ABSTRACT

WILSON, JR., DAVID GAYE. Evaluation of Weed Management and the Agronomic Utility of Cotton Grown on a 15-Inch Row Configuration and the Biology and Ecology of Doveweed. (Under the direction of Alan C. York and Keith L. Edmisten.)

For more than a century, farmers planted cotton in rows spaced 91-cm or more apart. Row spacing was dictated primarily by equipment for cultivation, which was initially draft animals and later, tractors. Harvesting equipment also was designed to accommodate these wide row spacings. Recent advances in technology, especially herbicide-resistant cotton and the ability to spindle-pick cotton in 38-cm rows, have increased the potential for cotton production in narrow rows.

Field experiments were conducted to evaluate weed management systems in glufosinate-resistant cotton planted in 38- and 97-cm rows. Greater than 90% control of annual grasses and *Amaranthus* spp. in 2004 and *Ipomoea* spp. in both years was obtained in narrow-row cotton receiving glufosinate applied early postemergence (EPOST) and mid-postemergence (MPOST) to 2- and 6-leaf cotton, respectively. With good early season control by glufosinate and rapid canopy closure, there was little benefit from pendimethalin, fluometuron, or pyrithiobac applied preemergence (PRE), *S*-metolachlor or pyrithiobac mixed with glufosinate applied MPOST, or trifloxysulfuron applied late postemergence (LPOST) to 11-leaf cotton. In 2005, glufosinate alone applied EPOST and MPOST did not adequately control annual grasses and *Amaranthus* spp. Pendimethalin applied PRE alone or mixed with fluometuron or pyrithiobac increased control to greater than 90% and increased yields 59 to 75%. Pendimethalin PRE followed by *S*-metolachlor or pyrithiobac mixed with glufosinate at MPOST was no more effective than pendimethalin alone. Without PRE herbicides, trifloxysulfuron applied LPOST increased *Amaranthus* but not annual grass control. Cotton row spacing had no effect on cotton yield and little effect on weed control. Weed control and yield in narrow-row cotton with a PRE herbicide plus glufosinate applied twice was similar to that in wide-row cotton with a PRE herbicide, glufosinate applied twice, and trifloxysulfuron plus prometryn plus MSMA applied postemergence-directed.

Field experiments were conducted in 2004 and 2005 at Clayton and Rocky Mount, NC to determine weed management systems in 38-cm glyphosate-resistant cotton. Additionally, row spacing effects on weed

management were also examined.   Herbicide systems in the 38-cm row spacing controlled annual grasses more effectively when PRE herbicides or a mid-POST application of *S*-metolachlor was included. Control of *Ipomoea* spp. was more effective in systems including preemergence herbicides or glyphosate mixed with pyrithiobac POST. Programs containing sequential POST applications of glyphosate alone were effective in controlling Palmer amaranth and smooth pigweed. Cotton row spacing had little effect on weed control, and there were no differences in lint yield among herbicide systems in both row spacings. However, a 6% increase in lint yield was observed in the 38-cm rows compared to the 97-cm rows.

There has been a recent technological advancement of glyphosate-resistant cultivars that allow topical applications of glyphosate up to 7 days prior to harvest. Studies were conducted to evaluate weed management systems in narrow-row cotton utilizing this new glyphosate-resistance technology. At least one herbicide system controlled annual grasses, *Ipomoea* spp., and *Amaranthus* spp. at least 96, 93, and 99% late in the season.   Glyphosate applied alone to 1- and 6-leaf cotton provided excellent ($\geq$ 93%) late-season control of all species present in this study. Systems including *S*-metolachlor provided more effective late-season control of annual grasses, while systems including pendimethalin plus fluometuron or pyrithiobac PRE tended to provide more effective late-season control of *Ipomoea* spp.   There were no differences observed with respect to lint yield or fiber quality characteristics among herbicide systems.   This research illustrates that excellent overall weed control can be obtained in narrow-row glyphosate-resistant cotton, but systems including the use of residual herbicides may be more beneficial.

Studies were conducted to determine plant population effects on 38-cm cotton. The plant population densities under investigation ranged from 34,400 to 310,400 plants ha^{-1}. All plant populations in the 38-cm rows were compared to 97-cm rows with a population density of 115,800 plants ha^{-1}. Plant height, number of mainstem nodes, number of bolls per plant, and seed cotton weight per boll decreased as plant populations increased. However, when plant populations ranged from 102,800 to 301,400 plants ha^{-1}, a higher percentage of first position bolls and total seedcotton weight in the lower and middle portion of the canopy was noted for the 38-cm rows compared to 97-cm rows. Therefore, an earlier crop could possibly achieved in 38-cm rows by using populations of at least 120,000 plants ha^{-1} compared to the 97-cm rows. The amount of photosynthetically-active radiation (PAR) penetrating through the plant canopy at 10 wk after planting (WAP) averaged 19% less with a population density of at least 60,300 plants ha^{-1} in the 38-cm rows compared to the 97-

cm rows. This could lower the probability of late-season weed resurgence in cotton planted in 38-cm rows. There were no differences in lint yields with plant populations ranging from 60,300 to 301,409 plants ha^{-1}. However, decreases in lint yield with plant populations above or below those levels were observed. All fiber quality characteristics were within acceptable levels to avoid price discounts regardless of plant population density or row spacing. Our findings indicate that higher plant population densities than what is utilized in wide-row cotton production systems are not warranted in narrow-row cotton if it is to be spindle-picked.

An experiment was conducted at five locations during 2004 and 2005 to determine if MC application strategies currently recommended for wide-row cotton are valid for cotton planted in 38-cm rows. Cotton planted in 38- and 97-cm rows received MC in three application strategies. The low rate multiple (LRM) strategy consisted of MC at 12 g a.i. ha^{-1} applied three times at 2-wk intervals beginning at the first square stage. The modified early bloom (MEB) strategy consisted of MC at 24 g ha^{-1} applied 2 wk prior to early bloom and repeated at early bloom. The early bloom (EB) strategy consisted of MC at 24 g ha^{-1} applied at early bloom and repeated 2 wk later. Cotton in 38- and 97-cm rows responded similarly to MC, as indicated by lack of a MC application strategy by row spacing interaction for plant height, fruiting characteristics, fruit retention, lint yield, and fiber quality. Cotton in 38-cm rows was shorter, produced more bolls per unit area, had greater boll retention on first position sympodial sites, and yielded 10% more than cotton in wide rows. Except for plant height, which was reduced more by MC in the LRM and MEB strategies than in the EB strategy, cotton response was similar with each MC application strategy. Averaged over row spacings, MC increased lint yield 5%. Minor increases in fiber length were noted in MC-treated cotton, but MC did not affect micronaire, fiber strength, or fiber length uniformity. The results suggest current MC recommendations for wide-row cotton in North Carolina are appropriate for cotton in 38-cm rows. The LRM or MEB strategies would be preferred.

Laboratory and greenhouse experiments were conducted to determine the effect of temperature and seed burial depth on doveweed germination and emergence. Germination at constant temperature was well defined by a Gaussian model, which estimated peak germination at 28 C. However, based upon t-tests the effect of temperature treatments between 25 and 30 C did not differ ($P > t = 0.08$). The mean base temperature for germination (50%) was between 20 and 25 C. Similar maximum percent germination was observed for optimal treatments under both constant and alternating temperatures. Among alternating temperature treatments, 35/25 C regime gave the highest germination (77%). Germination was higher with alternating temperature regimes of

40/30 and 40/35 C (65 and 30%, respectively) than constant temperatures of 36 and 38 C (4 and 0%, respectively). No germination was observed at constant temperature of 38 C and alternating temperature regimes of 20/10 and 25/15. Light did not facilitate germination. In depth of emergence experiments, peak emergence was reached 2 wk after planting regardless of burial depth. Peak emergence was between 0 and 1 cm at 4 weeks after planting, and occurred from as deep as 4 cm. The mean emergence depth was 3.2 cm. Knowledge gained from this research will aid in an integrated weed management strategy for doveweed.

EVALUATION OF WEED MANAGEMENT AND THE AGRONOMIC UTILITY OF COTTON GROWN ON A 15-INCH ROW CONFIGURATION AND THE BIOLOGY AND ECOLOGY OF DOVEWEED

by

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DEDICATION

This effort is dedicated to my late grandfather, Perry Bailey. The love, support, and wisdom that he gave me over the years have molded me into the person that I am currently, and the person that I am striving to be. It only seems like yesterday that I was afflicted with a case of strep-throat and still having to work in the field trying to finish laying-by that season's cotton crop. I remember telling him how sick I was, and that I couldn't drive that tractor any longer. He replied with one of his typically emphatic comments, "Son, I know how sick you are. You only have two more fields to cultivate and we are finished. You'll have plenty of time to rest later." That is the work ethic that he instilled in me at a young age, and there is no doubt in my mind that is one of the character principals that has propelled me to where I am today. He left a fingerprint on numerous hearts and minds in this world, and if I can accomplish just half of what he did, I will be more than satisfied with myself.

BIOGRAPHY

David Gaye Wilson, Jr. was born on August 23, 1977 to David and Cheryl Wilson in Batesville, MS. He was raised in the nearby town of Crowder, MS on a family farm where cotton, rice, soybean, corn, and cattle were the major commodities. His love for agriculture began at the early age of three when his father let him sit in his lap and turn the steering wheel of a two-row cotton picker. A few years later, his interest in weed science began when he was instructed to remove cocklebur from the cotton fields via a hoe. He decided right then that if we could send a man to the moon then there has to be an easier way to keep cocklebur from growing in a cotton crop. Little did he know that there were easier methods, his father just didn't want him being unproductive by playing in the swimming pool all day.

Davie graduated from Senatobia High School in 1995. He attended Mississippi State University where he received a Bachelor of Science degree in Agronomy in 2000. Upon completion of his undergraduate degree, he remained at Mississippi State University where he accepted a graduate assistant position under the direction of Dr. Dan Reynolds. The primary focus of his master's research was the evaluation of trifloxysulfuron in glyphosate-resistant and BXN cotton systems. In 2003, the Department of Crop Science at North Carolina State University accepted Davie into a Ph.D. program under the direction of Drs. Alan York and Keith Edmisten. While at North Carolina State his research focused on various agronomic and weed management aspects of 15-inch, spindle-picked cotton. He has recently accepted a position with Monsanto as a Trait Development Representative.

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First and foremost I would like to thank my Lord and Savior, Jesus Christ. Without his guidance and sustaining grace, I would not have made it thus far in life. I would like thank my family, most notably my grandmother, Joan Bailey. Her love, support, and guidance have been key in my journey through life. Without her constant prodding, I probably wouldn't have made it this far. She taught me that complacency is the bane of character evolution, and for that I am truly grateful.

I would like to thank Alan York for giving me the opportunity to further my studies in one of the most respected programs in the country. He is one of the most patient, wisest, and honorable men that I have ever come into contact with. I don't think I would have accomplished as much as I have in such a short period of time if it wasn't for his guidance and nose-to-the-grindstone attitude. It is because of him that I now speak proper English and not the back-water dialect he so vehemently despised. I would like to also thank Keith Edmisten for making me understand that I don't know as much about cotton as I think I do. A special thanks also goes out to John Wilcut, Mike Burton, and J.R. Bradley for serving on my graduate committee.

This research would not have been possible without the help of Rick Seagroves, Jamie Hinton, Andrew Gardner, Josh Beam, Jamie Lanier, Guy Collins, Gary Hamm, and Steve Hoyle. Hopefully one day when they think of me they won't remember having to box-map or crawl around on their hands and knees thinning plots. Additionally, if it wasn't for Jamie Lanier I would have been hand-picking my plots. I truly believe he is the Southern version of MacGyver. He can make farm machinery out of a sheet of paper, fishing line, a tube of toothpaste, and a "left-handed, metric, adjustable wrench". An additional thanks to Jan Spears for guidance and allowing me the use of her lab while I was conducting my germination experiments.

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CHAPTER I

General Introduction

For more than a century, farmers planted cotton in rows spaced 91-cm or more apart (Burmester, 1996). Row spacing was dictated primarily by equipment for cultivation, which was initially draft animals and later, tractors. Harvesting equipment also was designed to accommodate these wide row spacings. Recent advances in technology, especially herbicide-resistant cotton, have increased the potential for cotton production in narrow rows.

The current low profit margin for cotton is making it very difficult for even the most efficient U.S. cotton growers to remain solvent. Cotton growers are very interested in technologies and management systems which will reduce their production costs, and at the same time increase yield. There has been considerable interest in planting cotton in 19- to 25-cm row spacings (Ultra Narrow Row, UNR). Although UNR cotton may reduce production costs and increase yields in some areas, acceptance of this practice has been limited because of the technology that has been available for producers to plant and harvest UNR cotton (Atwell et al., 1996; Brown et al., 1998). Planting cotton to a 19- or 25-cm row spacing requires the use of a grain drill that is not particularly modified for cotton seed size and shape, nor are they accurate enough to plant the exact plant populations at appropriate depths needed for sufficient stands to maximize yield potential. Harvesting UNR cotton presents a similar problem. UNR cotton must be harvested using a broadcast finger-stripper attached to a conventional cotton stripper because the row spacings are too narrow for a conventional spindle picker or brush stripper. This type equipment removes the entire boll (including the carpel walls) as well as some of the peduncles and short limbs from the cotton plant. If there are any leaves left on the cotton plant after defoliation, they may also be harvested and mixed with the cotton fiber as well. An extractor-type field cleaner is used on the stripper harvesters to remove some of the foreign matter, but it does not nearly get all of it. This causes the commercial ginner increased ginning costs as well as slowing productivity. As a result, producers delivering this “trashy” cotton to a commercial gin are subjected to a significant dockage in payment for their product due to the foreign matter mixed with the marketable lint, which increases ginning costs, and decreases lint grades caused by the harvesting method. There also seems to be a stigma associated with UNR cotton. Regardless of grade, buyers pay less if they know it is UNR.

Recent advances in technology have the potential to remedy these types of situations. There has been a spindle-type picker commercialized with the ability to harvest cotton planted in a narrow-row (38-cm) configuration (Willcutt et al., 2005). This will significantly reduce the amount of foreign matter that is mixed with cotton when finger-stripped and possibly keep the lint grades at acceptable levels to maximize the producers' payments on their product. It will also possibly eliminate the need to plant short and slender cotton varieties that are needed in a UNR configuration, thereby allowing farmers to plant a wider array of varieties tailored to their growing region. Existing narrow-row planters can be used to plant cotton on 38-cm row configurations with minimal modifications, such as seed plates designed for cotton seed size and shape. They are capable of planting exact plant populations on 38-cm rows, thereby eliminating the use of the grain drill method. This will allow producers to be fully efficient and minimize their seed input cost by being extremely precise on their seed placement. When this new machine technology is coupled with the recent weed control technologies like Roundup Ready, Roundup Ready Flex, and Liberty Link, this will possibly make the 38-cm cotton system very appealing to cotton producers. It can possibly save them production time, and provide them greater return on their monetary inputs.

Agronomic and Physiological Aspects

A number of studies have compared UNR cotton to conventionally spaced cotton. But, to date, there has been little done on the 38-cm spacing configuration in an overall production system sense. A few studies, however, have focused on cotton in 38-cm rows. Jost and Cothren (2001) reported minimal differences in plant growth and yield between plant densities of 136,000 and 199,000 plants ha^{-1} in 19- and 38-cm row spacings. No conclusive argument could be made to recommend one or more of these row spacing and plant density configurations exclusively. The reasons for the inconclusiveness seemed to be directly correlated to soil type, which were historically conducive to excessive vegetative growth rather than row spacing and plant population configuration.

