-node ratio; NAWF, nodes above white flower; DP, Deltapine; FM, Fibermax

ABSTRACT

Plant growth regulators are routinely utilized to manage cotton (*Gossypium hirsutum* L.) growth and maturity. The objective of this research was to compare the response of several, transgenic cotton cultivars with differing growth habits and maturities to mepiquat pentaborate (MPB) application in two different growing environments. Three MPB application regimes and an untreated control were imposed on Deltapine (DP) 444 BG/RR, an early-maturing, determinate fruiting cultivar; Fibermax (FM) 960 BR, a medium-maturing, relatively determinate fruiting cultivar; and DP 555 BG/RR, a medium- to full-maturing, indeterminate fruiting cultivar. Mepiquat pentaborate applications decreased plant height, height-to-node ratio, and enhanced maturity for all cultivars. Overall the mean plant height of the cotton cultivars was higher in South Carolina. The two DP cultivars were taller than FM 960 BR, and DP 555 BG/RR matured the latest. In South Carolina 2006, percent plant height reduction was greatest with FM 960 BR, however actual plant height reductions were not different in any year. Yield was not significantly influenced by cultivar or MPB application; although, a trend of decreasing yield from 3-12% with increasing MPB application occurred in Virginia. Mepiquat pentaborate application decreased micronaire and increased the fiber length of all cultivars. Based on percent height reduction, plant growth regulator management may need to vary by cultivar in some years; however, actual plant height reduction suggests that cotton cultivars do not respond differently to MPB application. Additionally higher rates and earlier timings of PGR's may be more appropriate in South Carolina where more vegetative growth was observed.

Cotton (*Gossypium hirsutum* L.) growth and maturity are influenced by many factors including environmental conditions, cultivar genetics, and seasonal management strategies (Kerby, 1985; Kerby et al., 1986; Gwathmey and Craig, 2003). In the northern region of the cotton belt, where heat unit accumulation is limited during the growing season, producers are encouraged to select cultivars and utilize plant growth regulator (PGR) application strategies that hasten maturity, allowing for timely harvest (Gwathmey and Craig, 2003; Faircloth, 2007b).

Cotton is a perennial plant with an indeterminate fruiting pattern, that may vary in length by cultivar and management practices employed (Zhao and Oosterhuis, 2000; Edmisten, 2007a). While vegetative growth continues throughout the growing season, plant resources begin to shift toward reproductive growth approximately 35 days after planting, as the plant begins forming fruiting structures (Gwathmey and Craig, 2003; Edmisten, 2007a). Excessive vegetative growth may occur due to abundant nitrogen, moisture, and fruit abscission (York, 1983a; York, 1983b; Edmisten, 2007b). This excessive vegetative growth may delay reproductive growth, increase late season fruit shedding and boll rot due to shading, increase insect damage, decrease defoliation and harvest efficiency, and reduce yields (York, 1983b; Cathey and Meredith, 1988; Zhao and Oosterhuis, 2000).

Managing cotton for earliness, especially in indeterminate cultivars, is a key consideration in the northern region of the cotton belt due to limited heat unit accumulation (Gwathmey and Craig, 2003). For this reason, most cultivars planted in Virginia are relatively early maturing to allow timely removal from the field prior to losses due to inclement fall weather (Faircloth, 2007c). These early maturing cultivars must also have a high yield potential and acceptable fiber quality. In South Carolina, where more heat units are accumulated relative to the northern region of the cotton belt, producers may be able to utilize later maturing cultivars as the growing season is extended.

Plant growth regulators are frequently applied to cotton to hasten maturity through a reduction in vegetative growth, shifting plant resources to reproductive growth (Cathey and Meredith, 1988; Zhao and Oosterhuis, 2000; Gwathmey and Craig, 2003). Plant growth regulator application decreases gibberellic acid concentration within plant cells, thereby reducing cell wall plasticity (Behringer et al., 1990; Potter and Fry, 1993; Yang et al., 1996). This ultimately reduces vegetative growth in cotton by decreasing main stem and sympodial branch internode length, as well as leaf area of expanding leaves, resulting in a shorter, more compact plant (Kerby, 1985; Cathey and Meredith, 1988; Gwathmey and Craig, 2003).

Factors that should be considered prior to PGR application include fertility, moisture level, cultivar, field history, and previous PGR applications (Gwathmey and Craig, 2003; Faircloth, 2007b). Reported responses of cotton to PGR application include decreased plant height, earlier onset of flowering and physiological cutout, and increased boll retention lower on the plant (Gwathmey and Craig, 2003; Nuti et al., 2006). Physiological cutout is defined as the date of the last effective flowering that will allow adequate time for bolls to mature, which was determined to occur at an average of 5.0 nodes above white flower (NAWF=5) (Bourland et al., 2001). The determination of physiological cutout can be used as a basis for measuring plant maturity across different environments and cultivars (Bourland et al., 2001; Gwathmey and Craig, 2003). Cotton growth responses to PGR application have been consistent, while yield responses have been inconsistent (Kerby, 1985; Cathey and Meredith, 1988; Zhao and Oosterhuis, 2000; Nuti et al., 2006).

There are numerous PGR's commercially available, most being slight variations of or additives to the mepiquat chloride (MC) molecule (1,1-dimethylpiperidinium chloride) (Gwathmey and Craig, 2003). Mepiquat pentaborate (MPB) (Pentia™, BASF, Research Triangle Park, NC) is a PGR applied to cotton which contains the active ingredient MPB (N,N- dimethylpiperidinium pentaborate) at 98.3 g ai l^{-1}. This PGR utilizes five boron molecules along with mepiquat (BASF Ag Products, 2007). Mepiquat pentaborate has been reported to effect cotton growth and development similar to other MC products, including a reduction in plant height and number of fruiting branches, plus hastened maturity, while not altering boll retention or lint yield compared to untreated cotton (Coccaro et al., 2003; Coccaro et al., 2004; Gwathmey and Craig, 2003; Gwathmey and Craig, 2004).

Various cultivars may respond differently to PGR application as there are distinctions in growth habits and maturity associated with cultivar genetics. Gwathmey and Craig (2003) reported that single MC applications hastened the maturity of later, more indeterminate cultivars causing earlier physiological cutout, but had no effect on the flowering of earlier, more determinate cultivars. Multiple MC applications have been reported to also hasten flowering and reduce plant height, with the greatest response occurring with indeterminate cultivars (Gwathmey and Craig, 2003). Gwathmey and Craig (2003) concluded that more aggressive MC application resulted in excessive growth control of early maturing cultivars, causing a reduction in yield, while MC application benefited indeterminate cultivars through a reduction in vegetative growth and increased yield.

There is limited research examining the response of cultivars with different growth habits and maturities to PGR application (Gwathmey and Craig, 2003). Furthermore, no research has examined the impact of MPB application on cultivars in multiple environments. The objective of this research was to measure and compare the response of several commercially available, transgenic cotton cultivars with differing growth habits and maturities to MPB application in environments accumulating different levels of heat units.

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) during 2005 on an Eunola sandy loam (fine-loamy, siliceous, semiactive, thermic Aquic Hapludults) and in 2006 on a Dragston fine sandy loam (coarse-loamy, mixed, semiactive, thermic Aeric Endoaquults). The experiment was also conducted at the Clemson University, Pee Dee Research and Education Center in Florence, SC (34°16' N, 79°42' W) during 2005 on a Noboco loamy sand (fine-loamy, siliceous, subactive, thermic Oxyaquic Paleudults) and in 2006 on a Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults).

Twelve treatment combinations were examined in a split-plot design with four replicates, where cultivar was the main-plot factor and plant growth regulator application regimes were the sub-plot factor. Plots consisted of four 12.2-m long rows spaced on 91.4-cm centers in Virginia and 96.5-cm centers in South Carolina. Three cotton cultivars were planted: Deltapine (DP) 444 BG/RR, an early-maturing, determinate fruiting cultivar; Fibermax (FM) 960 BR, a medium-maturing, relatively determinate fruiting cultivar; and DP 555 BG/RR, a medium- to full-maturing, indeterminate fruiting cultivar (Faircloth et al., 2005; Bowman, 2007). Seed were planted 5 May 2005 and 16

May 2006 in Virginia, and 10 May 2005 and 2006 in South Carolina. The treatments are listed in Table 7 and consisted of an untreated and three plant growth regulator application regimes. These plant growth regulator applications were made using MPB. Decisions on fertility, weed control, and insect control were made according to respective state cooperative extension recommendations (Jones et al., 2005; Faircloth et al., 2007).

All data were collected from the center two rows of the plots, including plant stand, internode length (data not shown), two plant heights (late July and end of season), number of apical main-stem (AMS) nodes, height-to-node ratio (HNR), nodes above white flower (NAWF), lint yield, and fiber quality. Plant mapping data were collected at the end of the growing season in Virginia during 2005 and 2006 to determine the total number of monopodial branches, monopodial bolls, first and second position sympodial bolls, first sympodial node, and the percent retention of sympodial bolls plant^{-1}. Plant mapping data were not collected in South Carolina.

Harvest aid applications were applied uniformly across all treatments, and the center two rows of each plot were harvested using a two-row commercial spindle cotton harvester. Harvest dates were 1 Nov. 2005 and 3 Nov. 2006 for Virginia, and 10 Oct. 2005 and 1 Nov. 2006 for South Carolina. Seed-cotton samples from each plot were retained and ginned on a 10-saw gin to determine lint yield. A sub-sample was sent to the USDA classing office in Florence, SC to determine physical fiber properties using high volume instrument analysis.

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 (Table 8), the data are presented by location, year, or location and year. 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 both locations (Table 9, Figures 3 and 4).

RESULTS AND DISCUSSION

Environmental Conditions

Total heat unit accumulation from 1 May to 31 October at both locations ranged from 1138 to 1585, with South Carolina accumulating approximately 200 to 300 more heat units each year than Virginia (Table 9, Figures 3 and 4). Total precipitation ranged from 55.3 to 82.7 cm from 1 May to 31 October during 2005 and 2006. Variability in cotton response to PGR application and cultivar selection between locations and years observed in this experiment may have been influenced by differences in precipitation events and heat unit accumulation associated with each environment. Previous research on cotton has attributed many of the differences in growth and yield across years and locations to environmental conditions (Cathey and Meredith, 1988; Pettigrew, 2002; Pettigrew and Adamczyk, 2006; Siebert and Alexander, 2006).