Increasing cotton plant density reduces the rate of early node production and the final number of main-stem nodes (Grimes et al., 1978; Kerby et al., 1990). Fowler and Ray (1977) evaluated two different cotton cultivars with respect to growth habit in equidistant spacings of 12.7, 17.8, 25.4, 38, and 50.8 cm. They concluded, as have others (Bilbro and Quisenberry, 1973), that plant height, node numbers, and plant dry weight decreased as plant density increased. They also demonstrated that leaf-area-index (LAI) accumulated more rapidly at higher plant densities, but a greater proportion of photoassimilates was directed to vegetative growth rather than reproductive growth. These observations led Fowler and Ray to conclude that plant density would affect yield both positively with LAI accumulated early in the season, and negatively through lowering the fruiting-vegetative ratio. A high fruiting-vegetative ratio has been shown to be desirable in cotton (Meredith and Wells, 1989).

Fowler and Ray (1977) found significantly more fruiting structures per unit ground area in narrow spacings. According to Pearce et al. (1965) and Williams et al. (1965), more fruiting structures per unit land area should enhance earliness. However, no differences were detected for earliness in the Fowler and Ray study. The lack of earliness was attributed to the height of the first fruiting branch being greater at high densities and to lower fruiting-vegetative ratios, and Fowler and Ray suggested that a high fruiting-vegetative ratio may be a key factor in breeding cotton for a high population density, narrow-row culture.

In studies conducted by Nichols et al. (2002), 19-, 38-, and 96-cm row spacings were evaluated with plant populations ranging from 185,000 to 370,000 plants ha^{-1} using current transgenic and non-transgenic cultivars. They found that transgenic varieties in narrow rows yielded as well or better than conventional varieties in most cases. There was no yield advantage found for okra-leaf varieties in narrow-row cotton. Row spacing had little impact on fiber quality, and differences in fruiting characteristics were largely due to variety, with row spacing having little effect. Overall, cotton produced in narrow-row configurations yielded similar to cotton produced in conventional-row spacings. This research conflicted with the findings of Heitholt et al. (1992), where lint yield of okra-leaf cotton was greater when grown in narrow rather than wide rows.

Closer row spacings and elevated plant densities in UNR cotton also led to more rapid canopy closure, compared to conventionally spaced cotton (Jost and Cothren, 2000). Rapid canopy closure could reduce weed competition (Snipes, 1996; Culpepper and York, 2000), increased light interception (Krieg, 1996), and possibly decrease soil water evaporation. Krieg (1996) determined that up to 40% of the available water supply is lost to evaporation from the soil in traditional row spacings. A greater proportion of the total water supply may be accessible to the plant in 38-cm cotton rather than being lost to evaporation.

There is also another reason to consider the new cultural methodology of 38-cm cotton compared to the

UNR system. One of the concerns with UNR cotton is that fiber quality may be sacrificed. Heitholt et al. (1992) showed that narrow rows resulted in earlier canopy closure. Buxton et al. (1979) showed that narrow-row spacings caused a greater percentage of fruit to be set earlier. Both of these factors, along with reduced boll size observed in high densities (Fowler and Ray, 1977), have the potential to negatively affect fiber quality. However, studies with more current cultivars have failed to show any detectable influence of narrow or UNR spacings on fiber quality. Anthony et al. (2000) reported that UNR, stripped cotton processed with properly equipped gins yielded HVI and manual grades equivalent to those obtained from conventional spindle-picked cotton with the exception of trash content. Spindle-picked cotton has been shown to yield better color +b, fiber strength, fiber length, uniformity index, neps, and non-lint content than stripper- harvested cotton (McAlister III and Rogers, 2005). However, other studies with fairly current cultivars have failed to show any detectable influence of narrow or UNR spacings on fiber quality (Gerik et al., 1998; Heitholt et al., 1993; Smith et al., 1989). It is noted that these studies involved hand-picking the cotton as opposed to using a finger-type stripper.

Weed Management

Management of weeds to reduce yield loss and increase harvesting efficiency and quality is crucial for narrow-row cotton production. Switching to narrow-row cotton production eliminates the ability to use cultivation and post-directed herbicide applications. Herbicide-resistant cotton will play a key role in an overall production scheme. Earlier crop canopy closure is achieved in a 38-cm row spacing compared to cotton grown on 91- to 101-cm rows (Jost and Cothren, 2000). This earlier canopy closure may aid in late-season weed management.

Row spacing affects canopy closure, thus influencing the growth and development of both crop and weeds. Knezevic et al. (2003) concluded that planting soybeans in wide rows reduces early-season crop tolerance to weeds requiring earlier weed management programs. The critical time for weed removal (CTWR) for soybeans grown on 38-cm rows was at the V2 growth stage, whereas in 76-cm rows the CTWR coincided with the V1 stage of growth. It has also been found that weeds grown with soybean planted in 19-cm rows produced less aboveground biomass and reduced yield less than weed species grown with soybeans in 76-cm rows (Hock et al., 2006).

Studies conducted by Culpepper and York (2000) found that many grass and broadleaf weeds can be sufficiently controlled in UNR cotton. In their studies involving glyphosate-resistant cultivars, the use of residual soil-applied herbicides proved to be beneficial. They also noted consistent and often greater net returns where soil-applied herbicides were used. These same findings were also reported in glyphosate-resistant soybeans grown on 19-cm rows (Norsworthy, 2004). Studies conducted by Norris et al. (2002) found that better weed control in glufosinate-resistant soybean was achieved on a 38-cm row spacing compared to 76-cm rows. Sequential applications of glufosinate were adequate in controlling broadleaf weeds and barnyardgrass, but the addition of soil-applied herbicides into the system increased the efficacy of glufosinate on large crabgrass. With the introduction of glufosinate-resistant and Roundup Ready Flex™ cultivars, producers may have the option of total post-emergence (POST) programs for cotton planted on 38-cm row spacings.

Doveweed

Doveweed (*Murdannia nudiflora* (L.) Brenan) has historically been a problematic weed in turf, but has become increasingly more common in North Carolina row-crop production. This is mostly due to the widespread adoption of glyphosate-resistant crops, which allowed producers to eliminate soil-applied herbicides and abandon tillage and cultivation. Doveweed, and other members of the Commelinaceae, are not adequately controlled with glyphosate programs (Culpepper et al., 2004; York et al., 1998; York and Culpepper, 2006).

Doveweed is a member of the family Commelinaceae. It is a annual that has the capability of rooting at the lower nodes (Radford, 1968). The leaves are linear to lanceolate, and the sheaths are ciliated and tubular. The stem can be erect or creeping, and always branching. The inflorescence is a cyme which can be terminal or axillary. The flowers are always zygomorphic in symmetry with three free petals and three free sepals (i.e. the petals and sepals are not fused). The petals are blue or violet in color. The fruit is a three-celled capsule, with two seeds per cell. It is often misidentified as marsh dayflower (*Murdannia keisak* (Hassk.) Hand. Mazz.). The are several distinguishing characteristics between the two species, none of which are vegetative. For marsh dayflower, the flower symmetry is always actinomorphic with pink petals and the sepals are green with red dots, whereas with doveweed the petals are always zygomorphic and the petal color is blue or violate. To date, little research has been conducted on the biological and ecological aspects of this weed.

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CHAPTER II

Effect of Row Spacing on Weed Management in Glufosinate-Resistant Cotton (*Gossypium hirsutum*)[1]

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Abstract: Transgenic, herbicide-resistant cotton and commercialization of equipment to spindle-pick in 38-cm rows has renewed interest in narrow-row cotton production. Field experiments were conducted at four locations in North Carolina during 2004 and 2005 to evaluate weed management systems in glufosinate-resistant cotton planted in 38- and 97-cm rows. Weeds included broadleaf signalgrass, goosegrass, fall panicum, large crabgrass, Palmer amaranth, smooth pigweed, pitted morningglory, and tall morningglory. Greater than 90% control of annual grasses and *Amaranthus* spp. in 2004 and *Ipomoea* spp. in both years was obtained in narrow-row cotton receiving glufosinate applied early postemergence (EPOST) and mid-postemergence (MPOST) to 2- and 6-leaf cotton, respectively. With good early season control by glufosinate and rapid canopy closure, there was little benefit from pendimethalin, fluometuron, or pyrithiobac applied preemergence (PRE), *S*-metolachlor or pyrithiobac mixed with glufosinate applied MPOST, or trifloxysulfuron applied late postemergence (LPOST) to 11-leaf cotton in 2004. In 2005, weeds were larger at time of the initial glufosinate application, and glufosinate applied EPOST and MPOST did not adequately control annual grasses and *Amaranthus* spp. Pendimethalin applied PRE alone or mixed with fluometuron or pyrithiobac increased control to greater than 90% and increased yields 59 to 75%. Pendimethalin PRE followed by *S*-metolachlor or pyrithiobac mixed with glufosinate at MPOST was no more effective than pendimethalin alone. Without PRE herbicides, trifloxysulfuron applied LPOST increased *Amaranthus* but not annual grass control. Cotton row spacing had no effect on cotton yield and little effect on weed control. Weed control and yield in narrow-row cotton with a

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PRE herbicide plus glufosinate applied twice was similar to that in wide-row cotton with a PRE herbicide, glufosinate applied twice, and trifloxysulfuron plus prometryn plus MSMA applied postemergence-directed.

Nomenclature: Fluometuron; *S*-metolachlor; MSMA; pendimethalin; prometryn; pyrithiobac; trifloxysulfuron; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash #[3] BRAPP; fall panicum, *Panicum dichotomiflorum* Michx. # PANDI; goosegrass, *Eleusine indica* (L.) Gaertn. # ELEIN; large crabgrass, *Digitaria sanguinalis* (L.) Scop.# DIGSA; Palmer amaranth, *Amaranthus palmeri* (S.) Wats. # AMAPA; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; smooth pigweed, *Amaranthus hybridus* L. # AMACH; tall morningglory, *Ipomoea purpurea* (L.) Roth # PHBPU; cotton, *Gossypium hirsutum* L. 'FM 958LL'.

Additional Index Words: herbicide-resistant crops; Liberty Link® cotton; narrow-row cotton.

Abbreviations: EPOST, early postemergence; GR, glufosinate-resistant; LPOST, late postemergence; MPOST, mid-postemergence; PDIR, postemergence-directed; PRE, preemergence; UNR, ultra-narrow-row.

INTRODUCTION

The current low profit margin for cotton makes it difficult for U.S. producers to remain solvent. Producers are interested in technologies and management systems which will reduce production costs, increase yields, or both. Yields of corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and peanut (*Arachis hypogaea* L.) have been increased by planting the crops in narrow rows (Johnson and Hoverstad 2002; Johnson et al. 2005; Leuschen et al. 1992). During the 1990's, some growers in North Carolina and other states began producing ultra-narrow-row (UNR) cotton, which is planted in 19- to 25-cm rows using a grain drill and harvested with finger-stripper harvesters. Finger strippers are more economical to own and operate than spindle-type harvesters, thus reducing production costs (Parvin et al. 2000; Vories et al. 2001). Greater yields and net returns have sometimes been obtained with UNR cotton relative to cotton in the typical 76- to 97-cm rows, especially on less productive land (Bullen and Brown 2000; Nichols et al. 2004; Parvin et al. 2000). However, there are problems associated with UNR cotton. Erratic stands are sometimes achieved with grain drills, and there are fiber quality issues

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th street, Lawrence, KS 66044-8897.

associated with the harvesting methodology (McAllister and Rogers 2005; Vories et al. 2001).

A harvester capable of spindle-picking cotton planted in 38-cm rows has recently been commercialized (Willcutt et al. 2006). This equipment will facilitate harvest of narrow-row cotton without the foreign matter and other fiber quality concerns associated with finger-stripped cotton (McAllister and Rogers 2005; Vories et al. 2001). Cotton can be planted in 38-cm rows using unit planters which produce consistently better stands than grain drills (Wiatrak et al. 1998). High plant populations are needed in UNR cotton to maintain a short, compact plant to facilitate harvesting (Wright et al. 2000). Those high populations, a significant expense with transgenic cultivars, are not necessary in spindle-picked cotton in 38-cm rows (Wilson 2005).

Management of weeds to reduce yield loss and increase harvesting efficiency and fiber quality is crucial for narrow-row cotton production. Narrow-row production eliminates cultivation and postemergence-directed (PDIR) herbicide applications. Herbicide-resistant cotton, which allows topical application of broad-spectrum herbicides such as glufosinate or glyphosate, is instrumental in a narrow-row production system. Earlier canopy closure associated with narrow rows should also aid late-season weed management (Hock et al. 2006; Yelverton and Coble 1990).

Glufosinate is a postemergence herbicide that inhibits glutamine synthetase (EC 6.3.1.2), the enzyme involved in conversion of glutamic acid and ammonia into glutamine (Dekker and Duke 1995; Devine et al. 1993; Wendler et al. 1990). Inhibition of glutamine synthetase by glufosinate leads to rapid accumulation of ammonia and glyoxylate when nitrite is being photosythetically reduced to ammonia during periods of photorespiration (Dekker and Duke 1995). Accumulation of glyoxylate and ammonia is accompanied by the cessation of photosynthesis, disruption of chloroplast structures, vesiculation of the stroma, and ultimately death of the plant (Devine et al. 1993; Hinchee et al. 1993).

Glufosinate-resistant (GR) cotton, commercialized in 2004, was created through insertion of a gene from the fungus *Streptomycyes viridochromogenes* which encodes for phosphinothricin acetyltransferase. This enzyme converts the active portion of the herbicide molecule, L- phosphinothricin, into the nontoxic acetylated form, *N*-acetyl-L-phosphinothricin (Devine et al., 1993; Hinchee et al., 1993). The transformed cotton has excellent tolerance of glufosinate, normally a non-selective herbicide, applied postemergence (Blair-Kerth et al. 2001). Glufosinate can be applied topically to GR cotton from crop emergence until the early bloom stage (Anonymous

2006).

Glufosinate controls many weeds commonly found in cotton, corn, and soybean (Bradley et al. 2000; Culpepper and York 1999; Culpepper et al. 2000; Hamill et al. 2000; York and Culpepper 2004). Norris et al. (2002) reported greater weed control in GR soybean in 38-cm rows compared with 76-cm rows. Row spacing had little effect on weed control in GR corn regardless of the herbicide system used (Jones et al. 2001). This may be due to canopy formation characteristics of corn. Norsworthy and Oliveira (2004) observed similar canopy light interception by narrow- and wide-row corn throughout the growing season.

New harvesting technologies make production of cotton grown in 38-cm rows feasible. To date, no results have been published from studies comparing weed control and cotton yield between narrow- and wide-row GR cotton. Therefore, the objective of our study was to evaluate weed management systems and cotton yields in GR cotton planted in 38- and 97-cm row spacings.

MATERIALS AND METHODS

The experiment was conducted on the Central Crops Research Station near Clayton, NC and the Upper Coastal Plain Research Station near Rocky Mount, NC in 2004 and 2005. Soils for each site are described in Table 1. Weed species and densities at each site are listed in Table 2.

Glufosinate-resistant ‘FM 958LL’ cotton was planted into conventionally prepared seed beds on May 11, 2004 and May 11, 2005 at Clayton and on May 10, 2004 and May 12, 2005 at Rocky Mount. Two separate vacuum-type planters set on 38- or 97-cm row spacings were used for seeding. Seeding rates were 6.6 and 12.5 seed per m of row for the 38- and 97-cm row spacings, respectively. Plots were 9 m long by four 97-cm rows or eight 38-cm rows. The experimental design was a randomized complete block with treatments replicated three times at Clayton in 2004 and Rocky Mount in 2005 or four times at the other locations.

Ninety and 110 kg/ha of N, as ammonium nitrate, was broadcast prior to planting at Clayton and Rocky Mount, respectively, in 2004. No additional nitrogen was applied during the season. At both locations in 2005, 45 kg/ha of N, as ammonium nitrate, was broadcast at the pinhead square stage of cotton and repeated 3 wk later. Phosphorus, potassium, and boron were applied according to soil test recommendations. Aldicarb ([2-methyl-2-(methylthio) propionaldehyde O-(methylcarbamoyl)oxime]) was applied in the seed furrow at 0.07 g ai/m of row in 2004 to control thrips (*Frankliniella* spp.) and other early season insects. Seed were treated with imidacloprid {1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine} in 2005 at the rate of 0.375 mg ai/seed. Acephate (*O*,*S*-dimethyl acetylphosphoramidothioate) was applied POST as needed for additional early season insect control. Mid- and late-season insect management was standard for cotton production in North Carolina. Plant growth regulation was accomplished using mepiquat chloride (*N*,*N*-dimethylpiperidinium chloride) applied POST as needed beginning when cotton was at the 10-leaf stage of growth. Harvest preparation consisted of defoliation by a mixture of tribufos (*S*,*S*,*S*-tributyl phosphorotrithioate), thiadiazuron (*N*-phenyl-*N'*-1,2,3-thiadiazol-5-ylurea), and ethephon [(2-chloroethyl)phosphonic acid].

Twelve and six herbicide systems were evaluated in cotton grown in 38- and 97-cm rows, respectively. The first eight treatments in the narrow-row cotton included pendimethalin, pendimethalin plus fluometuron, pendimethalin plus pyrithiobac, or no herbicide applied PRE followed by glufosinate applied EPOST to two-leaf cotton and glufosinate applied MPOST to six-leaf cotton, and either no herbicide LPOST or trifloxysulfuron applied LPOST to 11-leaf cotton. The remaining four treatments consisted of pendimethalin applied PRE followed by glufosinate applied EPOST and glufosinate plus *S*-metolachlor or glufosinate plus pyrithobac applied MPOST followed by no herbicide or trifloxysulfuron applied LPOST.

The first four treatments for cotton in 97-cm rows consisted of pendimethalin, pendimethalin plus fluometuron, pendimethalin plus pyrithiobac, or no herbicide applied PRE followed by glufosinate applied EPOST and MPOST and prometryn plus trifloxysulfuron plus MSMA applied PDIR to 46-cm cotton. The remaining two treatments were pendimethalin applied PRE followed by glufosinate applied EPOST, glufosinate plus *S*-metolachlor or glufosinate plus pyrithiobac applied MPOST, and prometryn plus trifloxysulfuron plus MSMA POST-DIR. A non-treated check was included for both row spacings. Pendimethalin, fluometuron, and pyrithiobac were applied PRE at 1110, 1120, and 48 g ai/ha, respectively. Glufosinate, pyrithiobac, *S*-metolachlor, and trifloxysulfuron were applied EPOST, MPOST, and LPOST at 468, 48, 1387, and 5.3 g ai/ha, respectively. Prometryn, trifloxysulfuron, and MSMA were applied PDIR at 1110, 9.8, and 2220 g ai/ha, respectively. A nonionic surfactant[4] at 0.25% (v/v) was included with trifloxysulfuron applied LPOST and with prometryn plus trifloxysulfuron plus MSMA applied POST-DIR. The commercial formulation of glufosinate[5] did not require an adjuvant.

The PRE herbicides were applied on the day of planting. Cotton had 2, 6, and 11 leaves when treated EPOST, MPOST, and LPOST, respectively. These growth stages were achieved 2, 4, and 7 wk after planting, respectively, in 2004 and 4, 6, and 9 wk after planting in 2005. The PDIR applications were made to cotton in 97-cm rows on the same day as cotton treated LPOST in 38-cm rows. Cotton averaged 46 cm tall when PDIR herbicides were applied. Herbicides were applied PRE, EPOST, MPOST, and LPOST using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles calibrated to deliver 140L ha^{-1} at 159 kPa. Postemergence-directed herbicides were broadcast using a CO_2-pressurized backpack sprayer equipped with three flat-fan nozzles per row middle calibrated to deliver 140L ha^{-1} at 152 kPa. In 2004, annual grasses had 2 to 4, 3 to 4, and 3 to 5 leaves at time of EPOST, MPOST, and LPOST applications, respectively, while *Amaranthus* spp. had 3 to 6, 5 to 12, and 2 to 8 leaves, respectively. Annual grasses in 2005 had 3 to 7, 4 to 14, and 5 to 18 leaves at EPOST, MPOST, and LPOST, respectively. *Amaranthus* spp. in 2005 had 4 to 10, 4 to 12, and 3 to 10 leaves at EPOST, MPOST, and LPOST, respectively. *Ipomoea* spp. in both years had 1 to 3, 2 to 5, and 2 to 6 leaves at EPOST, MPOST, and LPOST, respectively.

Weed control and cotton injury were estimated visually 2 wk following EPOST and MPOST applications and again in late August (hereafter referred to as late-season). Visual estimates of weed control and cotton injury were based on a scale of 0 to 100%, where 0 = no weed control or cotton injury and 100 = complete weed control or cotton death (Frans et al. 1986). There were no readily apparent differences in response to herbicide systems among annual grass species or between *Ipomoea* spp., hence annual grasses were evaluated as a group and *Ipomoea* spp. as a group. Percent canopy closure for each row spacing was estimated visually at the time of herbicide applications and at each evaluation date. The center four 38-cm rows and the center two 97-cm rows

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[4] Induce, alkylarylpolyoxylkane ether, free fatty acids, and isopropyl (90%), and water and formulation acids (10%). Helena Chemical Co., 225 Schilling Blvd., Suite 300, Collierville, TN 38017.

[5] Ignite herbicide. Bayer CropScience, 2 T. W. Alexander Drive, Research Triangle Park, NC 27709.

were harvested using a spindle-type picker[6] modified to harvest multiple row spacings (Lanier et al. 2005). A sample of mechanically harvested seed cotton was collected from each plot and used to determine lint percentage and fiber quality. Seed cotton was ginned on a laboratory gin without lint cleaning, hence cotton grades are not presented as they would not be representative of cotton ginned commercially. However, fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Data for crop injury and weed control were arcsine square root transformed prior to ANOVA using the PROC MIXED procedure of the Statistical Analysis System (version 9.1; SAS Institute Inc.; Cary, NC). Data from non-treated checks were not included in the analyses. Non-transformed data are presented with statistical interpretation based on transformed data. Weed control and crop injury at 2 wk after EPOST and MPOST herbicide applications (prior to LPOST or PDIR applications) were pooled over like treatments. Data for weed control and crop injury 2 wk after EPOST herbicide application were analyzed for a 2 (row spacings) by 4 (PRE herbicides) factorial treatment arrangement. Data for evaluations 2 wk after MPOST application were analyzed for a 2 (row spacings) by 6 (PRE and MPOST herbicide combinations) factorial treatment arrangement. Data for late-season weed control, cotton yield, lint percentage, and fiber properties were analyzed in two steps. First, data from 38-cm rows only were analyzed for a 6 (PRE and MPOST herbicide combinations) by 2 (0 and 5.3 g/ha trifloxysulfuron LPOST) factorial treatment arrangement. If a PRE/MPOST herbicide by LPOST herbicide interaction was not observed and the main effect of trifloxysulfuron rates was not significant, data from cotton in the 38-cm rows were averaged over trifloxysulfuron rates. The next ANOVA compared herbicide systems and row spacings as a 2 (row spacing) by 6 (PRE and MPOST herbicide combinations) factorial treatment arrangement. Means for significant main effects or interactions were separated using Fisher's Protected LSD at $P = 0.05$ (Saxton 1998).

RESULTS AND DISCUSSION

Uniformly spaced stands of 156,000 and 120,000 plants/ha were obtained in the 38- and 97-cm rows,

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[6] PRO-12 VRS row units. John Deere Co., One John Deere Place, Moline, IL 61265.

respectively (data not shown). In other research (Wilson 2005), lint yields were similar with 62,000 to 247,000 plants/ha in 38-cm rows. The canopy of cotton in 38-cm rows was closed by 7 to 9 wk after planting whereas canopy closure in 97-cm rows did not occur until 12 to 13 wk after planting.

Weed Control. A location by treatment interaction was not observed for control of annual grasses and *Amaranthus* spp., but a year by treatment interaction was noted at each evaluation. An effect of row spacing and a herbicide by row spacing interaction were not observed for annual grass or *Amaranthus* spp. control at any evaluation in either year.

Excellent control (> 90%) of annual grasses and *Amaranthus* spp. was observed at all evaluations in 2004. All herbicide programs controlled annual grasses at least 96, 94, and 93% 2 wk after EPOST application, 2 wk after MPOST application, and late in the season, respectively (Tables 3, 4, and 5). Only minor increases in control were noted when residual herbicides were included in the glufosinate-based systems. Pendimethalin, pendimethalin plus fluometuron, and pendimethalin plus pyrithiobac applied PRE increased annual grass control 2 percentage points 2 wk after the EPOST application of glufosinate (Table 3). Pendimethalin alone did not increase annual grass control 2 wk after the MPOST glufosinate application, but fluometuron or pyrithiobac mixed with pendimethalin and applied PRE increased control 2 to 3 percentage points (Table 4). *S*-metolachlor and pyrithiobac mixed with glufosinate increased control 3 to 4 percentage points 2 wk after MPOST application. By late in the season, the only residual herbicide that increased annual grass control was fluometuron applied PRE, which increased control 4 percentage points.

All herbicide programs also controlled *Amaranthus* spp. very well in 2004. *Amaranthus* spp. were controlled 99% by all herbicide programs 2 wk after EPOST glufosinate application and at least 95 and 91% 2 wk after MPOST application and late in the season, respectively (Tables 3, 4, and 5). Only minor increases in control were noted 2 wk after MPOST application and late in the season when residual herbicides were included in the glufosinate-based systems. With excellent early season control by glufosinate followed by crop canopy closure, there was little opportunity for a benefit in annual grass or *Amaranthus* spp. control from the residual herbicides.

Glufosinate applied alone was generally less effective on annual grasses and *Amaranthus* spp. in 2005 than in 2004. Timing of postemergence herbicide applications was based on crop growth stage. Cool temperatures during the second and third week after planting in 2005 slowed cotton growth, and the EPOST application was made 4 wk after planting in 2005 compared with 2 wk after planting in 2004. Weeds were larger at time of the EPOST application in 2005, and the annual grasses and *Amaranthus* spp. were less effectively controlled (Corbett et al. 2004; Steckel et al. 1997).

Glufosinate applied alone controlled annual grasses and *Amaranthus* spp. only 69 and 74%, respectively, 2 wk after the EPOST application in 2005 (Table 3). Pendimethalin applied PRE increased annual grass and *Amaranthus* spp. control 26 and 23 percentage points, respectively. Pendimethalin plus fluometuron and pendimethalin plus pyrithiobac were only 3 to 4 percentage points more effective than pendimethalin alone. Control of both annual grasses and *Amaranthus* spp. increased following the second (MPOST) application of glufosinate (Table 4). At 2 wk after the MPOST application, annual grasses and *Amaranthus* spp. were controlled 84 and 95%, respectively. In previous research (Culpepper et al. 2000; Murdock et al. 2003; Wiesbrook et al. 2001), control of annual grasses and *Amaranthus* spp. was increased with multiple applications of glufosinate. Regrowth may occur on plants not completely killed by glufosinate applied once, and new plants may emerge following a single application (Coetzer et al., 2002). Glufosinate has no soil residual activity (Vencill 2002). The residual herbicides applied PRE or mixed with glufosinate at MPOST increased control of annual grasses and *Amaranthus* spp. to at least 97 and 100%, respectively. Similar results were noted by Gardner and York (2006).

Trifloxysulfuron applied LPOST to cotton in 38-cm rows did not affect late-season control of annual grasses (P > F = 0.5213) in 2005. Trifloxysulfuron has little activity on annual grasses (Crooks et al. 2004). When data were averaged over trifloxysulfuron rates of 0 and 5.3 g/ha, a herbicide program by row spacing interaction was noted for annual grass control (Table 5). Control was similar in both row spacings with pendimethalin plus fluometuron applied PRE and pendimethalin applied PRE followed by glufosinate plus *S*-metolachlor or glufosinate plus pyrithiobac at MPOST. Control by these treatments was at least 95%. In contrast, greater control was noted in the wide-row cotton which received glufosinate only, pendimethalin PRE followed by glufosinate, and pendimethalin plus pyrithiobac PRE followed by glufosinate. These differences were attributed to control by prometryn plus trifloxysulfuron plus MSMA applied PDIR in the wide-row cotton.

Trifloxysulfuron applied LPOST in the narrow-row cotton had a minor impact on late-season *Amaranthus* control (P > F = 0.0008), hence data for the narrow-row cotton could not be pooled over the two rates of trifloxysulfuron in 2005. A herbicide system by row spacing interaction was noted. *Amaranthus* spp. were controlled 88% late in the season in narrow-row cotton receiving only glufosinate (Table A-2.1). All of the residual herbicides applied PRE or mixed with glufosinate applied MPOST increased control in narrow rows to 100%. Trifloxysulfuron applied LPOST also increased control to 100%. Glufosinate applied EPOST and MPOST followed by prometryn plus trifloxysulfuron plus MSMA applied PDIR in wide-row cotton controlled *Amaranthus* spp. 96%. All other treatments in the wide-row cotton controlled *Amaranthus* spp. 100%.

Ipomoea spp. were controlled very well by all herbicide systems in both wide- and narrow-row cotton at all evaluation dates in both years. Trifloxysulfuron normally controls *Ipomoea* spp. well (Corbett et al. 2004). Because of excellent control by glufosinate, however, trifloxysulfuron applied LPOST to narrow-row cotton did not affect *Ipomoea* spp. control (P > F = 0.5858). There also were no differences in *Ipomoea* control among herbicide programs or between row spacings. Averaged over locations and years, *Ipomoea* spp. were controlled 94 to 97, 97 to 99, and 95 to 98% 2 wk after EPOST application, 2 wk after MPOST application, and late in the season, respectively (Tables 3, 4, and 5).

Crop Response. Neither glufosinate nor any of the herbicides applied PRE injured cotton. *S*-metolachlor and pyrithiobac applied MPOST injured cotton 5 and 13%, respectively, 2 wk after application, but no injury was visible late in the season (Table A-2.1).

Yields of non-treated check plots were assumed to be zero as these plots were decimated by weeds and could not be harvested mechanically. Visually, yield of non-treated checks appeared to be reduced at least 95%. Data for seed cotton yield were pooled over locations within years.

Trifloxysulfuron applied LPOST to narrow-row cotton did not affect seed cotton yield (P > F = 0.7406 in 2004; 0.9678 in 2005). Averaged over trifloxysulfuron rates in narrow-row cotton, there was not an interaction for row spacing by herbicide program. Additionally, the main effect of row spacing was not significant in either year (P > F = 0.6555 in 2004; 0.9284 in 2005). Averaged over row spacings, there were no differences among herbicide programs for seed cotton yield in 2004 (Table 6). Lack of differences in yield among herbicide programs is a reflection of the excellent weed control in 2004 with all herbicide programs. Seed cotton yields in 2004 ranged from 3140 to 3430 kg/ha. In 2005, seed cotton yields were lowest in cotton that received only glufosinate. This was attributed to early season competition from annual grasses and *Amaranthus* spp. due to less than adequate control by glufosinate applied in the absence of residual herbicides. All of the residual herbicides applied PRE increased seed cotton yield 59 to 75%. Greatest yields were obtained with pendimethalin plus fluometuron applied PRE.

No differences in lint percentage nor the fiber quality parameters recorded were noted among herbicide programs or between row spacings. Averaged over treatments, locations, and years, lint percentage, micronaire, fiber upper half mean length, uniformity index, and fiber strength averaged 42%, 4.9, 2.85 cm, 83%, and 310 kN mg/kg, respectively (Table A-2.2).