Growth Characteristics

Plant height data are reported by year and location due to trial × treatment interactions (Table 8). In Virginia 2005, cultivar had no influence on plant height in late July, while in South Carolina 2005 and Virginia 2006, DP 444 BG/RR and DP 555 BG/RR plants were significantly taller than FM 960 BR (Table 10). DP 444 BG/RR plants were the tallest in late July in South Carolina 2006. End of season plant height measurements resulted in DP 444 BG/RR and DP 555 BG/RR having the tallest plants during both years in Virginia. In South Carolina 2005, DP 555 BG/RR plants were tallest at the end of the season, while there were no differences found between cultivars in end of season height in South Carolina 2006. In South Carolina 2006 only, the greatest plant height response occurred in July with FM 960 BR with a 25.05% decrease in height (expressed as percent of untreated), compared to DP 444 BG/RR and DP 555 BG/RR, which were reduced 12.29 and 13.28%, respectively. However, there were no differences in actual plant height reduction with respect to the untreated compared to the treated cotton in any year, suggesting that these cultivars did not respond differently to MPB application. Gwathmey and Craig (2003) reported that determinate and indeterminate cotton cultivars respond differently to PGR application with respect to plant height measured as a percent of untreated cotton; however the actual plant height reduction is not compared. Previous research found that plant height response to PGR's based on percent reduction of height was greatest with indeterminate cultivars (Gwathmey and Craig, 2003); however, in three out of four years in this experiment all cultivars responded the same to MPB application.

Mepiquat pentaborate application decreased plant height compared to the untreated cotton in Virginia and South Carolina in both years, except for the end of season measurement in South Carolina 2006, in which the untreated and lowest rate of MPB were statistically the same (Table 11). Plant growth regulator application has consistently resulted in a reduction of plant height in comparison to untreated cotton (Zhao and Oosterhuis, 2000; Gwathmey and Craig, 2003; Nichols et al., 2003, Siebert and Stewart, 2006).

Due to a significant location × treatment interaction, NAWF data were analyzed by location. Combined over years, NAWF was highest for DP 555 BG/RR at 6.7 NAWF, followed by FM 960 BR at 6.2, and DP 444 BG/RR at 5.9 in Virginia (Table 12). In South Carolina, NAWF was highest for DP 555 BG/RR at 6.6 NAWF, while DP 444 BG/RR and FM 960 BR were not different from each other at 5.2 and 5.8 NAWF, respectively. The NAWF measurements have been observed to correlate with cultivar maturity (Gwathmey and Craig, 2003). Mepiquat pentaborate application influenced earliness in Virginia with all MPB treatments having fewer NAWF than the untreated cotton, while MPB application had no influence on NAWF in South Carolina. The Virginia data is consistent with previous research that reported PGR's can hasten earliness based on NAWF (Coccaro et al., 2003; Gwathmey and Craig, 2003; Coccaro et al., 2004; Gwathmey and Craig, 2004).

There were no differences in the number of AMS nodes plant^{-1} due to MPB application in this experiment (Table 12). However, previous research has reported that the number of AMS nodes plant^{-1} decreases with PGR application (Oosterhuis and Egilla, 1996; Nichols et al., 2003; Nuti et al., 2006; Siebert and Stewart, 2006). The number of AMS nodes plant^{-1} varied by cultivar in Virginia and South Carolina, with the indeterminate cultivar DP 555 BG/RR producing more AMS nodes than either FM 960 BR or DP 444 BG/RR.

Height-to-node ratio data were combined over location due to significant year × treatment interactions. Cultivar and MPB both influenced the HNR in 2005. DP 444 BG/RR had a significantly higher HNR of 5.00 cm, compared to the FM 960 BR and DP 555 BG/RR cultivars, which had HNR's of 3.91 and 4.33 cm, respectively. Mepiquat pentaborate applications reduced HNR to 4.16, 4.16, and 3.99 cm respectively as total season rates increased, compared to the untreated control, which had a HNR of 5.35 cm. Similar results have been found when PGR's are applied to cotton and were attributed to shortened internode lengths (Zhao and Oosterhuis, 2000; Nichols et al., 2003; Nuti et al., 2006; Siebert and Stewart, 2006). Height-to-node ratio was not influenced by cultivar or MPB application in 2006.

Virginia plant mapping data were combined for both years and resulted in no statistical significance for the number of monopodial branches, total sympodial bolls, first position sympodial bolls, first sympodial node, and the percent retention of first and second sympodial bolls plant^{-1} for either cultivar or MPB applications (data not shown).

Lint Percentage and Yield

Lint percentage data were analyzed by year and location due to significant trial × treatment interactions. In Virginia 2005 and South Carolina 2005 and 2006, DP 555 BG/RR had a higher lint percentage than either DP 444 BG/RR or FM 960 BR, while in Virginia 2006 the DP 444 BG/RR and DP 555 BG/RR cultivars produced the highest lint percentage, compared to FM 960 BR (Table 10). DP 555 BG/RR contains small seeds and has consistently produced a numerically higher lint percentage in cultivar trials relative to DP 444 BG/RR and FM 960 BR (Bowman, 2007; Faircloth, 2007c).

In both years for Virginia and South Carolina, MPB decreased the lint percentage when compared to the untreated control (Table 11). Plant growth regulator application has been reported to reduce lint percentage (Kerby, 1985; Cathey and Meredith, 1988; Zhao and Oosterhuis, 2000; Biles and Cothren, 2001). Although seed weight was not recorded in this experiment, previous research has attributed this reduction in lint percentage to an increase in seed weight following PGR application (York, 1983b; Oosterhuis and Egilla, 1996; Biles and Cothren, 2001),

In this experiment there was no yield response to either cultivar or MPB treatments (Table 12). However, with limited heat unit accumulation in Virginia, there was a trend (P=0.0635) of decreasing yields of 3-12% with increasing total MPB application rates with the highest yield in untreated plots, while yields were not influenced in South Carolina. Gwathmey and Craig (2003) reported reduced lint yields in cultivars varying in maturity following PGR applications. This was attributed to excessive vegetative growth of untreated indeterminate cultivars and excessive control of vegetative growth on early maturing cultivars (Gwathmey and Craig, 2003). This variability has been attributed to differences in various factors including vegetative growth, seasonal heat unit accumulation, and precipitation (Kerby, 1985; Cathey and Meredith, 1988; Gwathmey and Craig; 2003, Siebert and Stewart, 2006). Environmental conditions conducive to excessive vegetative growth, or limited heat unit accumulation and reduced growing season length have resulted in a positive yield response with PGR application (York, 1983b; Kerby, 1985; Kerby et al., 1986; Cathey et al., 1988).

Fiber Quality

Micronaire, fiber length, strength, and length uniformity are influenced by both genetics and environmental conditions (Meredith and Bridge, 1973; Meredith et al., 1975; Bednarz et al., 2005). Faircloth et al. (2004) reported differences in micronaire values due to cultivar. Applying PGR's to cotton has resulted in inconsistent changes in micronaire (Kerby, 1985; Cathey and Meredith, 1988; Nuti et al., 2006; Siebert and Stewart, 2006). In this experiment, micronaire data were analyzed by location due to significant location × treatment interactions. In Virginia, micronaire values of FM 960 BR and DP 555 BG/RR were higher (4.65 and 4.58 units, respectively) than DP 444 BG/RR (4.22 units), while there were no differences in micronaire due to cultivar in South Carolina (Table 12). The micronaire of lint from cotton treated with MPB was less than the untreated cotton in South Carolina, while MPB had no effect on micronaire in Virginia.

Fiber length data were analyzed separately by year and location due to significant trial × treatment interactions. DP 444 BG/RR and DP 555 BG/RR fibers were longer at 2.94 and 2.90 cm, respectively in Virginia 2005, compared to FM 960 BR at 2.84 cm (Table 10). However, in South Carolina 2005 the cultivar DP 444 BG/RR produced the longest fibers at 2.93 cm. Cultivar had no influence on fiber length in 2006 for either location. As reported in previous research, in Virginia 2006 and South Carolina 2005 and 2006, MPB application increased fiber length (Table 11) (Cathey and Meredith, 1988; Nuti et al., 2006).

Kerby (1985), Cathey and Meredith (1988), and Nuti et al. (2006) observed an increase in fiber strength following application of PGR's to cotton. Consistent with results reported by Siebert and Stewart (2006), MPB had no influence on fiber strength in either Virginia or South Carolina for this experiment (Table 12). With respect to cultivar, FM 960 BR fiber had the highest strength value at 33.56 and 32.87 g tex^{-1} in Virginia and South Carolina, respectively. Bowman (2007) and Faircloth (2007c) reported FM 960 BR to consistently have numerically higher fiber strength than either DP 444 BG/RR or DP 555 BG/RR in cultivar trials.

Fiber length uniformity data were analyzed by location due to significant location × treatment interactions. DP 444 BG/RR and FM 960 BR resulted in higher length uniformity values, compared to DP 555 BG/RR in both Virginia and South Carolina (Table 10). York (1983a) reported variable fiber length uniformity amongst cultivars. As previously reported by Nichols et al. (2003) and Siebert and Stewart (2006), MPB application had no influence on fiber length uniformity in either Virginia or South Carolina (Table 11).

CONCLUSIONS

Mepiquat pentaborate application reduced plant height and enhanced maturity for all cultivars when compared to the untreated cotton. In South Carolina 2006, FM 960 BR had a greater response to MPB application based on percent height reduction, than the most and least determinate cultivars, DP 444 BG/RR and DP 555 BG/RR, respectively. FM 960 BR was the shortest of the three cultivars as well. The difference in percent height reduction in that one year and location suggests that in some years plant growth regulator management may need to vary by cultivar as the growth habit of cultivars may be influenced by genetic factors. However, actual plant height reduction measurements suggest that cotton cultivars do not respond differently to MPB application, as there were no differences in response in any year.