Results from this study demonstrate that excellent control of annual grasses, *Amaranthus* spp., and *Ipomoea* spp. can be obtained in GR cotton grown in both 38- and 97-cm row spacings. Glufosinate is sometimes only marginally effective on annual grasses and *Amaranthus* spp. (Beyers et al. 2002; Coetzer et al. 2002; Corbett et al. 2004; Culpepper et al. 2000; York and Culpepper 2004). In this experiment, the greatest and most consistent control of annual grasses and *Amaranthus* spp. was obtained when PRE herbicides were included in the glufosinate-based herbicide systems. Similar results have been observed previously (Beyers et al. 2002; Gardner and York 2006; Murdock et al. 2003; York and Culpepper 2004). Weed control in GR cotton in 38-cm rows receiving a PRE herbicide and glufosinate applied postemergence twice was similar to that in 97-cm rows receiving a PRE herbicide, two postemergence applications of glufosinate, and a PDIR application of prometryn plus trifloxysulfuron plus MSMA. Yields were similar with GR cotton in 38- and 97-cm rows. This is in contrast to observations in glyphosate-resistant cotton, where yield increases of 10 to 20% were noted with 38-cm rows (Wilson 2006). This may indicate that the particular GR cultivar used in this experiment is not well adapted to narrow-row production.

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Table 1. Description of soils at experiment sites in 2004 and 2005.

Year	Location	Soil Series	Soil Texture	Soil pH	Soil humic matter
					%
2004	Clayton	Johns[a]	Sandy loam	5.9	1.37
	Rocky Mount	Nahunta[b]	Loamy sand	5.8	0.86
2005	Clayton	Dothan[c]	Loamy sand	5.9	0.97
	Rocky Mount	Goldsboro[d]	Sandy loam	6.1	1.1

[a] Fine-loamy, siliceous, semiactive, thermic Aquic Hapludults.

[b] Fine-silty, siliceous, subactive, thermic Aeric Paleaquults.

[c] Fine-loamy, kaolinitic, thermic Plinthic Kandiudults.

[d] Fine-loamy, siliceous, subactive, thermic Aquic Paleudults.

Table 2. Weed density in non-treated checks at experiment sites.

	2004		2005	
Species	Clayton	Rocky Mount	Clayton	Rocky Mount
	plants/m^2			
Broadleaf signalgrass	5	12	12	15
Fall panicum	2		13	
Goosegrass	10	14	48	16
Large crabgrass		5		3
Palmer amaranth	80		8	
Pitted morningglory	6	3	19	12
Smooth pigweed		9		28
Tall morningglory	11	5	8	13

Table 3. Control of annual grasses, *Amaranthus* spp., and *Ipomoea* spp. 2 wk after early postemergence herbicide application to glufosinate-resistant cotton.[a]

	Annual grasses[c]		*Amaranthus* spp.[d]		*Ipomoea*
Preemergence herbicides[b]	2004	2005	2004	2005	spp.[e]
	%				
None	96 b	69 c	99 a	74 c	94 a
Pendimethalin	98 a	95 b	99 a	97 b	95 a
Pendimethalin + fluometuron	98 a	99 a	99 a	100 a	97 a
Pendimethalin + pyrithiobac	98 a	98 a	99 a	100 a	96 a

[a] Data averaged over two row spacings. All treatments received glufosinate applied early postemergence at 468 g/ha to two-leaf cotton. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] Pendimethalin, fluometuron, and pyrithiobac applied preemergence at 1110, 1120, and 48 g/ha, respectively.

[c] Data averaged over two locations per year. Annual grasses consisted of mixtures of broadleaf signalgrass, fall panicum, and goosegrass at one location and mixtures of broadleaf signalgrass, goosegrass, and large crabgrass at the second location.

[d] Data averaged over two locations per year, with Palmer amaranth at one location and smooth pigweed at the second location.

[e] Data averaged over two years and two locations per year. Species consisted of a mixture of pitted morningglory and tall morningglory.

Table 4. Control of annual grasses, *Amaranthus* spp., and *Ipomoea* spp. 2 wk after mid-postemergence herbicide application to glufosinate-resistant cotton.[a]

Preemergence herbicides[b]	Mid-postemergence herbicides[c]	Annual grasses[d]		*Amaranthus* spp.[e]		*Ipomoea* spp.[f]
		2004	2005	2004	2005	
		%				
None	Glufosinate	94 b	84 b	95 b	95 b	98 a
Pendimethalin	Glufosinate	95 b	97 a	95 b	100 a	97 a
Pendimethalin + fluometuron	Glufosinate	97 a	99 a	97 a	100 a	98 a
Pendimethalin + pyrithiobac	Glufosinate	98 a	99 a	98 a	100 a	98 a
Pendimethalin	Glufosinate + *S*-metolachlor	99 a	98 a	98 a	100 a	98 a
Pendimethalin	Glufosinate + pyrithiobac	98 a	99 a	99 a	100 a	99 a

[a] Data averaged over two row spacings. All treatments received glufosinate applied early postemergence at 468 g/ha to two-leaf cotton. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] Pendimethalin, fluometuron, and pyrithiobac applied preemergence at 1110, 1120, and 48 g/ha, respectively.

[c] Glufosinate, *S*-metolachlor, and pyrithiobac applied mid-postemergence to six-leaf cotton at 468, 1387, and 48 g/ha, respectively.

[d] Data averaged over two locations per year. Annual grasses consisted of mixtures of broadleaf signalgrass, fall panicum, and goosegrass at one location and mixtures of broadleaf signalgrass, goosegrass, and large crabgrass at the second location.

[e] Data averaged over two locations per year, with Palmer amaranth at one location and smooth pigweed at the second location.

[f] Data averaged over two years and two locations per year. Species consisted of a mixture of pitted morningglory and tall morningglory.

Table 5. Late-season control of annual grasses and *Amaranthus* spp. in glufosinate-resistant cotton.[a]

		Annual grasses[d]				
			2005			
Preemergence herbicides[b]	Mid-postemergence herbicides[c]	2004	38-cm rows	97-cm rows	*Amaranthus* spp.[e] 2004	*Ipomoea* spp.[f]
		%				
None	Glufosinate	93 c	76 f	84 e	91 c	97 a
Pendimethalin	Glufosinate	94 bc	93 d	97 abc	93 b	96 a
Pendimethalin + fluometuron	Glufosinate	98 a	98 ab	100 a	95 a	97 a
Pendimethalin + pyrithiobac	Glufosinate	94 bc	94 cd	99 a	95 a	96 a
Pendimethalin	Glufosinate + *S*-metolachlor	93 c	97 abc	100 a	94 ab	97 a
Pendimethalin	Glufosinate + pyrithiobac	95 b	95 bcd	98 ab	94 ab	97 a

[a] Data averaged over two row spacings. All treatments received glufosinate applied early postemergence at 468 g/ha to two-leaf cotton. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] Pendimethalin, fluometuron, and pyrithiobac applied preemergence at 1110, 1120, and 48 g/ha, respectively.

[c] Glufosinate, *S*-metolachlor, and pyrithiobac applied mid-postemergence to six-leaf cotton at 468, 1387, and 48 g/ha, respectively.

[d] Data averaged over two locations per year. Data in 2004 averaged over two row spacings. Annual grasses consisted of mixtures of broadleaf signalgrass, fall panicum, and goosegrass at one location and mixtures of broadleaf signalgrass, goosegrass, and large crabgrass at the second location.

[e] Data averaged over two locations, with Palmer amaranth at one location and smooth pigweed at the second location.

[f] Data averaged over two years and two locations per year. Species consisted of a mixture of pitted morningglory and tall morningglory.

Table 6. Seed cotton yield of glufosinate-resistant cotton as affected by herbicide systems.[a]

Herbicides[b]		Yield	
Preemergence[c]	Mid-postemergence[d]	2004	2005
		kg/ha	
None	Glufosinate	3370 a	1790 c
Pendimethalin	Glufosinate	3300 a	2840 b
Pendimethalin + fluometuron	Glufosinate	3210 a	3130 a
Pendimethalin + pyrithiobac	Glufosinate	3270 a	2950 ab
Pendimethalin	Glufosinate + *S*-metolachlor	3430 a	2970 ab
Pendimethalin	Glufosinate + pyrithiobac	3140 a	2980 ab

[a] Data averaged over two row spacings and two locations per year. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] All treatments included glufosinate applied early postemergence at 468 g/ha to two-leaf cotton. All treatments to cotton in 97-cm rows included prometryn + trifloxysulfuron + MSMA at 1110 + 9.8 + 2220 g/ha applied postemergence-directed to 46-cm cotton. Data for cotton in 38-cm rows averaged over 0 and 5.3 g/ha of trifloxysulfuron applied late-postemergence to 11-leaf cotton.

[c] Pendimethalin, fluometuron, and pyrithiobac applied preemergence at 1110, 1120, and 48 g/ha, respectively.

[d] Glufosinate, *S*-metolachlor, and pyrithiobac applied mid-postemergence to six-leaf cotton at 468, 1387, and 48 g/ha, respectively.

CHAPTER III

Influence of Row Spacing and Herbicide Systems on Weed Management in Glyphosate-Resistant Cotton[7]

DAVID G. WILSON JR. and ALAN C. YORK[8]

Abstract: There has been renewed interest in narrow-row cotton production with the ability to spindle-pick the crop when grown on 38-cm row configurations. Transgenic, herbicide-resistant cotton is a key component in narrow-row cotton production because of the inability post-directed herbicides or cultivate. Field experiments were conducted in 2004 and 2005 at Clayton and Rocky Mount, NC to determine weed management systems in 38-cm glyphosate-resistant cotton. Additionally, row spacing effects on weed management were also examined. Herbicide systems in the 38-cm row spacing controlled annual grasses more effectively when PRE herbicides or a mid-POST application of *S*-metolachlor was included. Control of *Ipomoea* spp. was more effective in systems including preemergence herbicides or glyphosate mixed with pyrithiobac POST. Programs containing sequential POST applications of glyphosate alone were effective in controlling Palmer amaranth and smooth pigweed. Cotton row spacing had little effect on weed control, and there were no differences in lint yield among herbicide systems in both row spacings. However, a 6% increase in lint yield was observed in the 38-cm rows compared to the 97-cm rows.

Nomenclature: Fluometuron; glyphosate; *S*-metolachlor; MSMA; pendimethalin; prometryn; pyrithiobac; trifloxysulfuron; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash #[9] BRAPP; goosegrass, *Eleusine indica* (L.) Gaertn. # ELEIN; fall panicum, *Panicum dichotomiflorum* Michx. # PANDI; large crabgrass, *Digitaria sanguinalis* (L.) Scop.# DIGSA; Palmer amaranth, *Amaranthus palmeri* (S.) Wats. # AMAPA; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; smooth pigweed, *Amaranthus hybridus* L. # AMACH; tall

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[7] Received for publication date, and in revised form date.

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[9] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th street, Lawrence, KS 66044-8897.

morningglory, *Ipomoea purpurea* (L.) Roth # PHBPU; cotton, *Gossypium hirsutum* L. # GOSHI 'ST 5599BR'.

Additional Index Words: glyphosate-resistant cotton; herbicide-resistant crops; Roundup Ready cotton; narrow row; row spacing; weed control; yield.

Abbreviations: POST, postemergence; PRE, preemergence; wk, weeks

INTRODUCTION

For more than a century, farmers planted cotton in rows spaced 91-cm or more apart (Burmester 1996). Row spacing was dictated primarily by equipment for cultivation, which was initially draft animals and later, tractors. Harvesting equipment also was designed to accommodate these wide row spacings. Recent advances in technology, especially herbicide-resistant cotton, have increased the potential for cotton production in narrow rows (Atwell et al 1996; Brown et al. 1998; Vories 1999).

There has been interest in planting cotton in 19- to 25-cm row spacings (ultra-narrow-row, UNR). Yields of corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and peanut (*Arachis hypogaea* L.) have been increased by planting the crops in narrow rows (Johnson and Hoverstad 2002; Johnson et al. 2005; Leuschen et al. 1992). Although UNR cotton may reduce production costs and increase yields in some areas, acceptance of this practice has been limited because of the technology that has been available for producers to plant and harvest UNR cotton (Atwell 1996; Brown et al. 1998). UNR cotton is planted using a grain-drill, and harvested with a finger-type stripper. Finger strippers are more economical to own and operate than spindle-type harvesters, thus reducing production costs (Parvin et al. 2000; Vories et al. 2001). Greater yields and net returns have sometimes been obtained with UNR cotton relative to cotton in the typical 76- to 101-cm rows, especially on less productive land (Bullen and Brown 2000; Nichols et al. 2004; Parvin et al. 2000). However, there are problems associated with UNR cotton. Erratic stands are sometimes achieved with grain drills, and there are fiber quality issues associated with the harvesting methodology (McAllister and Rogers 2005; Vories et al. 2001).

There has been a commercial harvester[10] developed that is capable of spindle-picking cotton planted on a 38-cm row configuration. This equipment will significantly reduce the amount of foreign matter that is mixed

[10] PRO-12 VRS row units. John Deere Co., One John Deere Place, Moline, IL 61265.

with cotton that is associated with finger-stripping and keep the lint grades at acceptable levels to maximize the producers' payments on their product (McAllister III and Rogers 2005). Additionally, cotton can be planted on 38-cm rows using the same type planting units that are used in wide-row production which will produce a more uniform stand. This production system eliminates the need for high plant populations (Buxton et al. 1977; Wilson 2006), a significant expense in transgenic, UNR cotton.

Prior to the introduction of pyrithiobac in 1996, cotton was the only major agronomic crop grown in the United States without a postemergence-over-the-top (POT) herbicide for annual broadleaf weed control that did not cause potential maturity delays or reduced yield (Guthrie and York 1989; Snipes and Mueller 1992; Wilcut et al. 1995). Before the introduction of herbicide-resistant cotton varieties, the lack of a POT herbicide for broadleaf weed control was exacerbated by reduced early-season vigor of cotton, wide-row spacings (76 to 97 cm), and delayed shading of the row middles, which typically does not occur until at least 75 to 90 d after planting (Wilcut et al. 1995). Earlier crop canopy closure is achieved in a 38-cm row spacing compared to cotton grown in 91- to 101-cm rows (Jost and Cothren 2000).

Row spacing affects canopy closure, thus influencing the growth and development of both crop and weeds. Knezevic et al. (2003) concluded that planting soybean in wide rows reduces early season crop tolerance to weeds requiring earlier weed management programs. It has also been found that weeds grown with soybean planted in 19-cm rows produced less aboveground biomass and reduced yield less than weeds grown with soybeans in 76-cm rows (Hock et al. 2006). Additionally, reduced late-season weed resurgence after postemergence herbicide applications before canopy closure has been observed in narrow-row soybean (Yelverton and Coble 1990). Therefore, earlier canopy closure may aid in late-season weed management and possibly allow for less herbicide inputs.

Management of weeds to reduce yield loss and increase harvesting efficiency and quality is crucial for narrow-row cotton production. The ability to use cultivation and post-directed herbicide applications are not feasible in a narrow-row cotton production system. Therefore, herbicide-resistant cotton will play a key role in an overall production scheme. However, effective POST control of weeds could be possible with glyphosate-resistant cotton. Culpepper and York (2000) found that many grass and broadleaf weeds can be sufficiently controlled in UNR cotton In their studies, residual soil-applied herbicides proved to be beneficial in glyphosate-resistant UNR cotton. They also noted consistent and often greater net returns where soil-applied herbicides were used compared to POST-only systems. These same findings were also reported in glyphosate-resistant soybean grown on 19-cm rows (Norsworthy 2004).

New planting and harvesting technologies make production of cotton grown in a 38-cm row spacing more feasible. Therefore, the objectives of our study were to determine weed management systems in 38-cm cotton, and determine if row spacing has an influence on weed control.

MATERIALS AND METHODS

The experiment was conducted on the Central Crops Research Station near Clayton, NC and the Upper Coastal Plain Research Station near Rocky Mount, NC in 2004 and 2005. Soils for each site are described in Table 1. Weed species and densities at each site are listed in Table A-3.1.