Based on changes in the growth parameters measured in this experiment, MPB applications can reduce vegetative growth and hasten maturity. The reduction in vegetative growth and increase in earliness following PGR application increases the probability of defoliation and harvest prior to freezing temperatures and inclement fall weather, which is an annual challenge in Virginia. While there were some responses in fiber quality properties due to MPB application, these differences were limited and may be related to hastened maturity following MPB application.

The trend of decreasing yields observed in association with increasing total season MPB application rates and early applications examined in this experiment suggests that as strategies become more aggressive in controlling vegetative growth, yield losses may result in Virginia. In environments where heat unit accumulation is not as limited as Virginia (i.e. South Carolina), vegetative growth measured as plant height appears to be greater and thus higher rates and earlier timings may be more appropriate, possibly reducing the potential for yield reduction. Since our findings are limited to only two years and locations, further research should be conducted to compare the response of other cultivars to various MPB rates and timings and in multiple environments. Documenting variations in cultivar response to PGR applications could result in refined PGR recommendations. In conclusion, cultivar plant height response measured as percent height reduction to MPB application can vary in some instances, especially in environments where heat unit accumulation is limited. Also, more aggressive strategies may result in yield reduction in those environments.

Table 7. Plant growth regulator treatments applied to cotton in Virginia and South Carolina during 2005 and 2006.

Treatment	Description	Common name	Application timing	Application rate
1	Untreated			
2	Plant growth regulator	mepiquat pentaborate	pin-head square	12.2 g ai ha^{-1}
			match-head square	18.3 g ai ha^{-1}
			early bloom	24.4 g ai ha^{-1}
3	Plant growth regulator	mepiquat pentaborate	pin-head square	24.4 g ai ha^{-1}
			match-head square	24.4 g ai ha^{-1}
			early bloom	36.5 g ai ha^{-1}
4	Plant growth regulator	mepiquat pentaborate	5-leaf stage	12.2 g ai ha^{-1}
			pin-head square	24.4 g ai ha^{-1}
			match-head square	36.5 g ai ha^{-1}
			early bloom	48.8 g ai ha^{-1}

Table 8. Analysis of variance for cultivar and mepiquat pentaborate (MPB) and main effect interactions on July and end of season (EOS) plant height, July and EOS plant height reduction percentage (July hgt. % and EOS hgt. %), nodes above white flower (NAWF), apical main-stem (AMS) nodes, height-to-node ratio (HNR), lint percentage (Lint %), lint yield (Yield), micronaire (Mic.), fiber length (UHM), fiber strength (Str.), fiber uniformity (Uni.) at Suffolk, VA and Florence, SC during 2005 and 2006.

Source	July plt. hgt.	July hgt. %	EOS plt. hgt.	EOS hgt. %	NAWF	AMS Nodes	HNR	Lint %	Yield	Mic.	UHM	Str.	Uni.
				Virginia and South Carolina (2005 and 2006)									
Trial†	***	*	***	*	***	***	***	***	***	***	*	***	***
CULTIVAR	**	NS	*	NS	***	**	**	***	NS	**	NS	***	**
Trial × CULTIVAR	***	**	***	NS	NS	**	*	***	*	**	***	***	**
MPB	***	***	***	***	***	**	**	***	*	*	***	*	NS
Trial × MPB	***	***	**	*	NS	NS	*	NS	NS	NS	NS	NS	*
CULTIVAR × MPB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Trial × CULTIVAR × MPB	NS	*	NS	NS	NS	NS	**	NS	NS	NS	***	NS	NS

† Trial represents the Year × Location interaction

*** Significant at the 0.05 probability level.**

**** Significant at the 0.01 probability level.**

***** Significant at the 0.001 probability level.**

NS denotes no significance

Table 9. Monthly and total cumulative heat units (HU) and precipitation (Precip.) recorded at Suffolk, VA and Florence, SC during 2005 and 2006.

	2005			
	Suffolk, VA		Florence, SC	
Month	HU†	Precip. ‡	HU	Precip.
	°C	cm	°C	cm
May	76	9.7	133	12.2
June	247	5.2	280	19.1
July	351	11.6	389	13.0
August	330	5.9	365	17.6
September	231	6.6	293	0.7
October	81	16.3	121	11.3
Total	1316	55.3	1585	73.9
	2006			
	Suffolk, VA		Florence, SC	
Month	HU	Precip.	HU	Precip.
	°C	cm	°C	cm
May	97	7.8	167	17.1
June	226	23.2	275	19.8
July	314	6.9	364	2.9
August	315	6.0	361	14.8
September	143	19.9	209	16.2
October	43	18.9	79	5.6
Total	1138	82.7	1455	76.4

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

‡ Monthly average precipitation.

Table 10. Location, year and cultivar effect on late July plant height (July plt. hgt.), July plant height reduction percentage (July hgt. %), end of season plant height (EOS plt. hgt.), EOS actual height reduction (EOS hgt. red.), EOS plant height reduction percentage (EOS hgt. %), lint percentage (Lint %), fiber length (UHM), and fiber uniformity (Uni.) in Suffolk, VA and Florence, SC in 2005 and 2006.

Location	Cultivar‡	July plt. hgt.	July hgt. %	EOS plt. hgt.	EOS hgt. red.	EOS hgt. %	Lint %	UHM§	Uni.
		cm	%	cm	cm	%	%	cm	%
VA 2005†	DP 444	54.10	30.01	72.97	24.08	32.19	45.37	2.94	83.74
	FM 960	46.58	27.57	62.15	18.39	30.38	43.54	2.84	83.65
	DP 555	50.47	18.26	71.25	16.54	23.89	46.93	2.90	82.41
LSD (0.05)*		NS	NS	7.52	NS	NS	0.55	0.06	1.09
VA 2006	DP 444	73.41	30.92	79.29	21.48	29.58	45.08	2.89	83.78
	FM 960	60.11	31.24	67.94	22.38	32.80	42.96	2.91	84.05
	DP 555	70.60	28.07	80.94	18.56	21.64	46.12	2.93	82.98
LSD (0.05)		2.91	NS	9.94	NS	NS	2.45	NS	NS
SC 2005	DP 444	80.73	21.04	84.72	16.56	21.35	40.94	2.93	82.30
	FM 960	67.53	21.92	73.95	18.85	25.47	38.74	2.84	81.57
	DP 555	80.66	21.87	97.36	24.64	26.83	42.83	2.84	80.54
LSD (0.05)		5.87	NS	10.72	NS	NS	1.14	0.04	0.77
SC 2006	DP 444	47.81	12.29	84.67	12.81	17.07	40.17	2.88	82.31
	FM 960	40.06	25.06	79.49	12.21	17.37	41.13	2.92	82.13
	DP 555	39.38	13.28	84.17	4.68	6.62	39.76	2.94	81.88
LSD (0.05)		7.27	9.08	NS	NS	NS	0.95	NS	NS

† Virginia and South Carolina data reported individually for 2005 and 2006.

‡ Cultivars displaying differing maturities and growth habits (Deltapine 444 BG/RR, Fibermax 960 BR, and Deltapine 555 BG/RR).

§ Upper half mean staple length.

NS, * denotes level of significance for no significance and P = 0.05 level respectively.

Table 11. Location, year and mepiquat pentaborate (MPB) application effect on late July plant height (July plt. ht.), July plant height reduction percentage (July hgt. %), end of season plant height (EOS plt. ht.), EOS plant height reduction percentage (EOS hgt. %), lint percentage (Lint %), fiber length (UHM), and fiber uniformity (Uni.) in Suffolk, VA and Florence, SC in 2005 and 2006.

Location	MPB application ‡	July plt. hgt.	July hgt. %	EOS plt. hgt.	EOS hgt. %	Lint %	UHM§	Uni.
	g ai ha^{-1}	cm	%	cm	%	%	cm	%
VA 2005†	Untreated	62.54	0.00	88.46	0.00	46.51	2.86	83.29
	54.9	50.75	18.13	63.96	26.98	45.24	2.90	83.03
	85.3	46.81	24.71	63.06	27.67	44.89	2.91	83.31
	121.9	41.34	33.00	59.69	31.81	44.48	2.91	83.43
LSD (0.05)*		4.48	7.29	6.85	7.41	0.75	NS	NS
VA 2006	Untreated	88.25	0.00	96.67	0.00	45.78	2.86	82.96
	54.9	67.96	24.07	75.94	21.30	44.86	2.90	83.74
	85.3	60.77	31.56	63.76	29.37	44.45	2.92	84.15
	121.9	57.47	34.63	64.72	35.12	43.78	2.96	83.49
LSD (0.05)		3.23	4.08	7.70	8.93	NS	0.05	NS
SC 2005	Untreated	91.11	0.00	105.36	0.00	42.30	2.83	81.48
	54.9	72.85	20.08	81.63	22.11	40.78	2.88	82.04
	85.3	70.89	22.10	76.97	26.13	40.04	2.90	81.72
	121.9	70.37	22.66	77.43	25.40	40.23	2.87	81.65
LSD (0.05)		3.90	4.24	7.10	6.42	0.63	0.03	NS
SC 2006	Untreated	48.67	0.00	92.68	0.00	41.44	2.87	82.13
	54.9	44.25	8.37	86.11	6.34	40.05	2.94	82.27
	85.3	39.33	19.26	76.80	16.89	39.70	2.93	81.98
	121.9	37.42	23.00	75.53	17.83	40.22	2.93	82.05
LSD (0.05)		3.50	7.42	10.31	8.92	1.00	0.04	NS

† Virginia and South Carolina data reported individually for 2005 and 2006.

‡ Total amount of MPB applied in grams of active ingredient per hectare during the growing season.

§ Upper half mean staple length.

NS, * denotes level of significance for no significance and P = 0.05 level respectively.

Table 12. Location, cultivar, and mepiquat pentaborate (MPB) application effect on nodes above white flower (NAWF), apical main-stem nodes (AMS nodes), lint yield (Yield), micronaire (Mic.), and fiber strength (Str.) in Suffolk, VA and Florence, SC in 2005 and 2006.