Glyphosate-resistant ‘ST 5599 BR’ cotton was planted into conventionally prepared seedbeds on May 11, 2004, and May 11, 2005, at Clayton and on May 10, 2004, and May 12, 2005, at Rocky Mount. Two separate vacuum-type planters set on 38- or 97-cm row spacings were used for seeding. Seeding rates were 6.6 and 12.5 seed per m of row for the 38- and 97-cm row spacings, respectively. Plots were 3 m wide by 9 m in length for the 38-cm row spacing and 3.8 m wide by 9 m in length for the 97-cm row spacing.

Ninety and 110 kg/ha of N, as ammonium nitrate, was broadcast prior to planting at Clayton and Rocky Mount, respectively, in 2004. No additional nitrogen was applied during the season. At both locations in 2005, 45 kg/ha of N, as ammonium nitrate, was broadcast at the pinhead square stage of cotton and repeated 3 wk later. Phosphorus, potassium, and boron were applied according to soil test recommendations. Aldicarb ([2-methyl-2-(methylthio) propionaldehyde O-(methylcarbamoyl)oxime]) was applied in the seed furrow at 0.2 g ai/m of row in 2004 to control thrips (*Frankliniella* spp.) and other early season insects. Seed were treated with imidacloprid {1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine} in 2005 at the rate of 0.375 mg ai/seed. Acephate (*O*,*S*-dimethyl acetylphosphoramidothioate) was applied POST as needed for additional early season insect control. Mid- and late-season insect management was standard for cotton production in North Carolina. Plant growth regulation was accomplished using mepiquat chloride (*N*, *N*-dimethylpiperidinium chloride) applied POST as needed beginning when cotton was at the 10-leaf stage of growth. Harvest preparation consisted of defoliation by a mixture of merphos (*S*,*S*,*S*-tributyl phosphorotrithioite), thiadiazuron (*N*-phenyl-*N’*-1,2,3-thiadiazol-5-ylurea), and ethephon [(2-chloroethyl) phosphonic acid].

The experimental design was a randomized complete block arrangement of treatments with four replications. There were two objectives included in the study. The first objective was to evaluate weed management systems in 38 cm glyphosate-resistant cotton. The second objective was to evaluate row spacing effects on weed management in 38 and 97 cm glyphosate-resistant cotton. Treatments for the first objective included a factorial arrangement of three PRE by four POST options. The PRE options included pendimethalin plus fluometuron, pendimethalin plus pyrithiobac, or no PRE, while the four POST options included glyphosate applied MPOST, glyphosate applied alone or tankmixed with *S*-metolachlor or pyrithiobac at MPOST followed by trifloxysulfuron applied LPOST.

Treatments for the second objective include a factorial arrangement of two row spacings (38 and 97 cm) by five herbicide systems. Systems included either no PRE followed by glyphosate alone or tankmixed with *S*-metolachlor or pyrithiobac applied MPOST or pedimethalin plus fluometuron or pendimethalin plus pyrithiobac applied PRE followed by glyphosate applied MPOST. Late POST applications of trifloxysulfuron or trifloxysulfuron plus prometryn plus MSMA in the 38- and 97-cm rows, respectively. In both objectives, treatments that did not include a PRE herbicide received a EPOST application of glyphosate when cotton was in the 1-leaf growth stage. A nontreated check was included for each row spacing.

Pendimethalin, fluometuron, and pyrithiobac were applied PRE at 1110, 1120, and 48 g ai/ha, respectively. Glufosinate, pyrithiobac, *S*-metolachlor, and trifloxysulfuron were applied EPOST, MPOST, and LPOST at 1120, 48, 1387, and 5.3 g ai/ha, respectively. A nonionic surfactant[11] at 0.25% (v/v) was included with LPOST applications of trifloxysulfuron alone, and POST-DIR applications of prometryn plus trifloxysulfuron plus MSMA. The commercial formulation of glyphosate did not require an adjuvant (Anonymous 2005).
The PRE herbicides were applied on the day of planting. In 2004, the EPOST, MPOST and LPOST herbicide applications were made 2, 4, and 7 wk after planting, respectively. In 2005, the EPOST, MPOST and LPOST herbicide applications were made 3, 5, and 8 wk after planting, respectively. Cotton had 1, 4, and 11 leaves when treated EPOST, MPOST, and LPOST, respectively. The POST-DIR applications were made to cotton in 97-cm rows on the same day as cotton treated LPOST in 38-cm rows. Cotton averaged 46 cm tall when POST-

[11] Induce, alkylarylpolyoxylkane ether, free fatty acids, and isopropyl (90%), and water and formulation acids (10%). Helena Chemical Co., 225 Schilling Blvd., Suite 300, Collierville, TN 38017.

DIR herbicides were applied. Herbicides were applied PRE, EPOST, MPOST, and LPOST using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles calibrated to deliver 140L ha^{-1} at 159 kPa. Postemergence-directed herbicides were broadcast using a CO_2-pressurized backpack sprayer equipped with three flat-fan nozzles per row middle calibrated to deliver 140L ha^{-1} at 152 kPa.

In 2004, annual grass species had 1 to 8 leaves at time of EPOST, MPOST, and LPOST applications, respectively, whereas the *Ipomoea* spp. and *Amaranthus* spp. had 1 to 4 and 1 to 10 leaves at all application timings, respectively. In 2005, annual grass species had 1 to 7 leaves at time of EPOST, MPOST, and LPOST applications, respectively, whereas the *Ipomoea* spp. and *Amaranthus* spp. had 1 to 9 and 3 to 12 leaves at all application timings, respectively. Weed densities at time of each herbicide application are listed in Table A-3.1.

Weed control and cotton injury were estimated visually 3 wk after MPOST applications, and again in late August. Visual estimates of weed control and cotton injury were based on a scale from 0 to 100%, where 0 = no weed control and cotton injury and 100 = complete weed control or cotton death (Frans et al. 1986). There were no readily apparent differences in response to herbicide systems among annual grass species or between *Ipomoea* spp., hence annual grasses were evaluated as a group and *Ipomoea* spp. as a group. The center four rows were harvested in the 38-cm row spacing, while the center two rows were harvested in the 96-cm row spacing. Harvesting was achieved by using a spindle-type picker modified for small-plot use and multiple row spacings (Lanier et al. 2005). A sample of mechanically harvested seed cotton was collected from each plot and used to determine lint percentage and fiber quality. Seed cotton was ginned on a laboratory gin without lint cleaning, hence cotton grades are not presented as they would not be representative of cotton ginned commercially. However, fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Data were subjected to ANOVA using the MIXED procedure in SAS with treatment sums of squares partitioned to fit the factorial treatment arrangements in both objectives of the study. Data were arcsine square root transformed prior to ANOVA; non-transformed data are presented with statistical interpretation based on transformed data. In the first objective, data for late-season weed control, crop injury, lint yield, and fiber characteristics were analyzed for a 3 (PRE herbicides) by 4 (POST herbicide options) factorial treatment arrangement. In the second objective, data for late-season weed control, crop injury, lint yield, and fiber characteristics were analyzed for a 2 (row spacings) by 5 (herbicide systems) factorial treatment arrangement.

Means for significant main effects or interactions were separated based on Fisher's Protected LSD at $P = 0.05$ (Saxton 1998).

RESULTS AND DISCUSSION

Effect of Weed Management Systems on 38 cm Cotton. There was a lack of a location by herbicide system interaction for annual grasses and morningglory species, however a year by herbicide system interaction was observed. Therefore, data for annual grasses and morningglory species were pooled over locations within each year. Additionally, there was a lack of year by herbicide system and location by system interactions which allowed for pooling control data for pigweed species over both years and locations. Trends in weed control for all systems were similar at 3 wk after MPOST (Table A-3.2), therefore only late-season control data are presented.

Annual grasses. In 2004, late-season annual grasses were controlled at least 88% for systems containing no PRE and sequential POST applications of glyphosate alone, with and without trifloxysulfuron applied LPOST (Table 2). However, when a PRE herbicide, *S*-metolachlor, or pyrithiobac were added into the system, late-season control was increased to at least 94%. Glyphosate has no soil residual activity (Askew and Wilcut 1999; Askew et al. 1999; Culpepper and York 1998), and trifloxysulfuron has poor activity on annual grasses when applied POST (Crooks et al 2003). Additionally, pyrithiobac has been observed to have residual grass activity when applied PRE (Alan York, unpublished data). In 2005, late-season annual grasses were controlled at least 99% in all systems.

Ipomoea species. In 2004, excellent (> 90%) late-season control of *Ipomoea* spp. was observed in all systems (Table 2). Sequential applications of glyphosate applied EPOST and MPOST controlled *Ipomoea* spp. 92% late in the season. Pendimethalin plus pyrithiobac applied PRE and glyphosate alone followed by glyphosate plus pyrtithiobac increased control 6 percentage points. Additionally, trifloxysulfuron applied LPOST did not improve control in systems that did not include a PRE herbicide. Trifloxysulfuron has been reported to control morningglory species that were present in the study (Porterfield et al. 2002, Richardson et al. 2004). Inadequate spray coverage is most likely the reason for not observing an increase in control, due to complete canopy formation at the late-POST application timing. In 2005, excellent late-season control (> 98%) was observed in all systems (Table 2). Only minor increases in control were observed when residual herbicides or trifloxysulfuron were included into the glyphosate-based systems. With excellent control by glyphosate early in the season followed by crop canopy closure, there was little opportunity for a benefit in *Ipomoea* spp. control from residual herbicides or trifloxysulfuron.

Amaranthus species. Excellent late-season pigweed control (≥ 98%) was observed in all systems (Table 2). Glyphosate has been observed to be effective on both smooth pigweed and Palmer amaranth (Askew et al. 2002; Corbett et al. 2004; Culpepper and York 1998). With excellent control by glyphosate early in the season followed by crop canopy closure, there was little benefit in *Amaranthus* spp. control from PRE herbicides, *S*-metolachlor, pyrithiobac, or trifloxysulfuron.

Influence of Row Spacing on Weed Management. There was a lack of a location by row spacing by herbicide system interaction for annual grasses and morningglory species, however a year by row spacing by herbicide system interaction was observed. Therefore, data for annual grasses and morningglory species were pooled over locations within each year. Additionally, there was a lack interactions between years, locations, row spacings, and herbicide systems which allowed for pooling control data for pigweed species over both years and locations. Trends in weed control for all systems were similar at 3 wk after mid-POST (Table A-3.3), therefore only late-season control data are presented.

Annual Grasses. In 2004, late-season annual grass control was ≥ 88% for all herbicide systems in both row spacings (Table 3). Late season control in glyphosate-based systems was 88 and 92% in the 38- and 97-cm rows, respectively. Pendimethalin plus fluometuron and pendimthalin plus pyrithiobac increased late-season annual grass control in the 38-cm rows 9 and 8 percentage points, while than the comparable systems in the 97 cm rows only increased control by 2 percentage points. In the absence of a PRE herbicide, MPOST applications of glyphosate plus *S*-metolachlor or pyrithiobac increased late-season annual grass control in the 38-cm rows compared to sequential POST applications of glyphosate alone. Conversely, an increase in late-season control was not evident in the 97-cm rows when *S*-metolachlor or pyrithiobac were added into the system. Which is most likely due to the level of control received from POST-DIR applications of prometryn plus trifloxysulfuron plus MSMA. Systems in the 38-cm rows that included PRE herbicides or *S*-metolachlor MPOST provided higher (3 to 7%) late-season annual grass control than all systems in the 97-cm rows. This can be attributed to earlier season canopy closure in the 38 cm rows coupled with the residual activity of pendimethalin and *S*-

metolachlor. Systems including PRE herbicides have been shown to be more beneficial for annual grass control in cotton and soybeans planted on 19-cm row spacings (Norsworthy et al. 2004; York and Culpepper 2000). In 2005, late-season annual grass control was 100% for all systems in both row spacings. With excellent control (> 98%) of annual grasses by glyphosate alone at 3 wk after MPOST applications (Table A-3.3), there was little benefit of adding PRE herbicides or *S*-metolachlor into the system, regardless of row spacing.

Ipomoea species. In 2004, excellent (≥ 92%) late-season *Ipomoea* spp. control was observed for all systems in both row spacings (Table 3). In the 38-cm rows, PRE and POST applications pyrithiobac increased control 3 and 6 percentage points, compared to sequential applications of glyphosate alone. Pyrithiobac has been observed to be efficacious on pitted morningglory (Jordan et al. 1993; Paulsgrove and Wilcut 2001). Additionally, there were no late-season control differences among herbicide systems in the 97-cm rows. Systems in the 38-cm rows that included PRE herbicides, *S*-metolachlor, or sequential applications of glyphosate alone did not increase late-season control compared to all other systems in the 97-cm rows. In 2005, the same trends that were observed in 2004 were not evident and late-season morningglory control was at least 98% for all systems in both row spacings.

Amaranthus species. There was a lack of row spacing (p > F = 0.0712) and herbicide system (p > F = 0.2568) main effects on late-season *Amaranthus* spp. control. Excellent late-season control (≥ 98%) was observed for all herbicide systems in both row spacings (Table A-3.4). Systems that included PRE herbicides, *S*-metolachlor, or pyrithiobac did not increase control in either row spacing, compared to sequential applications of glyphosate. Glyphosate is effective on both smooth pigweed and Palmer amaranth (Askew et al. 2002; Corbett et al. 2004; Culpepper et al. 1998). There were no row spacings effects on late-season pigweed control (p = 0.2384).

Crop Response. Glyphosate did not visibly injure cotton. Injury from of *S*-metolachlor, pyrithiobac applied MPOST was at most 1 and 7% 3 wk after application, and no injury was observed late in the season (Table A-3.5).

Yield. There was a lack of a year by herbicide system and location by herbicide system interaction for the first objective of the study. Therefore, data for cotton lint yield were pooled over years and locations. Additionally, there was a lack of a year by row spacing by herbicide system and location by row spacing by herbicide system interaction for the second objective. However, there was a row spacing main effect noted and data are presented in this fashion.

Cotton lint yields ranged from 1663 to 1810 kg/ha, with no differences noted among herbicide systems in the 38 cm rows (Table 4). However, a 6% increase in lint yields were observed in the 38-cm rows compared to the 97- cm rows (Table 5). The lint yield increase in the 38-cm rows is attributable to earlier season canopy closure and not herbicide system effects on weed control. It has been found that cotton yields often increase as row spacings decrease because greater light interception by the crop canopy increases the number of mature fruits per hectare (Heitholt et al. 1992; Jost and Cothren 2000; Wilson 2006).

Fiber characteristics. No differences among row spacings or herbicide systems were noted for micronaire, fiber length, fiber length uniformity, or fiber strength; which averaged 4.69, 2.82 cm, 83%, and 304 kN m/kg, respectively (Table A-3.6).

Results from this study demonstrate that excellent control of many annual grass, morningglory, and pigweed species can be obtained in narrow-row glyphosate-resistant cotton. Annual grasses were controlled more effectively in systems that included PRE herbicides or a mid-POST application of *S*-metolachlor. Late-season annual grass control has been observed to be more consistent when PRE herbicides are used in glyphosate-resistant cotton and soybean planted on 19-cm row spacings (Norsworthy et al. 2004; York and Culpepper 2000). In 38 cm cotton, where cultivation or POST-directed herbicides are not an option, residual control by PRE herbicides may be more beneficial. Morningglory control was more effective in systems including PRE herbicides or mid-POST applications of pyrithiobac, and programs containing sequential POST applications of glyphosate were effective in controlling Palmer amaranth and smooth pigweed. The early canopy closure observed in the 38-cm row spacing did prevent the late-season resurgence of the weed species present in this study. There were no differences in lint yield among herbicide systems in both row spacings. However, a 6% lint yield increase was observed in the 38-cm rows compared to the 97-cm rows.

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Table 1. Description of soils at trial sites in 2004 and 2005.