Location	Cultivar‡	NAWF	AMS nodes	Yield	Mic.	Str.
		no.	no.	kg ha^{-1}	units	g tex^{-1}
VA†	DP 444	5.93	15.82	1601	4.22	29.86
	FM 960	6.20	17.25	1643	4.65	33.56
	DP 555	6.67	18.43	1702	4.58	30.13
LSD (0.05)*		0.27	1.65	NS	0.25	2.78
SC	DP 444	5.17	18.65	1490	4.31	28.96
	FM 960	5.80	21.05	1420	4.52	32.87
	DP 555	6.56	22.64	1504	4.49	28.74
LSD (0.05)		0.71	2.84	NS	NS	2.95
	MPB application§					
	g ai ha^{-1}					
VA	Untreated	6.91	17.91	1750	4.51	30.72
	54.9	6.20	17.19	1694	4.49	31.39
	85.3	5.90	16.90	1607	4.45	31.32
	121.9	6.10	16.61	1541	4.49	31.28
LSD (0.05)		0.08	NS	NS	NS	NS
SC	Untreated	6.69	21.39	1544	4.54	29.86
	54.9	5.59	20.94	1471	4.44	30.20
	85.3	5.55	20.50	1401	4.37	30.33
	121.9	5.54	20.29	1469	4.41	30.38
LSD (0.05)		NS	NS	NS	0.07	NS

† Virginia and South Carolina data reported by location for 2005 and 2006.

‡ Cultivars displaying differing maturities and growth habits (Deltapine 444 BG/RR, Fibermax 960 BR, and Deltapine 555 BG/RR).

§ Total amount of MPB applied in grams of active ingredient per hectare during the growing season.

NS, * denotes level of significance for no significance and P = 0.05 level respectively.

Figure 3. Monthly heat unit accumulation recorded at Suffolk, VA and Florence, SC.

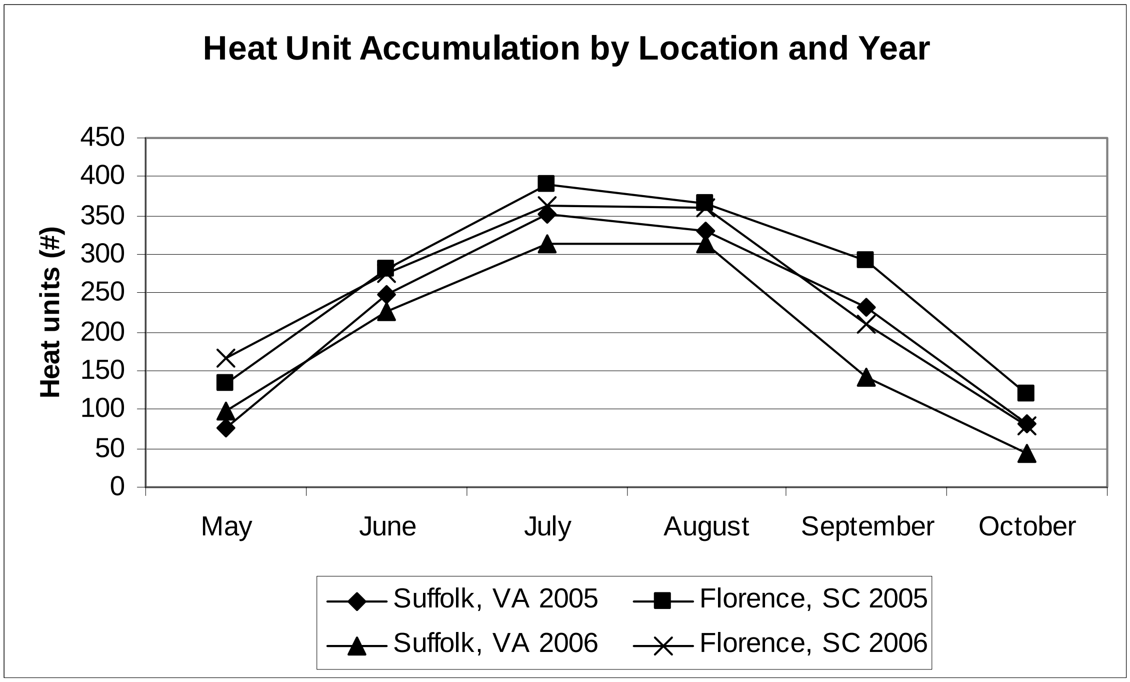
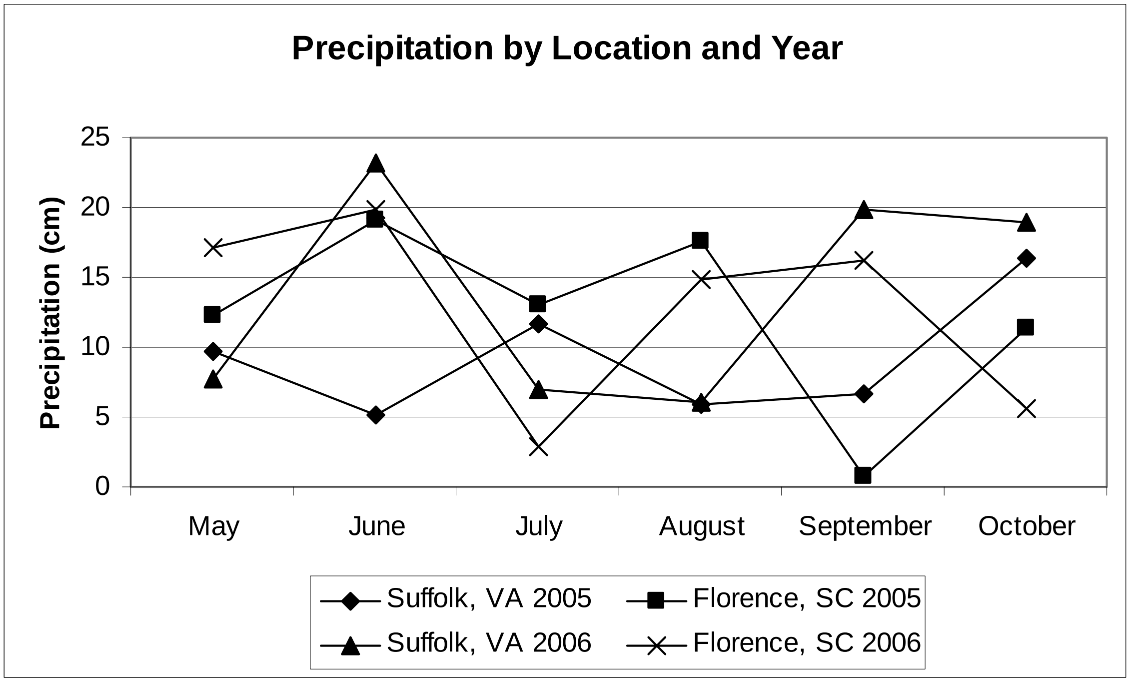


Figure 4. Monthly precipitation recorded at Suffolk, VA and Florence, SC.



CHAPTER 4

Cotton (*Gossypium hirsutum* L.) Response to the Interaction of Trifloxysulfuron-sodium and Mepiquat Chloride Application

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Abbreviations: HNR, height-to-node ratio; NAWF, nodes above white flower; AMS, apical main-stem nodes; FNA, fifth node application; ENA, eighth node application

ABSTRACT

Trifloxysulfuron-sodium (TFS), an acetolactate synthase (ALS)-inhibiting herbicide, utilized postemergence (POST) in cotton (*Gossypium hirsutum* L.) to control certain broadleaf weeds may also cause a growth stunting response visually similar to mepiquat chloride (MC) applications. The objective of this research was to examine cotton response to POST broadcast application timings and rates of TFS in multiple environments with and without MC to determine if TFS application alters the need for early season MC application. Six TFS treatments, including a fifth node application (FNA) or eighth node application (ENA) with rates of 5.3 g ai ha^{-1} or 7.9 g ai ha^{-1} with or without MC, along with an untreated, were evaluated on Deltapine 444 BG/RR. Trifloxysulfuron-sodium application decreased plant height at 2-3 weeks after treatment in Virginia 2005, but had no effect on end of season plant height. Maturity and the height-to-node ratio (HNR) were not influenced by TFS; however the number of apical main-stem (AMS) nodes increased with the FNA compared to untreated cotton. Lint yield was not altered by any treatment relative to the untreated cotton. Lint percentage, fiber length, and fiber strength were not influenced by TFS, while micronaire and fiber length uniformity were inconsistent. Mepiquat chloride application reduced plant height and enhanced maturity in three out of four years, reduced HNR in all years, and had no influence on the number of AMS nodes, yield, micronaire, fiber length, and fiber length uniformity. Based on these results, TFS application does not appear to have the same season-long effects on plant growth and maturity as MC application.

Early season postemergence (POST) broadcast herbicide applications are often necessary in cotton (*Gossypium hirsutum* L.) to control weeds prior to the 12-true leaf stage (Faircloth, 2007d). Trifloxysulfuron-sodium (TFS) (Envoke®, Syngenta Crop Protection, Greensboro, NC) (N-[(4,6-Dimethoxy-2-pyrimidinyl)amino]carbonyl-3-(2,2,2-trifluoro-ethoxy)-pyridin-2-sulfonamide sodium salt) is an acetolactate synthase enzyme (ALS, EC 4.1.3.18)-inhibiting, POST broadleaf weed herbicide, which may be utilized after the fifth leaf stage in cotton (Hudetz et al., 2000; Richardson et al., 2004a; Richardson et al., 2007a; Richardson et al., 2007b).

Trifloxysulfuron-sodium application provides 70% or greater control of numerous common broadleaf weeds in cotton including common cocklebur (*Xanthium strumarium* L.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray), hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill], ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], palmer amaranth (*Amaranthus palmeri* S. Wats.), pitted morningglory (*Ipomoea lacunosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), tall morningglory [*Ipomoea purpurea* (L.) Roth], sicklepod [*Senna obtusifolia* L.) Irwin & Barneby], as well as yellow nutsedge (*Cyperus esculentus* L.) (Porterfield et al., 2002a; Richardson et al., 2003a; Branson et al., 2005; Richardson et al., 2007b). Hudetz et al. (2000) and Troxler et al. (2003) reported that TFS application also resulted in the suppression of other problematic weeds including johnsongrass [*Sorghum halepense* (L.) Pers.] and purple nutsedge (*Cyperus rotundus* L.), however TFS has been unsuccessful in controlling several annual grass species, jimsonweed (*Datura stramonium* L.), prickly sida (*Sida spinosa* L.), smallflower morningglory [*Jacquemontia tamnifolia* (L.) Griseb.], spurred anoda [*Anoda cristata* (L.) Schlecht.], and velvetleaf (*Abutilon theophrasti* Medicus) (Troxler et al., 2003; Porterfield et al., 2003; Brecke and Stephenson, 2006; Richardson et al., 2006). Mixtures of TFS with other POST herbicides including bromoxynil, glyphosate, and pyrithiobac have been reported to increase the control of some of these less susceptible weeds, while complementing the weed control already demonstrated by these herbicides (Porterfield et al., 2003; Richardson et al., 2004b; Branson et al., 2005; Thomas et al., 2006).

Visual cotton injury has been observed due to early season POST TFS application through chlorosis of the treated foliage, stunting, and occasional necrotic lesions, which is typical of ALS-inhibiting herbicides (Richardson et al., 2004a; Richardson et al., 2004b; Koger et al., 2005; Thomas et al., 2006). Trifloxysulfuron-sodium applications to cotton POST at the two- to four-true leaf stage caused injury ranging from 6-67% at one week after treatment (WAT) (Porterfield et al., 2002a, Branson et al., 2002; Richardson et al., 2006; Richardson et al., 2007a), while label applications made after the four-true leaf stage resulted in injury ranging from 0-24% at one WAT (Porterfield et al., 2002a; Branson et al., 2005; Koger et al., 2005; Richardson et al., 2006). The injury associated with TFS may be increased by applications made to early plantings during cool, wet weather, but is usually transient with little to no visual symptoms three to four WAT (Porterfield et al., 2002a; Porterfield et al., 2002b; Crooks et al., 2003; Richardson et al., 2003b).

Stunting due to POST TFS application has been reported as a decrease in plant height within one to two WAT (Hoffman and Cothren, 2002; Richardson et al., 2004a; Thomas et al., 2006; Collins et al., 2007). However, Richardson et al. (2004a) reported that stunted plant heights were not significantly different from untreated cotton at eight WAT. Collins et al. (2007) concluded that TFS reduces height-to-node ratio (HNR), sympodial boll retention, and may delay crop maturity. Casteel et al. (2004) reported that TFS application did not influence end of season plant height, main-stem nodes, HNR, or first and outer position boll retention. Cotton lint yields and fiber quality properties have generally been unaffected by single TFS applications when compared to other herbicides or untreated weed-free treatments (Richardson et al., 2003b; Richardson et al., 2004a; Richardson et al., 2007a; Richardson et al., 2007b). However, Casteel et al. (2004) reported a yield reduction with label TFS application on nine to ten leaf cotton compared to untreated cotton, while Koger et al. (2005) reported that sequential POST over-the-top TFS applications may reduce yields.

Plant growth regulator (PGR) applications are made in cotton to reduce vegetative growth by decreasing main-stem and sympodial branch internode lengths (Kerby, 1985; Cathey and Meredith, 1988; Gwathmey and Craig, 2003; Collins et al., 2007), and hasten maturity through a reduction in vegetative growth, shifting plant resources to reproductive growth (Cathey and Meredith, 1988; Zhao and Oosterhuis, 2000; Gwathmey and Craig, 2003). Plant growth regulator application decreases gibberellic acid concentration within plant cells, thereby reducing cell wall plasticity (Behringer et al., 1990; Potter and Fry, 1993; Yang et al., 1996). Collins et al. (2007) suggested that a reduction in PGR application rates may be necessary when used in conjunction with TFS to avoid excessive vegetative control and possible yield reduction. The reported reduction of plant height associated with TFS application may alter the need for early season PGR application.

There has been limited research published examining the interaction of TFS and MC application on cotton (Casteel et al., 2004; Collins et al., 2007). The objective of this research was to examine cotton response to multiple timings and rates of POST broadcast applications of TFS with and without PGR application. Since previous research has reported differential cotton response following TFS application and response is influenced by temperature and precipitation, this experiment was conducted in two environments.

MATERIALS AND METHODS

In 2005 and 2006, field experiments were conducted at the Virginia Tech Tidewater Agricultural Research and Extension Center in Suffolk, VA (36°41' N, 76°46' W) on a Nansemond fine sandy loam (coarse-loamy, siliceous, subactive, thermic Aquic Hapludults), and at the North Carolina State University Upper Coastal Plain Research Station near Rocky Mount, NC (35°54' N, 77°43' W) on a Goldsboro loamy sand (fine-loamy, siliceous, subactive, thermic Aquic Paleudults).

Seven treatment combinations were examined in a randomized complete block design with three replications in Virginia 2005, and four replications in Virginia 2006 and North Carolina 2005 and 2006. Plots consisted of four 12.2-m long rows spaced on 91.4-cm centers. Cultivar Deltapine 444 BG/RR was planted in Virginia and North Carolina during both years. The treatments are listed in Table 13 and consisted of an untreated and six rates and timings of TFS in the presence or absence of mepiquat chloride (MC) (Pix® Plus Plant Regulator, BASF, Research Triangle Park, NC). A nonionic surfactant at 0.25% v/v (Induce®, Helena Chemical Company, Collierville, TN) was included with each of the TFS treatments. Decisions on fertility, late season weed control, and insect control were followed according to respective state cooperative extension recommendations (Edmisten et al., 2007; Faircloth et al., 2007).

All data were collected from the center two rows of the plots including in-season plant heights (2-3 WAT and end of season), nodes above white flower (NAWF) (early-August), lint yield, and fiber quality. Plant mapping data were collected at the end of the growing season in Virginia and North Carolina during 2005 and 2006 to determine the number of apical main-stem (AMS) nodes, HNR, total number of monopodial bolls, first sympodial node, first and second fruiting position sympodial bolls, total number of bolls, percent retention of first and second fruiting position sympodial bolls, and boll distribution by nodal zone. Only the number of AMS nodes and HNR are reported due to minimal differences in all other plant mapping data. 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 both locations (Table 14, Figures 5 and 6).

Defoliant applications were applied uniformly across all treatments. The center two rows of each plot were harvested approximately two weeks later 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 sub-sample was sent to the USDA classing office in Florence, SC to determine physical fiber properties using a high volume instrument analysis.

Data were analyzed using PROC GLM with contrasts for specific hypotheses to evaluate the significance of TFS application timings and rates, along with MC application (Table 15) (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 (Table 16), the data is presented separately by location and year.

RESULTS AND DISCUSSION

Environmental Conditions

Total heat unit accumulation at both locations ranged from 1138 to 1436, with North Carolina accumulating approximately 120 heat units more each year than Virginia (Table 14, Figures 5 and 6). Total precipitation ranged from 52.2 to 89.6 cm between May and October. In three out of four years, precipitation did not occur for at least 2-3 days before and following TFS treatment, while in North Carolina 2006 precipitation amounts of 0.2 cm and 1.0 cm accumulated shortly following the fifth node application (FNA) and the eighth node application (ENA), respectively. Previous researchers have observed cotton growth response following TFS application is influenced by environmental conditions shortly before and following application (Branson et al., 2002; Richardson et al., 2003b; Branson et al. 2005; Richardson et al., 2007b). These conditions may include cool temperatures and/or moisture-saturated soils, which may slow the metabolism of TFS in cotton (Askew and Wilcut, 2002; Branson et al., 2002; Branson et al., 2005; Richardson et al., 2007b).

Due to excessively rank growth in Virginia 2005, a late season MC application was applied to the untreated cotton and only the 2-3 WAT plant height of the growth characteristics is reported for that year. In North Carolina 2005, the 2-3 WAT and NAWF measurements were not collected for the TFS application timings and the untreated cotton, therefore those measurements are not reported.

Growth Characteristics

Consistent with previous research (Casteel et al., 2004; Richardson et al., 2004a; Collins et al. 2007; Richardson et al., 2007), plant height was reduced by approximately 3.5-7 cm by both TFS application timings at 7.9 g ai ha^{-1} compared to the untreated at 2-3 WAT in Virginia 2005 (Table 17), while the ENA at 7.9 g ai ha^{-1} resulted in shorter plants compared to the FNA at 7.9 g ai ha^{-1} at 2-3 WAT in Virginia 2006 (Table 18). End of season plant height was also affected by TFS application in Virginia 2006 only, as the ENA at 7.9 g ai ha^{-1} reduced plant height relative to the FNA at 7.9 g ai ha^{-1}. In contrast, Collins et al. (2007) reported that TFS consistently decreased end of season plant height by 5%. There were no differences in plant height at 2-3 WAT or end of season height due to TFS application in either year in North Carolina (Tables 19 and 20).

In the three years measured, MC application resulted in a decrease in end of season plant height compared to cotton that did not receive MC. Measurable end of season plant height reduction following MC application is reported repeatedly in the literature (Gwathmey and Craig, 2003; Casteel et al., 2004; Siebert and Stewart, 2006; Collins et al., 2007).

Trifloxysulfuron-sodium application timings and rates did not affect maturity based on NAWF at any location or year (Tables 17, 18, 19, and 20). Richardson et al. (2004a) and Richardson et al. (2007b) reported TFS application may delay maturity based on a lower number of white and pink flowers on the plant when counted at 3-5 days after first flower in TFS treated cotton. In this experiment, MC application hastened maturity based on NAWF relative to cotton that did not receive MC in three out of four years, which is consistent with previous research (York, 1983a; Cathey and Meredith, 1988; Coccaro et al., 2003; Gwathmey and Craig, 2003). There were no differences in maturity due to MC application in Virginia 2006.