Year	Location	Soil Series[a]	Soil Texture	Soil pH	Soil humic matter (%)
2004	Clayton	Dothan	Loamy sand	5.9	1.37
	Rocky Mt.	Nahunta	Loamy sand	5.7	0.97
2005	Clayton	Johns	Sandy Loam	5.3	1.03
	Rocky Mt.	Norfolk	Loamy Sand	5.8	0.56

[a] Dothan is a fine-loamy, kaolinitic, thermic Plinthic Kandiudults; Nahunta is a fine-silty, siliceous, subactive, thermic Aeric Paleaquults; Johns is a fine-loamy, siliceous, semiactive, thermic Aquic Hapludults; Norfolk is a fine-loamy, kaolinitic, thermic Typic Kandiudults.

Table 2. Late-season control of annual grasses, *Ipomoea* spp., and *Amaranthus* spp. in 38 cm glyphosate-resistant cotton.[a]

Herbicides[c, d]			Control[b]				
			Annual Grasses		*Ipomoea* spp.		*Amaranthus* spp.
PRE	MPOST	LPOST	2004	2005	2004	2005	
			%				
None	Glyp	None	88 d	100 a	92 e	99 a	99 a
	Glyp	Trif	88 d	100 a	92 e	99 a	98 a
	Glyp + Metol	Trif	98 a	100 a	94 de	100 a	99 a
	Glyp + Pyri	Trif	94 bc	100 a	98 abc	100 a	99 a
Pend + Fluo	Glyp	None	94 c	100 a	94 de	98 a	99 a
	Glyp	Trif	94 c	100 a	94 de	98 a	100 a
	Glyp + Metol	Trif	98 a	100 a	96 bcd	98 a	100 a
	Glyp + Pyri	Trif	98 a	99 a	99 a	98 a	100 a
Pend + Pyri	Glyp	None	94 c	100 a	95 cd	98 a	99 a
	Glyp	Trif	96 abc	100 a	95 cd	99 a	99 a
	Glyp + Metol	Trif	98 a	100 a	95 cd	99 a	100 a
	Glyp + Pyri	Trif	97 ab	100 a	97 abc	99 a	100 a

[a] Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at *P* = 0.05.

Table 2. Continued

[b] Data for annual grasses and morningglories are pooled over locations. Data for pigweed species are pooled over years and locations. Annual grasses consisted of a mixture of goosegrass, broadleaf signalgrass, and fall panicum at Clayton, and goosegrass, broadleaf signalgrass, and large crabgrass at Rocky Mount. Pigweed species consisted of Palmer amaranth at Clayton, and smooth pigweed at Rocky Mount. Morningglory species consisted of a mixture of tall morningglory and pitted morningglory at both locations.

[c] Systems not including a PRE herbicide received an EPOST application of glyphosate at 1120 g ai/ha when cotton was in the 1-leaf stage.

[d] Abbreviations and herbicide rates: Pend., pendimethalin (1110 g ai/ha); fluo., fluometuron (1120 g ai/ha); glyp, glyphosate (1120 kg ai/ha), pyri., pyrithiobac (48 g ai/ha, PRE and POST); metol, *S*-metolachlor (1387 g ai/ha); Trif, trifloxysulfuron (5.3 g ai/ha).

Table 3. Row spacing and herbicide system effect on late-season control of annual grasses, and *Ipomoea* spp. in 38 and 97 cm glyphosate-resistant cotton.[a]

			Control[b]			
	Herbicides[c, d]		Annual grasses		*Ipomoea* spp.	
Row Spacing (cm)	PRE	MPOST	2004	2005	2004	2005
			%			
38	None	Glyp	88 e	100 a	92 c	99 a
	None	Glyp + Metol	98 a	100 a	94 bc	100 a
	None	Glyp + Pyri	94 bc	100 a	98 a	100 a
	Pend + Fluo	Glyp	97 ab	100 a	94 bc	98 a
	Pend + Pyri	Glyp	96 ab	100 a	95 ab	99 a
97	None	Glyp	91 d	100 a	92 c	99 a
	None	Glyp + Metol	93 cd	100 a	94 bc	100 a
	None	Glyp + Pyri	94 bc	100 a	93 bc	100 a
	Pend + Fluo	Glyp	93 cd	100 a	94 bc	99 a
	Pend + Pyri	Glyp	93 cd	100 a	94 bc	99 a

[a] Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] Data for annual grasses and morningglories are pooled over locations. Annual grasses consisted of a mixture of goosegrass, broadleaf signalgrass, and fall panicum at Clayton, and goosegrass, broadleaf signalgrass, and large crabgrass at Rocky Mount. Morningglory species consisted of a mixture of tall morningglory and pitted morningglory at both locations.

Table 3. Continued

[c] Systems not including a PRE herbicide received an EPOST application of glyphosate at 1110 g ai/ha when cotton was in the 1-leaf stage. All systems in both row spacings received a LPOST application of trifloxysulfuron (38-cm rows; topical) or trifloxysulfuron plus prometryn plus MSMA (97-cm rows; directed).

[d] Abbreviations and herbicide rates: Pend., pendimethalin (1110 g ai/ha); fluo., fluometuron (1120 g ai/ha); glyp, glyphosate (1120 g ai/ha), pyri., pyrithiobac (48 g ai/ha, PRE and POST); metol, *S*-metolachlor (1387 g ai/ha).

Table 4. Lint cotton yield as effected by herbicide system in 38 cm glyphosate-resistant cotton.[a, b]

Herbicides[c]			
PRE[d]	MPOST[e]	LPOST[f]	Yield
			kg/ha
None	Glyp	None	1757 a
	Glyp	Trif	1775 a
	Glyp + Metol	Trif	1810 a
	Glyp + Pyri	Trif	1663 a
Pend + Fluo	Glyp	None	1753 a
	Glyp	Trif	1790 a
	Glyp + Metol	Trif	1702 a
	Glyp + Pyri	Trif	1803 a
Pend + Pyri	Glyp	None	1806 a
	Glyp	Trif	1715 a
	Glyp + Metol	Trif	1736 a
	Glyp + Pyri	Trif	1670 a

[a] Data are pooled over years and locations. Pigweed species consisted of Palmer amaranth at Clayton, and smooth pigweed at Rocky Mount. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at P = 0.05.

[b] Abbreviations: pend, pendimethalin; fluo, fluometuron; pyri, pyrithiobac; glyp, glyphosate; metol, *S*-metolachlor; trif, trifloxysulfuron.

[c] Herbicide rates: pendimethalin, 1110 g ai/ha; fluometuron, 1120 kg ai/ha; glyphosate, 1120 kg ai/ha; pyrithiobac (PRE and POST), 48 g ai/ha; *S*-metolachlor, 1387 g ai/ha; trifloxysulfuron, 5.3 g ai/ha.

[d] PRE herbicides applied the day of planting.

[e] MPOST treatments applied to 4-leaf cotton. Treatments without a PRE herbicide received an EPOST application of glyphosate at 1.1 kg ai/ha when cotton was in the 1-leaf stage.

[f] LPOST treatments applied to 11-leaf cotton.

Table 5. Row spacing influence on lint cotton yield.[a, b]

Row spacing (cm)	Yield
	kg/ha
38	1565 a
96	1477 b

[a] Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $P = 0.05$.

[b] Data are pooled over years, locations, and herbicide systems.

CHAPTER IV

TITLE: Weed Management in Narrow-Row, Glyphosate-Resistant Cotton

DISCIPLINE: Weed Science

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ABBREVIATIONS: PRE, preemergence; POST, postemergence; POT, postemergence over-the-top; WAP, weeks after planting; wk, weeks.

ABSTRACT

There is a renewed interest in narrow-row cotton production with the ability to spindle-pick cotton on a 38-cm row spacing. There are also new technological advances in weed management, such as glyphosate-resistant cultivars that allow topical applications of glyphosate up to 7 days prior to harvest. In light of this, research was conducted in North Carolina to evaluate weed management systems in narrow-row cotton utilizing this new glyphosate-resistance technology. At least one herbicide system controlled annual grasses, *Ipomoea* spp., and *Amaranthus* spp. at least 96, 93, and 99% late in the season. Glyphosate applied alone to 1- and 6-leaf cotton provided excellent (≥ 93%) late-season control of all species present in this study. Systems including *S*-metolachlor provided more effective late-season control of annual grasses, while systems including pendimethalin plus fluometuron or pyrithiobac PRE tended to provide more effective late-season control of *Ipomoea* spp. There were no differences observed with respect to lint yield or fiber quality characteristics among herbicide systems. This research illustrates that excellent overall weed control can be obtained in narrow-row glyphosate-resistant cotton, but systems including the use of residual herbicides may be more beneficial.

KEY WORDS

Roundup Ready Flex, glyphosate, weed control, weed management, preemergence herbicides, metolachlor, yield.

Cotton has traditionally be planted in rows spaced 91-cm (wide-row) or more apart (Burmester 1996). Row spacing was dictated primarily by equipment for cultivation, which was initially draft animals and later, tractors. Harvesting equipment also was designed to accommodate these wide row spacings. Recent advances in technology, especially herbicide-resistant cotton, have increased the potential for cotton production in narrow rows (Atwell et al 1996; Brown et al. 1998).

There has been considerable interest in planting cotton in 19- to 25-cm row spacings (ultra-narrow-row, UNR). Although UNR cotton may reduce production costs and increase yields in some areas, acceptance of this practice has been limited because of the technology that has been available for producers to harvest UNR cotton (Atwell 1996; Brown et al. 1998). Cotton planted in a UNR configuration must be harvested using a broadcast finger-stripper because the row spacings are too narrow for a conventional spindle picker or brush stripper . This type equipment removes the seed cotton as well as the carpel walls, some of the peduncles, and short limbs from the cotton plant. If there are any leaves left on the cotton plant after defoliation, they may also be harvested and mixed with the cotton fiber as well. This causes the commercial ginner increased ginning costs as well as slowing productivity (Anthony, 2000). Additionally, certain fiber quality characteristics such as fiber strength, fiber length, and uniformity index have been reported to be lower in finger-stripped cotton compared to spindle-picked cotton (McAllister and Rogers, 2005).

Recent advances in technology have the potential to remedy these types of situations. A cotton harvester has recently been developed with the ability to spindle-pick cotton on a 38-cm row (narrow-row) configuration. This will significantly reduce the amount of foreign matter that is mixed with cotton that is associated with finger-stripping, and keep the lint grades at acceptable levels to maximize the producers' payments on their product (McAllister and Rogers 2005).

Prior to the introduction of pyrithiobac in 1996, cotton was the only major agronomic crop grown in the United States without a postemergence-over-the-top (POT) herbicide for annual broadleaf weed control that did not cause potential maturity delays or reduced yield (Guthrie and York 1989; Paulsgrove and Wilcut 2001; Snipes and Mueller 1992; Wilcut et al. 1995). The lack of a POT herbicide for broadleaf weed control was exacerbated by reduced early-season vigor of cotton, wide row spacings, and delayed shading of the row middles, which typically does not occur until at least 75 to 90 days after planting (Wilcut et al. 1995).

Glyphosate-tolerant (Roundup Ready, Monsanto Co., St Louis, MO) cotton was introduced in 1997. Since it's introduction, this technology has been readily adopted by growers and offers a number of benefits, and the most notable is broad-spectrum weed control (Culpepper and York, 1998). In 2005, greater than 90% of cotton crop in the Southeastern growing region of the U.S. was in the form of glyphosate-tolerant varieties (USDA-AMS, 2005). The limitation of glyphosate-tolerant cotton is a short period in which topical applications of glyphosate can be applied. Producers are instructed to only apply glyphosate topically from cotyledonary to the four-leaf stage of growth (Anonymous, 2005), and subsequent topical applications after this period may result in yield reductions (Pline et al. 2002). Thereafter, glyphosate applications must be post-directed (Kerby and Voth, 1998; May et al., 2004). To circumvent this, glyphosate-resistant (Roundup Ready Flex, Monsanto Co., St. Louis, MO) varieties have been developed and will be commercially available for the 2006 growing season (Murdock and Mullins, 2006). This technology will offer growers an extended topical application window of glyphosate up to 7 days prior to harvest (Anonymous, 2005; Croon et al. 2005). This technology may be more beneficial in narrow-row cotton production due to the inability to use post-directed herbicide applications.

Effective POST control of weeds may be possible with glyphosate-resistant cotton. Studies conducted by Culpepper and York (2000) found that many grass and broadleaf weeds can be sufficiently controlled in UNR cotton. In their studies involving glyphosate-tolerant cultivars, the use of residual soil-applied herbicides proved to be beneficial. They also noted consistent and often greater net returns where soil-applied herbicides were used, compared to POST only systems. These same findings were also reported in glyphosate-resistant soybeans grown on 19-cm rows (Norsworthy, 2004).

It has been found that early crop canopy closure influences the growth and development of both crop and weeds. Knezevic et al. (2003) concluded that planting soybeans in wide rows reduces early-season crop tolerance to weeds requiring earlier weed management programs. It has also been observed that weeds grown with soybean planted in 19-cm rows produced less aboveground biomass and reduced yield less than weed species grown with soybean in 76-cm rows (Hock et al., 2006). Additionally, reduced late-season weed resurgence after postemergence herbicide applications before canopy closure has been observed in narrow-row soybean (Yelverton and Coble 1990). Therefore, earlier canopy closure may aid in late-season weed management, and possibly allow for less herbicide inputs.

New harvesting and weed management technologies make narrow–row cotton production more feasible. To date, no studies have directly compared weed control and cotton yield in narrow-row glyphosate-resistant cotton. Therefore, the objectives of our study was to evaluate weed management systems, and cotton yield as a result of those systems, in narrow-row glyphosate-resistant cotton.

MATERIALS AND METHODS

The experiment was conducted on the Central Crops Research Station near Clayton, NC and the Upper Coastal Plain Research Station near Rocky Mount, NC in 2004 and 2005. Trials were conducted in separate sites of each station in both years. Soils for each site are described in Table 1. Weed species consisted of a typical mixture of annual grasses, *Ipomoea* spp., and *Amaranthus* spp. found in North Carolina, and varied little in composition by year at each location. Annual grasses consisted of 52% goosegrass [*Elusine indica* (L.) Gaertn.], 28% broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash], and 20% fall panicum (*Panicum dichotomiflorum* Michx.) at Clayton, and 48% goosegrass, 37% broadleaf signalgrass, and 15% large crabgrass [*Digitaria sanguinalis* (L.) Scop.] at Rocky Mount. Annual morningglories consisted of 76% tall morningglory [*Ipomoea purpurea* (L.) Roth.], and 24% pitted morningglory (*Ipomoea lacunosa* L.) at Clayton, and 58% tall morningglory, and 42% pitted morningglory at Rocky Mount. Pigweed species consisted of Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] and smooth pigweed (*Amaranthus hybridus* L.) at Clayton and Rocky Mount, respectively. In 2004, densities for annual grasses, morningglories, and pigweeds were 17, 15, and 6 plants/m^2 at Clayton, and 31, 12, and 10 plants/m^2 at Rocky Mount, respectively. In 2005, densities for annual grasses, morningglories, and pigweeds were 38, 21, and 32 plants/m^2 at Clayton, and 21, 18, and 18 plants/m^2 at Rocky Mount, respectively. There was no differential control observed among like species (i.e. annual grasses and *Ipomoea* spp.), therefore species were rated as a group. Additionally, there was not a location by treatment interaction noted for *Amaranthus* spp. control, and in light of this data are averaged over locations.

A non-commercial cultivar of glyphosate-resistant cotton (Roundup Ready Flex; Monsanato Co., St. Louis, MO) containing the gene transformation event ‘MON 88913' was planted into conventionally prepared seedbeds on May 11, 2004, and May 11, 2005, at Clayton and on May 10, 2004, and May 12, 2005, at Rocky Mount. Seeding was accomplished using a vacuum-type planter set on a 38-cm row spacing. Seeding rates were 6.6

seed per m^{-1} of row, and plots were 3 m wide by 9 m in length.

Ninety and 110 kg/ha of N, as ammonium nitrate, was broadcast prior to planting at Clayton and Rocky Mount, respectively, in 2004. No additional nitrogen was applied during the season. At both locations in 2005, 45 kg/ha of N, as ammonium nitrate, was broadcast at the pinhead square stage of cotton and repeated 3 wk later. Phosphorus, potassium, and boron were applied according to soil test recommendations. Early-season thrips control was accomplished by using at-planting applications aldicarb (Temik insecticide; Bayer CropScience, Research Triangle Park, NC) in 2004, and imidacloprid (Gaucho Grande insecticide; Bayer CropScience) in 2005. Subsequent POST applications of acephate (Orthene 97S; Valent Agricultural Products; Walnut Creek, CA) were also applied as needed. Mid- and late-season insect management were standard for cotton production in North Carolina. Plant growth regulation was accomplished using mepiquat chloride (Pix Plus growth regulator; BASF Ag Products; Research Triangle Park, NC) applied POST as needed beginning when cotton was at the 10-leaf stage of growth. Harvest preparation consisted of defoliation by a mixture of tribufos (DEF 6 defoliant; Bayer CropScience; Research Triangle Park, NC), thiadiazuron (DROPP SC defoliant; Bayer CropScience, Research Triangle Park, NC), and ethephon (Prep defoliant; Bayer Crop Science; Research Triangle Park, NC).

The experimental design was a randomized complete block arrangement of treatments with four replications. Treatments consisted of 12 herbicide options including: glyphosate (Roundup WeatherMAX herbicide; Monsanto Co.; St Louis, MO) alone applied to 1- and 6-leaf cotton; glyphosate alone applied to 1-, 6-, and 12-leaf cotton; glyphosate alone applied to 1-, 6-, 12-, and 14-leaf cotton; glyphosate alone applied to 1- and 6-leaf cotton followed by trifloxysulfuron (Envoke herbicide; Syngenta Crop Protection, Inc.; Greensboro, NC) applied to 12-leaf cotton; glyphosate alone applied to 1-leaf cotton followed by glyphosate plus *S*-metolachlor (Dual Magnum herbicide; Syngenta Crop Protection; Greensboro, NC) applied to 6-leaf cotton followed by either glyphosate or trifloxysulfuron alone applied to 12-leaf cotton; glyphosate alone applied to 1-leaf cotton followed by glyphosate plus pyrithiobac (Staple herbicide; E.I. du Pont de Nemours and Co.; Wilmington, DE) applied to 6-leaf cotton followed by either glyphosate alone or glyphosate plus pyrithiobac applied to 12-leaf cotton; pendimethalin (Prowl 3.3 EC herbicide; BASF Ag Products; Research Triangle Park, NC) plus fluometuron (Cotoran 4L herbicide; Griffin LLC; Valdosta, GA) PRE followed by glyphosate alone applied to 4- and 12-leaf cotton followed by either nothing or glyphosate alone applied to 14-leaf cotton; pendimethalin plus pyrithiobac PRE followed by glyphosate alone applied to 4- and 12-leaf cotton followed by either nothing or glyphosate alone applied to 14-leaf cotton. An untreated check was included in all experiments.

Herbicides were applied at the following rates: pendimethalin, 1110 g ai/ha; fluometuron, 1120 g ai/ha; glyphosate, 1120 g ai/ha; the sodium salt of pyrithiobac, 48 g ai/ha (PRE and POST) and 24 g ai/ha (sequential POST); *S*-metholachlor, 1387 g ai/ha; trifloxysulfuron, 5.3 g ai/ha. A nonionic surfactant (Induce, Helena Chemical Co., Collierville, TN) was included at 0.25% v/v with trifloxysulfuron applications. The commercial formulation of glyphosate did not require an adjuvant (Anonymous, 2005). The PRE herbicides were applied the day of planting. Herbicides were broadcast using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (TeeJet XR11002 nozzles; Spraying Systems Co.; Wheaton, IL) and calibrated to deliver 140L ha^{-1} at 159 kPa.

Weed control was estimated visually 4, 8, and 16 wk after planting (WAP), while cotton injury was estimated visually at 8 and 16 WAP. Data at 4 and 8 WAP are reflective of control received 1 wk after 1-leaf , and 2 wk after 6-leaf applications, respectively. Visual estimates of weed control and cotton injury were based on a scale from 0 to 100%, where 0 = no weed control and cotton injury and 100 = complete weed control or cotton death (Frans et al., 1986). Harvesting was achieved by spindle-picking the center four rows out of each plot. A sample of mechanically harvested seed cotton was collected from each plot and used to determine lint percentage and fiber quality. Seed cotton was ginned on a laboratory gin without lint cleaning, hence cotton grades are not presented as they would not be representative of cotton ginned commercially. However, fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Data were subjected to ANOVA using the mixed procedure in SAS (version 9.1; SAS Institute Inc.; Cary, NC). Untreated checks were excluded from the analysis. Data were arcsine square root transformed prior to analysis of variance; non-transformed data are presented with statistical interpretation based on transformed data. Control data for all species at 4 and 8 WAP were averaged over like herbicide treatments, and appropriate interactions are displayed for all evaluation intervals. Means were separated based on Fisher's Protected LSD at $P = 0.05$ (Saxton 1998).

RESULTS AND DISCUSSION

Rainfall was adequate for PRE herbicide activation at each site. In 2004, both locations received at least 1.1 cm of rainfall within 1 wk after planting, while both locations received at least 3.4 cm of rainfall within 1 wk after planting in 2005 (Table 2).

Annual grass control. Glyphosate applied to 1-leaf cotton provided 98% control at 4 WAP (early-season control) compared to 93% control received from PRE systems (Table 2). Control was similar among all systems at 8 WAP (mid-season control), and control was not enhanced by the addition of PRE herbicides, *S*-metolachlor, or pyrithiobac into the system (Table 3). However, control was higher at 16 WAP (late-season control) in systems containing glyphosate plus *S*-metolachlor, compared to sequential applications of glyphosate alone applied to 1- and 6-leaf cotton (Table 4). Glyphosate has no residual activity (Franz et al.1997), and systems containing glyphosate plus *S*-metolachor have been observed to provide similar levels of late-season control in wide-row glyphosate-resistant cotton (Culpepper and York, 2005). Systems containing PRE herbicides or subsequent applications of glyphosate plus pyrithiobac, trifloxysulfuron, or glyphosate alone did not enhance control compared to glyphosate alone applied to 1- and 6-leaf cotton. Trifloxysulfuron has been reported to have poor activity on annual grasses when applied alone (Crooks et al., 2003). Additionally, an increase in late-season control by subsequent applications of glyphosate after the 6-leaf stage, in the absence of PRE herbicides, was most likely due to poor spray coverage as a result of complete canopy closure. Canopy closure in narrow-row cotton is achieved earlier in the growing season, compared to wide-rows (Jost and Cothren, 2000; Wilson, 2006).

***Ipomoea* spp. control.** Early season control by glyphosate applied to one-leaf cotton was 90% compared with PRE systems which was 80 to 83% (Table 2). In 2004, mid-season control was higher in POST only systems compared to systems including a PRE herbicide followed by glyphosate applied to 4-leaf cotton (Table 3). The addition of *S*-metolachlor or pyrithiobac into the system did not enhance control compared with sequential applications of glyphosate. Conversely, greater mid-season control was observed in 2005 with systems containing PRE herbicides, and the addition of pyrithiobac did not enhance control in the absence a

PRE herbicide. Pyrithiobac has been shown to provide poor control of tall morningglory (Corbett et al., 2004), which was the most abundant species found in all trials.

In 2004, late-season control was at least 93% for all systems (Table 4). Systems containing PRE herbicides provided greater control compared to systems containing sequential applications of glyphosate alone to 1- and 6-leaf cotton. In the absence of PRE herbicides, a subsequent application of glyphosate plus pyrithiobac, trifloxysulfuron, or glyphosate did not enhance control. Again, this is most likely due to poor spray coverage as a result of canopy closure. In 2005, the same trends were not observed and all systems controlled *Ipomoea* spp. at least 99% late in the season. This is most likely due to dry soil moisture conditions observed in the later part of the growing season coupled with decreased sunlight penetration through the crop canopy provided by the narrow-row spacing, which prevented weed resurgence (Table A-4.1). The same trends have been observed previously in narrow-row soybeans under the same environmental conditions (Yelverton and Coble, 1991).

***Amaranthus* spp. control.** Early-season control was 94% with pendimethalin plus fluometuron PRE, compared to 98 to 100% control provided by pendimethalin plus pyrithiobac PRE and glyphosate applied to 1-leaf cotton, respectively (Table 2). Mid- and late-season control was 99 to 100% for all systems (Tables 3 and 4). The addition of a PRE herbicide, *S*-metolachlor, pyrithiobac, trifloxysulfuron, or subsequent applications of glyphosate into the system did not enhance control compared to sequential applications of glyphosate alone applied to 1- and 6-leaf cotton. Glyphosate has been observed to be effective on *Amaranthus* spp. (Corbett et al., 2004; Culpepper and York, 1998, 2000; York and Culpepper, 2006).

Cotton response. Gyphosate did not visibly injure cotton. Injury from *S*-metolachlor and pyrithiobac applied POST was at most 5 and 12% 2 wk after application, and no injury was observed late in the season (Table A-4.2). Cotton lint yields ranged from 1750 to 1910 kg/ha, and there were no differences noted among herbicide systems (Table 5). Additionally, glyphosate applied topically to cotton past the four-leaf stage did not affect yield. No differences among herbicide systems were noted for micronaire, fiber length, fiber length uniformity, or fiber strength; which averaged 4.25, 2.85 cm, 84%, and 287 kN m/kg, respectively (Table A-4.3).

CONCLUSIONS

Results from this study demonstrate that excellent control of annual grasses, *Ipomoea* spp., and *Amaranthus* spp. can be obtained in narrow-row, glyphosate-resistant cotton. At least one herbicide system controlled all weed species evaluated at least 93% late in the season, and there were no differences in lint yield and fiber characteristics. Sequential applications of glyphosate alone controlled annual grasses, *Ipomoea* spp., and *Amaranthus* spp. 96, 93 to 99, and 99% late in the season, respectively. However, systems including *S*-metolachlor had a tendency to provide more effective late-season control of annual grasses, while systems including pendimethalin plus fluometuron or pyrithiobac PRE tended to provide more effective late-season control of *Ipomoea* spp. This is supported by other research that noted more consistent late-season weed control in cotton and soybean planted on 19-cm rows when soil-applied herbicides were used (Culpepper and York, 2000; Norsworthy, 2004). In narrow-row cotton, where post-directed herbicide applications are not feasible, the inclusion of residual herbicides may be more beneficial, especially in situations where plant stands are less than adequate to provide sufficient canopy coverage. Additionally, the usage of materials other than glyphosate will also aid in resistance management programs.

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Table 1. Description of soils at trial sites in 2004 and 2005

Year	Location	Soil Series	Soil Texture	Soil pH	Soil humic matter (%)
2004	Clayton	Dothan[w]	Loamy sand	5.9	1.37
	Rocky Mt.	Nahunta[x]	Loamy sand	5.7	0.97
2005	Clayton	Johns[y]	Sandy Loam	5.3	1.03
	Rocky Mt.	Norfolk[z]	Loamy Sand	5.8	0.56

[w] **Dothan is a fine-loamy, kaolinitic, thermic Plinthic Kandiudults**

[x] **Nahunta is a fine-silty, siliceous, subactive, thermic Aeric Paleaquults**

[y] **Johns is a fine-loamy, siliceous, semiactive, thermic Aquic Hapludults**

[z] **Norfolk is a fine-loamy, kaolinitic, thermic Typic Kandiudults**

Table 2. Control of annual grasses, *Ipomoea* spp., and *Amaranthus* spp. 4 wk after planting in narrow-row, glyphosate-resistant cotton[w]

	Control (%) [x]		
Herbicides[y, z]	**Annual grasses**	***Ipomoea* spp.**	***Amaranthus* spp.**
None	**98 a**	**90 a**	**100 a**
Pend + fluo	**93 b**	**80 b**	**94 b**
Pend + pyri	**93 b**	**83 b**	**98 a**

[w] Data are averaged over like treatments, years, and locations. Means within a column followed by the same letter are not different based on Fisher's Protected LSD test at *P* = 0.05.

[x] Annual grasses consisted of a mixture of goosegrass, broadleaf signalgrass, and fall panicum at Clayton, and goosegrass, broadleaf signalgrass, and large crabgrass at Rocky Mount. *Amaranthus* spp. consisted of Palmer amaranth at Clayton, and smooth pigweed at Rocky Mount. *Ipomoea* spp. consisted of a mixture of tall morningglory and pitted morningglory at both locations.

[y] Systems not including a PRE herbicide received an early POST application of glyphosate at 1120 g ai/ha when cotton was in the 1-leaf stage.

[z] Abbreviations and herbicide rates: Pend, pendimethalin (1120 g ai/ha); fluo, fluometuron (1120 g ai/ha); pyri, pyrithiobac (48 g ai/ha).

Table 3. Control of annual grass, *Ipomoea* spp., and *Amaranthus* spp. 8 wk after planting in narrow-row, glyphosate-resistant cotton[w]

Herbicides[y]			Control (%)[x]			
			Annual grasses	*Ipomoea* spp.		*Amaranthus* spp.
PRE[z]	4-leaf	6-leaf		2004	2005	
None	None	Glyp	99 a	95 a	90 b	100 a
None	None	Glyp + metol	100 a	95 a	90 b	100 a
None	None	Glyp + pyri	100 a	97 a	91 b	100 a
Pend + fluo	Glyp	None	98 a	91 b	94 a	99 a
Pend + pyri	Glyp	None	97a	92 b	94 a	99 a

[w] Data for annual grass and *Amaranthus* spp. species are averaged over like treatments, years, and locations. Data for *Ipomoea* spp. are averaged over like treatments and locations. Means followed by the same letter are not significantly different based on Fisher's Protected LSD test at $P = 0.05$.

[x] Annual grasses consisted of a mixture of goosegrass, broadleaf signalgrass, and fall panicum at Clayton, and goosegrass, broadleaf signalgrass, and large crabgrass at Rocky Mount. *Amaranthus* spp. consisted of Palmer amaranth at Clayton, and smooth pigweed at Rocky Mount. *Ipomoea* spp. consisted of a mixture of tall morningglory and pitted morningglory at both locations.

[y] Abbreviations and herbicide rates: Pend, pendimethalin (1120 g ai/ha); fluo, fluometuron (1120 g ai/ha); glyp, glyphosate (1120 g ai/ha); pyri, pyrithiobac (48 g ai/ha).

[z] Systems not including a PRE herbicide received an early POST application of glyphosate at 1120 g ai/ha when cotton was in the 1-leaf stage.

Table 4. Late-season control of annual grasses, *Ipomoea* spp., and *Amaranthus* spp. in narrow-row glyphosate-resistant cotton[w]

Herbicides[y]					Control (%)[x]			
					Annual grasses	*Ipomoea* spp.		*Amaranthus* spp.
PRE[z]	4-leaf	6-leaf	12-leaf	14-leaf		2004	2005	
None	None	Glyp	None	None	96 b	93 c	99 a	99 a
None	None	Glyp	Glyp	None	97 ab	94 bc	100 a	100 a
None	None	Glyp	Glyp	Glyp	97 ab	94 bc	100 a	100 a
None	None	Glyp	Trif	None	97 ab	94 bc	99 a	100 a
None	None	Glyp + metol	Glyp	None	100 a	95 abc	99 a	100 a
None	None	Glyp + metol	Trif	None	100 a	95 abc	100 a	100 a
None	None	Glyp + pyri	Glyp	None	98 ab	95 abc	99 a	100 a
None	None	Glyp + pyri	Glyp + pyri	None	98 ab	95 abc	99 a	100 a
Pend + fluo	Glyp	None	Glyp	None	99 ab	97 a	100 a	100 a
Pend + fluo	Glyp	None	Glyp	Glyp	99 ab	96 ab	100 a	100 a
Pend + pyri	Glyp	None	Glyp	None	99 ab	96 ab	100 a	100 a
Pend + pyri	Glyp	None	Glyp	Glyp	99 ab	97 a	100 a	100 a

[w] Data for annual grass and *Amaranthus* spp. are averaged over years, and locations. Data for *Ipomoea* spp. are averaged over locations. Means within a column followed by the same letter are not different based on Fisher's Protected LSD test at P = 0.05.