Similar to Casteel et al. (2004), TFS timing and rate of application had no influence on HNR at either location or year in this experiment. In contrast, Collins et al. (2007) reported that TFS application reduced HNR by 10%. Consistent with previous research (Nuti et al., 2006; Siebert and Stewart, 2006; Collins et al., 2007), MC application decreased the HNR in three out of four years (Tables 18, 19, and 20). In Virginia 2006, the number of AMS nodes increased with the FNA of TFS when compared to untreated cotton (Table 18), while there were no differences in either year in North Carolina (Tables 19 and 20). Mepiquat chloride did not influence the number of AMS nodes at either location both years, as reported by Zhao and Oosterhuis (2000), Casteel et al. (2004), and Siebert and Stewart (2006).

Lint Percentage, Yield, and Fiber Quality

Lint yield, micronaire, and fiber length uniformity results were inconsistent in this experiment. In Virginia 2006 only, lint yield and micronaire were reduced by TFS with the FNA relative to the ENA when the timings were averaged over rates (Table 18). Fiber length uniformity was influenced by TFS rate in Virginia 2005, with increased length uniformity with the 7.9 g ai ha^{-1} rate (Table 17). An interaction between timing and rate occurred in Virginia 2005 as the FNA and ENA at 5.3 g ai ha^{-1} increased length uniformity, while the converse occurred with the FNA and ENA at 7.9 g ai ha^{-1}. These parameters were not influenced by TFS application in any other years (Tables 17, 18, 19, and 20). Lint percentage, fiber length, and fiber strength resulted in no differences between TFS treatment rates and timings compared to the untreated in Virginia and North Carolina during 2005 and 2006 (data not shown). Previous research has concluded that label application rates and timings of TFS on cotton has no influence on lint yield or fiber quality properties in Virginia (Richardson et al., 2003b; Richardson et al., 2004a; Richardson et al., 2004b; Richardson et al., 2007b), while Collins et al. (2007) reported a 7% yield reduction North Carolina with TFS application.

Mepiquat chloride application had no effect on lint percentage, yield, micronaire, fiber length, and fiber length uniformity. Similar results were reported by Siebert and Stewart (2006). However, fiber strength was influenced by MC in North Carolina 2006 only, where MC application reduced fiber strength (28.13 g tex^{-1}) compared to cotton not treated with MC (29.16 g tex^{-1}). This data is inconsistent with previous research, as Kerby (1985), Cathey and Meredith (1988), and Nuti et al. (2006) reported an increase in strength with MC application.

CONCLUSIONS

These data suggest that at 2-3 WAT plant height can be reduced in certain years following TFS application, as often seen with ALS-inhibiting herbicides. End of season plant height does not seem to be significantly influenced by TFS applications. As previously reported, MC application frequently reduces end of season plant height. Based on these data, TFS application does not appear to impact maturity and HNR as does MC application. Overall, the height reduction and enhanced maturity effects documented in this experiment seem to be more reliable with MC application compared to TFS application, and suggests that TFS application provides no maturity or season-long vegetative growth benefits. Fiber quality properties were generally unaffected by TFS or MC application, possibly being impacted to a greater extent by specific environmental conditions.

Based on the findings of this experiment, producers would not be able to rely on TFS application for plant growth regulation in cotton as compared with MC application. Environmental conditions during certain years may result in additional growth response to TFS application; however there was no response with the heat unit accumulation and precipitation that occurred during this experiment. Since our findings are limited to only two environments and years, further research should be conducted to examine additional TFS application timings and rates compared to MC application in environmental conditions that would result in increased cotton growth response. In conclusion, TFS application may temporarily influence cotton growth in certain years; however the response is not consistent enough to avoid using MC for full season vegetative growth control and to enhance maturity.

Table 13. Herbicide and plant growth regulator treatments applied to cotton in Virginia and North Carolina during 2005 and 2006.

Treatment	Description	Common name	Application timing	Application rate
1	Untreated			
2	Herbicide	trifloxysulfuron-sodium	8th node	5.3 g ai ha^{-1}
	Plant growth regulator	mepiquat chloride	early bloom	24.4 g ai ha^{-1}
3	Herbicide	trifloxysulfuron-sodium	8th node	7.9 g ai ha^{-1}
	Plant growth regulator	mepiquat chloride	early bloom	24.4 g ai ha^{-1}
4	Herbicide	trifloxysulfuron-sodium	5th node	5.3 g ai ha^{-1}
	Plant growth regulator	mepiquat chloride	early bloom	24.4 g ai ha^{-1}
5	Herbicide	trifloxysulfuron-sodium	5th node	7.9 g ai ha^{-1}
	Plant growth regulator	mepiquat chloride	early bloom	24.4 g ai ha^{-1}
6	Herbicide	trifloxysulfuron-sodium	8th node	7.9 g ai ha^{-1}
7	Herbicide	trifloxysulfuron-sodium	5th node	7.9 g ai ha^{-1}

*** Nonionic surfactant at 0.25% v/v included with trifloxysulfuron-sodium applications.**

Table 14. Monthly and total cumulative heat units (HU) and precipitation (Precip.) recorded at Suffolk, VA, and Rocky Mount, NC during 2005 and 2006.

	2005			
	Suffolk, VA		Rocky Mount, NC	
Month	HU†	Precip. ‡	HU	Precip.
	°C	cm	°C	cm
May	76	9.7	98	11.5
June	247	5.2	252	13.6
July	351	11.6	369	6.6
August	330	5.9	352	6.8
September	231	6.6	260	4.4
October	81	16.3	105	9.3
Total	1316	55.3	1436	52.2
	2006			
	Suffolk, VA		Rocky Mount, NC	
Month	HU	Precip.	HU	Precip.
	°C	cm	°C	cm
May	97	7.8	123	11.2
June	226	23.2	240	25.9
July	314	6.9	334	18.0
August	315	6.0	341	10.1
September	143	19.9	165	15.4
October	43	18.9	57	9.0
Total	1138	82.7	1260	89.6

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

‡ Monthly average precipitation

Table 15. Trifloxysulfuron-sodium (TFS) and mepiquat chloride (MC) application contrasts analyzed for Virginia and North Carolina during 2005 and 2006.

Contrast	Name	TFS application timing	TFS application rate	MC application
1	TFS w/ MC	5th and 8th node	7.9 g ai ha^{-1}	Yes
	TFS w/o MC	5th and 8th node	7.9 g ai ha^{-1}	No
2	FNA 7.9 g ai ha^{-1}†	5th node	7.9 g ai ha^{-1}	Yes and no
	ENA 7.9 g ai ha^{-1}	8th node	7.9 g ai ha^{-1}	Yes and no
3	TFS 5.3 g ai ha^{-1}	5th and 8th node	5.3 g ai ha^{-1}	Yes
	TFS 7.9 g ai ha^{-1}	5th and 8th node	7.9 g ai ha^{-1}	Yes
4	FNA Avr.‡	5th node	5.3 and 7.9 g ai ha^{-1}	Yes
	ENA Avr.	8th node	5.3 and 7.9 g ai ha^{-1}	Yes
5	FNA 5.3 g ai ha^{-1}/ ENA 7.9 g ai ha^{-1}	5th and 8th node	5.3 and 7.9 g ai ha^{-1}	Yes
	FNA 7.9 g ai ha^{-1}/ ENA 5.3 g ai ha^{-1}	5th and 8th node	7.9 and 5.3 g ai ha^{-1}	Yes
6	Untreated	-	-	No
	FNA 7.9 g ai ha^{-1}	5th node	7.9 g ai ha^{-1}	No
7	Untreated	-	-	No
	ENA 7.9 g ai ha^{-1}	8th node	7.9 g ai ha^{-1}	No

Table 16. Analysis of variance for main effects and main effect interactions on 2-3 weeks after treatment (WAT) and end of season (EOS) plant (plt.) height (hgt.), nodes above white flower (NAWF), height-to-node ratio (HNR), apical main-stem (AMS) nodes, lint percentage (Lint %), lint yield, micronaire (Mic.), length (Len.), strength (Str.), uniformity (Uni.) at Suffolk, VA and Rocky Mount, NC during 2005 and 2006.

Source	2-3 WAT plt. hgt.	EOS plt. hgt.	NAWF	HNR	AMS nodes	Lint %	Lint yield	Mic.	Len.	Str.	Uni.
					Virginia and North Carolina (2005 and 2006)						
Trial†	***	***	***	***	***	***	***	***	***	***	***
Rep(Trial)	*	*	NS	**	NS	NS	NS	NS	NS	NS	NS
TFS	NS	**	**	**	NS	NS	NS	NS	NS	NS	NS
TFS × Trial	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Trial represents the Year × Location interaction

*** Significant at the 0.05 probability level.**

**** Significant at the 0.01 probability level.**

***** Significant at the 0.001 probability level.**

NS denotes no significance

Table 17: Trifloxysulfuron-sodium (TFS) application timing and rate and mepiquat chloride (MC) application effect on 2-3 week after treatment (WAT) plant (plt.) height (hgt.), end of season (EOS) plant height, nodes above white flower (NAWF), height-to-node ratio (HNR), apical main-stem (AMS) nodes, lint yield, micronaire (Mic.), strength (Str.), and fiber length uniformity (Uni.) at Suffolk, VA during 2005.

	Virginia 2005								
	2-3 WAT plt. hgt.	EOS plt. hgt.	NAWF	HNR	AMS nodes	Lint yield	Mic.	Str.	Uni.
	——— cm ———		no.	cm	no.	kg ha^{-1}	units	g tex^{-1}	%
TFS w/ MC	75.78	95.46	2.98	5.39	18.42	1742	4.17	29.08	83.93
TFS w/o MC	74.07	115.23	4.19	5.95	19.22	1840	4.08	27.95	83.38
Contrast (Pr>F)	NS	<0.0001	0.0046	0.0103	NS	NS	NS	NS	NS
FNA 7.9 g ai ha^{-1}†	75.42	106.72	3.85	5.82	18.28	1839	4.17	28.52	83.70
ENA 7.9 g ai ha^{-1}	74.43	103.72	3.32	5.52	19.36	1744	4.08	28.62	83.62
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
TFS 5.3 g ai ha^{-1}	76.72	96.82	3.00	5.43	18.53	1887	4.23	28.55	83.63
TFS 7.9 g ai ha^{-1}	75.78	95.46	2.98	5.39	18.42	1742	4.08	28.90	84.32
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	0.0484
FNA Avr.‡	75.45	94.87	3.17	5.53	17.89	1881	4.15	28.37	84.02
ENA Avr.	77.05	97.41	2.82	5.29	19.06	1748	4.17	29.08	83.93
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
FNA 5.3 g ai ha^{-1}/ ENA 7.9 g ai ha^{-1}	76.40	97.36	3.05	5.38	19.08	1873	4.07	28.83	83.57
FNA 7.9 g ai ha^{-1}/ ENA 5.3 g ai ha^{-1}	76.10	94.91	2.93	5.45	17.86	1757	4.25	28.62	84.38
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	0.0222
Untreated	79.67	-	-	-	-	-	-	-	-
FNA 7.9 g ai ha^{-1}	76.00	-	-	-	-	-	-	-	-
Contrast (Pr>F)	0.0409	-	-	-	-	-	-	-	-
Untreated	79.67	-	-	-	-	-	-	-	-
ENA 7.9 g ai ha^{-1}	72.13	-	-	-	-	-	-	-	-
Contrast (Pr>F)	0.0005	-	-	-	-	-	-	-	-

† Abbreviations: FNA, fifth node application; ENA, eighth node application

‡ FNA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC versus ENA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC.

Table 18: Trifloxysulfuron-sodium (TFS) application timing and rate and mepiquat chloride (MC) application effect on 2-3 week after treatment (WAT) plant (plt.) height (hgt.), end of season (EOS) plant height, nodes above white flower (NAWF), height-to-node ratio (HNR), apical main-stem (AMS) nodes, lint yield, micronaire (Mic.), strength (Str.), and fiber length uniformity (Uni.) at Suffolk, VA during 2006.

	Virginia 2006								
	2-3 WAT plt. hgt.	EOS plt. hgt.	NAWF	HNR	AMS nodes	Lint yield	Mic.	Str.	Uni.
	cm		no.	cm	no.	kg ha^{-1}	units	g tex^{-1}	%
TFS w/ MC	57.34	71.76	2.96	4.12	17.31	976	4.64	33.39	84.20
TFS w/o MC	60.28	81.34	3.00	4.78	17.58	996	4.53	33.01	84.38
Contrast (Pr>F)	NS	0.0003	NS	0.0112	NS	NS	NS	NS	NS
FNA 7.9 g ai ha^{-1}†	51.05	79.06	3.04	4.58	17.58	949	4.60	33.68	83.86
ENA 7.9 g ai ha^{-1}	39.06	74.04	2.93	4.49	17.31	1023	4.56	32.73	84.71
Contrast (Pr>F)	0.0159	0.0269	NS	NS	NS	NS	NS	NS	NS
TFS 5.3 g ai ha^{-1}	57.50	71.58	2.57	4.23	17.28	1025	4.55	32.68	84.77
TFS 7.9 g ai ha^{-1}	57.34	71.76	2.96	4.12	17.31	976	4.64	33.39	84.20
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
FNA Avr.‡	53.08	72.03	2.85	4.23	17.14	890	4.73	33.03	84.28
ENA Avr.	61.75	71.31	2.68	4.28	17.45	1111	4.45	33.04	84.68
Contrast (Pr>F)	NS	NS	NS	NS	NS	0.0330	0.0201	NS	NS
FNA 5.3 g ai ha^{-1}/ ENA 7.9 g ai ha^{-1}	57.52	68.60	2.84	4.12	17.29	1006	4.67	32.89	84.88
FNA 7.9 g ai ha^{-1}/ ENA 5.3 g ai ha^{-1}	57.32	74.75	2.69	4.39	17.31	995	4.52	33.18	84.08
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Untreated	65.70	86.30	2.87	5.30	16.94	1201	4.57	33.33	84.20
FNA 7.9 g ai ha^{-1}	49.20	82.93	3.10	4.76	18.00	1038	4.50	33.83	84.13
Contrast (Pr>F)	NS	NS	NS	NS	0.0247	NS	NS	NS	NS
Untreated	65.70	86.30	2.87	5.30	16.94	1201	4.57	33.33	84.20
ENA 7.9 g ai ha^{-1}	71.35	79.75	2.90	4.81	17.17	953	4.55	32.20	84.63
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Abbreviations: FNA, fifth node application; ENA, eighth node application

‡ FNA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC versus ENA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC.

Table 19: Trifloxysulfuron-sodium (TFS) application timing and rate and mepiquat chloride (MC) application effect on 2-3 week after treatment (WAT) plant (plt.) height (hgt.), end of season (EOS) plant height, nodes above white flower (NAWF), height-to-node ratio (HNR), apical main-stem (AMS) nodes, lint yield, micronaire (Mic.), strength (Str.), and fiber length uniformity (Uni.) at Rocky Mount, NC during 2005.

North Carolina 2005									
	2-3 WAT plt. hgt.	EOS plt. hgt.	NAWF	HNR	AMS nodes	Lint yield	Mic.	Str.	Uni.
	cm	cm	no.	cm	no.	kg ha^{-1}	units	g tex^{-1}	%
TFS w/ MC	57.00	62.65	1.05	4.94	12.73	1132	4.95	28.34	81.65
TFS w/o MC	56.52	68.38	1.99	5.28	13.02	1027	4.90	28.38	81.56
Contrast (Pr>F)	NS	NS	0.0003	0.0440	NS	NS	NS	NS	NS
FNA 7.9 g ai ha^{-1}†	56.02	64.71	1.64	5.02	12.98	1065	4.96	28.06	81.99
ENA 7.9 g ai ha^{-1}	57.20	66.31	1.40	5.20	12.77	1094	4.89	28.65	81.23
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
TFS 5.3 g ai ha^{-1}	54.75	60.77	1.30	4.83	12.90	1090	4.89	28.94	81.03
TFS 7.9 g ai ha^{-1}	57.00	62.65	1.05	4.94	12.73	1132	4.95	28.34	81.65
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
FNA Avr.‡	56.67	60.54	1.31	4.82	12.90	1084	4.94	28.40	81.88
ENA Avr.	55.09	62.88	1.04	4.96	12.73	1139	4.90	28.45	80.80
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
FNA 5.3 g ai ha^{-1}/ ENA 7.9 g ai ha^{-1}	57.25	62.27	1.21	4.92	12.96	1068	4.89	28.94	81.45
FNA 7.9 g ai ha^{-1}/ ENA 5.3 g ai ha^{-1}	54.50	61.15	1.14	4.86	12.67	1155	4.95	27.91	81.23
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Untreated	-	62.83	-	5.22	12.46	1046	4.93	27.83	82.20
FNA 7.9 g ai ha^{-1}	-	68.50	-	5.19	13.29	981	4.93	28.33	81.90
Contrast (Pr>F)	-	NS	-	NS	NS	NS	NS	NS	NS
Untreated	-	62.83	-	5.22	12.46	1046	4.93	27.83	82.20
ENA 7.9 g ai ha^{-1}	-	68.25	-	5.36	12.75	1073	4.88	28.43	81.23
Contrast (Pr>F)	-	NS	-	NS	NS	NS	NS	NS	NS

† Abbreviations: FNA, fifth node application; ENA, eighth node application

‡ FNA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC versus ENA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC.

Table 20: Trifloxysulfuron-sodium (TFS) application timing and rate and mepiquat chloride (MC) application effect on 2-3 week after treatment (WAT) plant (plt.) height (hgt.), end of season (EOS) plant height, nodes above white flower (NAWF), height-to-node ratio (HNR), apical main-stem (AMS) nodes, lint yield, micronaire (Mic.), strength (Str.), and fiber length uniformity (Uni.) at Rocky Mount, NC during 2006.

North Carolina 2006									
	2-3 WAT plt. hgt.	EOS plt. hgt.	NAWF	HNR	AMS nodes	Lint yield	Mic.	Str.	Uni.
	cm		no.	cm	no.	kg ha^{-1}	units	g tex^{-1}	%
TFS w/ MC	65.18	72.20	3.53	4.46	16.42	1143	4.44	29.16	84.29
TFS w/o MC	64.28	81.25	4.36	4.89	17.25	1123	4.56	28.13	83.59
Contrast (Pr>F)	NS	<0.0001	0.0031	0.0076	NS	NS	NS	0.0269	NS
FNA 7.9 g ai ha^{-1}†	64.20	77.55	3.95	4.75	16.88	1101	4.48	28.33	84.08
ENA 7.9 g ai ha^{-1}	65.25	75.90	3.94	4.59	16.79	1165	4.53	28.96	83.80
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
TFS 5.3 g ai ha^{-1}	64.16	74.50	3.71	4.41	17.13	1129	4.43	29.01	83.46
TFS 7.9 g ai ha^{-1}	65.18	72.20	3.53	4.46	16.42	1143	4.44	29.16	84.29
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
FNA Avr.‡	65.40	74.36	3.65	4.46	16.92	1110	4.46	28.84	83.96
ENA Avr.	63.94	72.34	3.59	4.41	16.63	1162	4.40	29.34	83.79
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
FNA 5.3 g ai ha^{-1}/ ENA 7.9 g ai ha^{-1}	65.10	73.36	3.68	4.48	16.63	1137	4.48	29.15	83.78
FNA 7.9 g ai ha^{-1}/ ENA 5.3 g ai ha^{-1}	64.24	73.34	3.56	4.40	16.92	1135	4.39	29.03	83.98
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Untreated	64.75	81.20	4.03	4.82	16.50	1079	4.58	28.80	83.60
FNA 7.9 g ai ha^{-1}	62.93	81.90	4.40	5.07	17.05	1086	4.53	27.80	83.68
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Untreated	64.75	81.20	4.03	4.82	16.50	1079	4.58	28.80	83.60
ENA 7.9 g ai ha^{-1}	65.63	80.60	4.33	4.72	17.46	1162	4.60	28.45	83.50
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Abbreviations: FNA, fifth node application; ENA, eighth node application

‡ FNA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC versus ENA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC.

Figure 5. Monthly heat unit accumulation recorded at Suffolk, VA and Rocky Mount, NC.

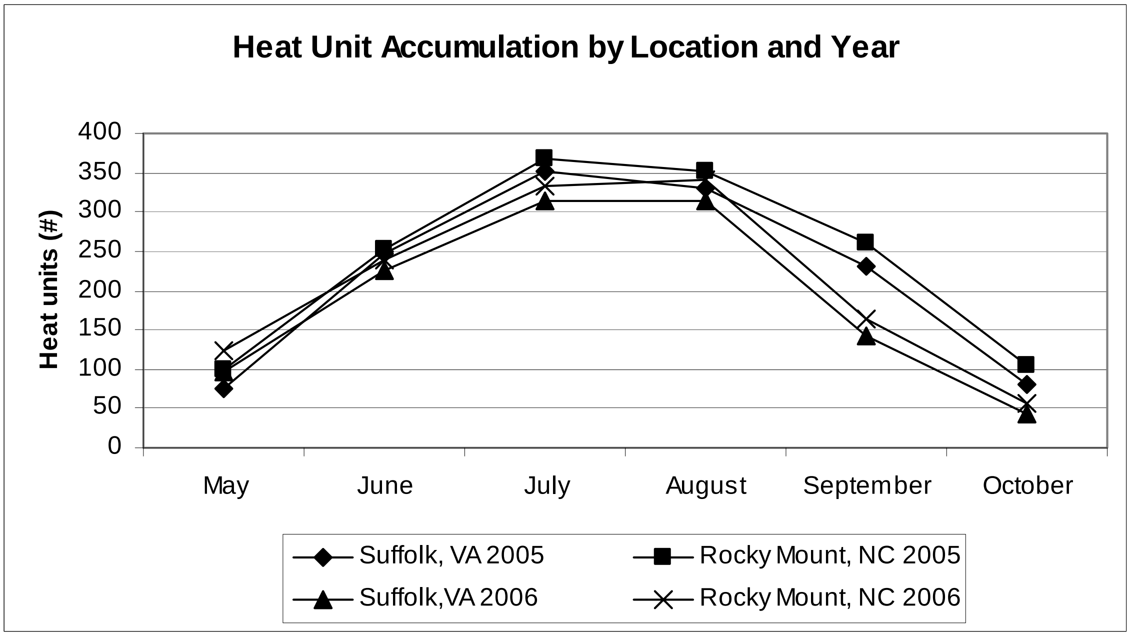
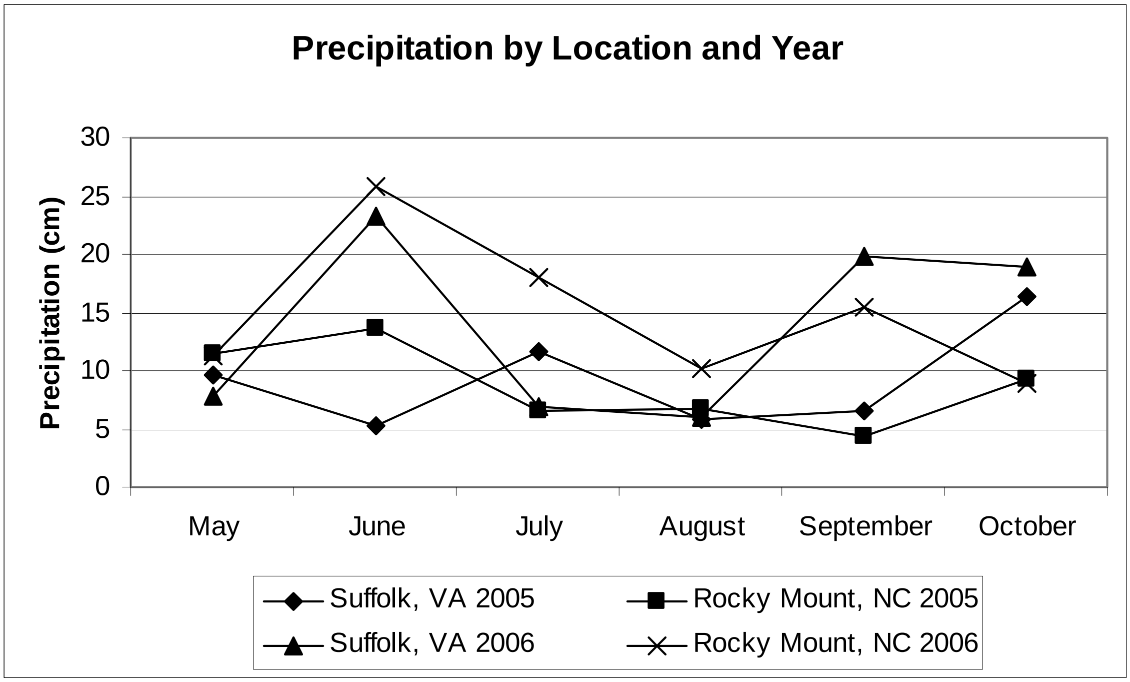


Figure 6. Monthly precipitation recorded at Suffolk, VA and Rocky Mount, NC.



CHAPTER 5

Conclusions

The plant population and planting date experiment results suggest that plant population is a critical factor in maximizing cotton yield. In this research, the lowest population of 5.3 plants m^{-2} reduced yields in Virginia and North Carolina, while this reduction occurred with the highest population of 17.1 plants m^{-2} in Louisiana. In the northern region of the cotton belt, the plant may not have been able to compensate for yield at excessively low populations. Although the growth parameters were not measured in Louisiana, the yield reduction associated with the 17.1 plants m^{-2} population may have occurred due to excessive vegetative growth.

In the same experiment, there was no benefit to planting in late-April to early-May versus late-May in Virginia and North Carolina. This may be due to the relatively low accumulation of heat units early in the growing season at these locations during these years compared to Louisiana. There should be more research conducted prior to using this research for recommendations, as a warm early season may be beneficial to cotton growth and development in some years. This was observed where yield was enhanced in the earlier planting in Louisiana, where greater than two times more heat units accumulate during May.

Based on the growth parameters measured in the cultivar response to MPB application trial, MPB applications can reduce vegetative growth and hasten maturity compared to untreated cotton. Since the determinate and indeterminate cultivars responded similarly to MPB application with respect to actual plant height reduction, this suggests that PGR management may be the same for each cultivar, even with differing maturities and fruiting patterns. However, with the greatest response in plant height reduction occurring with the intermediate maturing determinate cultivar, plant growth response to PGR application may be influenced more by genetic factors instead of length of fruiting pattern, suggesting that application should be made based on growth and maturity measurements.

The trend of decreasing yield observed with increasing total season MPB application, suggests that early, aggressive PGR strategies may result in yield loss in environments similar to Virginia, where heat unit accumulation is limited relative to the southern region of the cotton belt. However, in environments where the plants can continue to grow as the growing season is extended (i.e. South Carolina), these higher rate and early application regimes may be more appropriate as there were no declining yield trends.

In the TFS application experiment, end of season plant height and maturity were not influenced by TFS, however, MC application did reduce plant height and enhance maturity in most years. This suggests that MC is more reliable for controlling vegetative growth and enhancing maturity compared with TFS application. Overall, producers would not be able to rely on TFS application for full-season plant growth regulation, as usually demonstrated by MC application.

Fiber quality properties were generally inconsistent in all experiments and varied with year and location. Past research supports these inconsistent findings and similar to others the conclusion from this experiment is that this variability is influenced by differing environmental conditions occurring at the locations of the experiments.

From the observations in this research, heat unit accumulation seemed to influence cotton growth and development, yield and fiber quality response to the interaction of plant growth regulator and plant population and planting date, differing cultivars, and herbicide application. Some consistencies occurred within the results in environments with similar heat unit accumulation, as Virginia and North Carolina were similar in many instances with limited heat unit accumulation during the growing season, while results from Louisiana and South Carolina usually differed relative to Virginia.

In summary, plant population and planting date effects on cotton growth and development seem to be influenced by the heat accumulation of a particular location and growing season. The effect that MPB application has on different cultivars may vary in some cases, especially in environments similar to Virginia, where higher rates and early application regimes may result in an unfavorable response. With TFS application, cotton growth may be effected in certain years, but the response is inconsistent, and MC should be applied to achieve full season vegetative control.

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THE VITA

Nathan Brook O'Berry was born in Suffolk, Virginia on 20 April 1983. His parents are Kimberly F. Ashley and Ronald F. O'Berry, along with his stepfather William F. Ashley. He has a younger brother, Justin C. Ashley, who idolizes him and follows his every step.

Nathan grew up near Windsor, Virginia, and as a young boy spent much of his time on his grandfather's family farm. This is where Nathan's interest in agriculture originated, as he spent every weekend and summer working in the field with his grandfather and father where they raised peanuts, corn, soybeans, cotton, and wheat. Nathan continues to lend a helping hand to his father when possible as he still successfully operates the family farm.

In 2001, Nathan graduated from Windsor High School in the top ten of his class, with a GPA of 3.96. While in high school he was involved in many activities including baseball, football, FFA, DECA, and Beta Club. Following high school, Nathan began his collegiate career at Virginia Polytechnic Institute and State University (Virginia Tech) in Agricultural and Applied Economics. While at Virginia Tech he had the opportunity to compete on the Crop Judging Team and Weed Team, in which he won several team and individual awards. While completing his Bachelor of Science degree, Nathan began working at the Tidewater Agricultural Research and Extension Center in Suffolk, Virginia. This opportunity led him into his journey towards his Master of Science degree in Crop and Soil Environmental Sciences. During Nathan's research, he gained extensive knowledge in cotton, including plant growth regulator application, cultivars selection, and herbicide application. This research also allowed Nathan to provide advice to producers through the Virginia Cooperative Extension and the many producer and professional presentations he presented.

Nathan graduated with his Master of Science in August 2007, and continues to work in the agricultural field. With his past agricultural experiences and knowledge, Nathan looks forward to working with the producers across Virginia for years to come.