Table 4. Continued

[x] **Annual grasses consisted of a mixture of goosegrass, broadleaf signalgrass, and fall panicum at Clayton, and goosegrass, broadleaf signalgrass, and large crabgrass at Rocky Mount. *Amaranthus* spp. consisted of Palmer amaranth at Clayton, and smooth pigweed at Rocky Mount. *Ipomoea* spp. consisted of a mixture of tall morningglory and pitted morningglory at both locations.**

[y] **Abbreviations and herbicide rates: Pend, pendimethalin (1110 g ai/ha); fluo, fluometuron (1120 g ai/ha); glyp, glyphosate (1120 g ai/ha); pyri, pyrithiobac (48 g ai/ha PRE and POST; 24 g ai/ha sequential POST); trif, trifloxysulfuron (5.3 g ai/ha).**

[z] **Systems not including a PRE herbicide received an early POST application of glyphosate at 1120 g ai/ha when cotton was in the 1-leaf stage.**

Table 5. Lint yield as affected by herbicide systems in narrow-row glyphosate-resistant cotton[x]

Herbicides[y]					
PRE[z]	4-leaf	6-leaf	12-leaf	14-leaf	Lint Yield (kg/ha)
None	None	Glyp	None	None	1751 a
None	None	Glyp	Glyp	None	1756 a
None	None	Glyp	Glyp	Glyp	1814 a
None	None	Glyp	Trif	None	1822 a
None	None	Glyp + metol	Glyp	None	1883 a
None	None	Glyp + metol	Trif	None	1872 a
None	None	Glyp + pyri	Glyp	None	1905 a
None	None	Glyp + pyri	Glyp + pyri	None	1796 a
Pend + fluo	Glyp	None	Glyp	None	1829 a
Pend + fluo	Glyp	None	Glyp	Glyp	1809 a
Pend + pyri	Glyp	None	Glyp	None	1773 a
Pend + pyri	Glyp	None	Glyp	Glyp	1812 a

[x] Data are averaged over years and locations. Means followed by the same letter are not significantly different based on Fisher's Protected LSD test at *P* = 0.05.

[y] Abbreviations and herbicide rates: Pend, pendimethalin (1120 g ai/ha); fluo, fluometuron (1120 g ai/ha); glyp, glyphosate (1120 g ai/ha); pyri, pyrithiobac (48 g ai/ha PRE and POST; 24 g ai/ha sequential POST); trif, trifloxysulfuron (5.3 g ai/ha).

[z] Systems not including a PRE herbicide received an early POST application of glyphosate at 1120 g ai/ha when cotton was in the 1-leaf stage.

CHAPTER V

TITLE: Plant Population Effects on Narrow-Row Cotton

DISCIPLINE: Agronomy and Soils

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ABBREVIATIONS: PAR, photosynthetically active radiation; WAP, weeks after planting.

ABSTRACT

High plant populations are used in ultra-narrow-row cotton (*Gossypium hirsutum* L.) production to facilitate harvesting with a finger-type stripper. However, with the ability to spindle-pick cotton on a 38-cm row spacing and the high input cost of using transgenic cotton cultivars, the use of high plant populations may not be warranted. Studies were conducted in North Carolina to determine plant population effects on 38-cm cotton. The plant population densities under investigation ranged from 34,400 to 310,400 plants ha^{-1}. All plant populations in the 38-cm rows were compared to 97-cm rows with a population density of 115,800 plants ha^{-1}. Plant height, number of mainstem nodes, number of bolls per plant, and seed cotton weight per boll decreased as plant populations increased. However, when plant populations ranged from 102,800 to 301,400 plants ha^{-1}, a higher percentage of first position bolls and total seedcotton weight in the lower and middle portion of the canopy was noted for the 38-cm rows compared to 97-cm rows. Therefore, an earlier crop could possibly achieved in 38-cm rows by using populations of at least 120,000 plants ha^{-1}, compared to the 97-cm rows. The amount of photosynthetically-active radiation (PAR) penetrating through the plant canopy at 10 wk after planting (WAP) averaged 19% less with a population density of at least 60,300 plants ha^{-1} in the 38-cm rows compared to the 97-cm rows. This could lower the probability of late-season weed resurgence in cotton planted in 38-cm rows. There were no differences in lint yields with plant populations ranging from 60,300 to 301,409 plants ha^{-1}. However, decreases in lint yield with plant populations above or below those levels were observed. All fiber quality characteristics were within acceptable levels to avoid price discounts regardless of plant population density or row spacing. Our findings indicate that higher plant population densities than what is utilized in wide-row cotton production systems are not warranted in narrow-row cotton if it is to be spindle-picked.

KEY WORDS

15-inch cotton, earliness, maturity, yield, yield stability, fiber quality.

Cotton production has traditionally been associated with high input costs. As of late, cotton growers have been subjected to high production costs while the return on their commodity has been declining. Therefore, growers are always searching for ways to maximize net returns. One of the areas of interest has been the production of cotton on row spacings narrower than 91-cm apart.

Production of cotton using narrow-row spacings is not a new concept. Researchers began evaluating the utility of narrow-row cotton production as early as the late 1940's, and work continued through the 1970's (Hawkins and Peacock, 1973; Lewis, 1971). It was considered impractical with the production practices at the time, and as result research efforts were all but abandoned. However, interest in narrow-row cotton production increased again in the 1990's with technological advances such as glyphosate-resistant cotton, plant growth regulators, and more precise planting equipment (Atwell et al., 1996; Brown et al. 1998; Bader et al., 1999; Culpepper and York, 1998, 2000). This production practice was termed ultra-narrow-row (UNR) cotton, and was defined as planting cotton on row spacings < 25 cm (Atwell, 1996).

Although UNR cotton may reduce production costs and increase yields in some areas, especially on less productive land (Bullen and Brown, 2000; Nichols et al., 2004; Parvin et al., 2000), acceptance of this practice has been limited because of the technology that has been available for producers to harvest UNR cotton (Atwell 1996; Brown et al. 1998). Ultra narrow row cotton must be harvested using a broadcast finger-stripper because the row spacings are too narrow for a conventional spindle picker or brush stripper. Stripper harvesters are more economical to own, operate, and maintain than spindle-type harvesters (Larson et al, 1997). However, this type equipment removes the seed cotton as well as the carpel walls, some of the peduncles, and short limbs from the cotton plant. If there are any leaves left on the cotton plant after defoliation, they may also be harvested and mixed with the cotton fiber as well. This causes increased ginning costs as well as slowing productivity if the gin is not set up to receive stripper-harvested cotton (Anthony, 2000). Lower fiber quality in finger-stripped UNR cotton has also been of concern. Certain fiber quality characteristics, such as fiber strength, fiber length, and uniformity index have been reported to be lower in finger-stripped cotton compared to spindle-picked cotton (McAllister and Rogers, 2005). Additionally, there seems to be a stigma associated with UNR cotton. Regardless of grade, buyers will sometimes pay less if they know that it is UNR cotton.

A common production practice in UNR cotton is the use of high plant populations compared to traditional wide-row cotton (Perkins, 1998; Delaney et al. 2002). Plant population densities are often greater than 247,000 plants ha^{-1} (Perkins, 1998; Jones, 2001). One of the major reasons for such high plant populations is to create a compact plant with few or no vegetative branches to increase harvesting efficiency with a finger-stripper (Delaney et al., 2002). Increasing cotton plant density reduces the rate of early node production and the final number of main-stem nodes (Grimes et al., 1978; Kerby et al., 1990). Fowler and Ray (1977) evaluated different cotton cultivars with respect to growth habit in equidistant spacings of 13, 18, 25, 38, and 51 cm. They concluded, as have others (Bilbro and Quisenberry, 1973), that plant height, node numbers, and plant dry weight decreased as plant density increased. They also demonstrated that leaf-area index (LAI) accumulated more rapidly at higher plant densities, but a greater proportion of photoassimilates was directed to vegetative growth rather than reproductive growth. These observations led Fowler and Ray (1977) to conclude that plant density would affect yield both positively with LAI accumulated early in the season and negatively through a lower fruiting-vegetative ratio. A high fruiting-vegetative ratio is desirable in cotton (Meredith and Wells, 1989).

In 2005, 99% of the cotton crop in North Carolina was planted using transgenic cultivars (USDA-AMS, 2005). Transgenic varieties have additional technology fees associated with their use. However, there is a per acre cap on technology fees for production systems with high seeding rates. Nevertheless, variable costs due to seeding rates in UNR production can be as much as 2.7 times greater than in wide-row production, with 25% and 10% of total variable costs being attributed to seed inputs in UNR and wide-row production, respectively (Brown, 2006).

There has been a renewed interest in the narrow-row cotton production with the ability to spindle-pick cotton grown on a 38-cm row configuration (Willcutt, 2005). This harvesting method may significantly reduce the amount of foreign matter that is mixed with cotton when compared to finger-stripping, and possibly keep the lint grades at acceptable levels to maximize net returns. Additionally, one may be able to reduce the seeding rate on a narrow-row configuration, and thereby lowering the input costs equal to or lower than that of wide-row production. Therefore, the objective of our study was to determine if high plant populations in narrow-row (38-cm) cotton production are needed if the crop is to be spindle-picked. Factors considered were fruiting characteristics, lint yield, and various fiber quality parameters as affected by plant populations.

MATERIALS AND METHODS

The experiment was conducted on the Central Crops Research Station near Clayton, NC and the Upper Coastal Plain Research Station near Rocky Mount, NC in 2004 and 2005, and on a private farm near Belhaven, NC in 2005. Soils for each site are described in Table 1. Glyphosate-tolerant cotton cultivar ‘ST 5242 BR’ (Monsanto Co., St. Louis, MO) was planted into conventionally prepared seedbeds on 11 May, 2004, and 11 May, 2005, at Clayton, 10 May, 2004, and 12 May, 2005, at Rocky Mount, and 16 May, 2005 at Belhaven. Plots were 9 m long by twelve 38-cm rows or four 97-cm rows.

Treatments were arranged in a randomized complete block design with four replications and consisted of six plant populations on 38-cm rows and one plant population on 97-cm rows. Two separate vacuum-type planters set on 38- or 97-cm row spacings were used for seeding. Plots were over-seeded using a rate of 516,600 and 170,000 seed/ha^{-1} in the 38- and 97-cm rows, respectively. Cotton in the two-leaf stage of growth was hand-thinned to the desired plant populations of 34,400, 60,300, 120,800, 198,000 258,300, and 301,400 plants ha^{-1} in the 38-cm rows, and 115,800 plants ha^{-1} in the 97-cm rows. The population density in the 97-cm rows is a commonly used population for cotton planted on this row spacing in North Carolina and was chosen for comparison purposes (Edmisten, 2006).

Ninety and 110 kg ha^{-1} of N, as ammonium nitrate, was broadcast prior to planting at Clayton and Rocky Mount, respectively, in 2004. No additional nitrogen was applied during the season. At Clayton and Rocky Mount In 2005, 45 kg ha^{-1} of N, as ammonium nitrate, was broadcast at the pinhead square stage of cotton and repeated 3 wk later. At Belhaven in 2005, 45 kg ha^{-1} of N, as UAN (urea ammonium nitrate), was broadcast prior to planting and repeated with 45 kg ha^{-1} of N, as ammonium nitrate, when cotton was at the pinhead square stage. Phosphorus, potassium, and boron were applied according to soil test recommendations. Aldicarb (Temik insecticide; Bayer CropScience, Research Triangle Park, NC) was applied in the seed furrow at 0.2 g ai/m of row in 2004 to control thrips (*Frankliniella* spp.) and other early season insects. Seed were treated with imidacloprid (Gaucho Grande insecticide; Bayer CropScience) in 2005 at the rate of 0.375 mg ai per seed. Acephate (Orthene 97S; Valent Agricultural Products; Walnut Creek, CA) at 204 g ai ha^{-1} was applied POST as needed for additional early season insect control. Mid- and late-season insect management was standard for cotton production in North Carolina. In all trials, plant growth regulation was accomplished using mepiquat chloride (Pix Plus growth regulator; BASF Ag Products; Research Triangle Park, NC) applied at 0.58 L ha^{-1} when cotton was in the 10-leaf and early-bloom stage of growth.

Cotton was kept weed-free during the growing season by applying pendimethalin (Prowl 3.3 EC herbicide; BASF Ag Products; Research Triangle Park, NC) at 1110 g a.i. ha^{-1} plus fluometuron (Cotoran 4L herbicide; Griffin LLC; Valdosta, GA) at 1120 g a.i. ha^{-1} preemergence , glyphosate (Roundup WeatherMAX herbicide; Monsanto Co.; St Louis, MO) at 1120 g ha^{-1} to one-leaf cotton, and glyphosate at 1120 g ha^{-1} plus *S*-metolachlor (Dual Magnum herbicide; Syngenta Crop Protection; Greensboro, NC) at 1390 g a.i. ha^{-1} to four-leaf cotton. The 97-cm rows received an additional post-directed application of glyphosate at 1120 g ha^{-1} plus diruon (Direx 4L herbicide; Griffin LLC; Valdosta, GA) at 840 g a.i. ha^{-1} when cotton was 46 cm in height. Harvest preparation consisted of defoliation by a mixture of tribufos (DEF 6 defoliant; Bayer CropScience; Research Triangle Park, NC) at 1262 g a.i. ha^{-1}, thiadiazuron (DROPP SC defoliant; Bayer CropScience, Research Triangle Park, NC) at 112 g a.i. ha^{-1}, and ethephon (Prep defoliant; Bayer Crop Science; Research Triangle Park, NC) at 1120 g a.i. ha^{-1}.

Photosynthetically active radiation (PAR) was measured at 6 and 10 wk after planting in both years at Clayton using a line quantum sensor (LI-191 quantum sensor; LI-COR Inc.; Lincoln, NE) to monitor the amount of light penetrating through the crop canopy. Measurements were taken perpendicular to the rows, both above and below the canopy, with a total of three subsamples per plot. From these readings, the amount of PAR penetration through the crop canopy was determined by dividing the reading from below the canopy by the reading above the canopy and expressing the value as a percentage.

Two weeks following defoliation, 10 consecutive plants in 2004 and 20 consecutive plants in 2005 were hand-harvested by position according to box-mapping procedures described by Jenkins et al. (1990) prior to mechanical harvest. The Belhaven location was not boxed-mapped. The center four 38-cm rows and the center two 97-cm rows were harvested using a spindle-type picker modified to harvest multiple row spacings (Lanier et al., 2005). A sample of mechanically harvested seed cotton was collected from each plot and used to determine lint percentage and fiber quality. Seed cotton was ginned on a laboratory gin without lint cleaning, hence cotton grades are not presented as they would not be representative of cotton ginned commercially. However, fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Data variance was visually inspected by plotting residuals to confirm homogeneity of variance before statistical analysis. Both arcsine-transformed and nontransformed data were examined, and transformation did not improve homogeneity. Therefore, nontransformed data were subjected to analysis of variance using the MIXED procedure in SAS (version 9.1; SAS Institute Inc.; Cary, NC), and *P*-values for all main effects and interactions are presented in Tables A-5.1 through A-5.5. Means were separated using Fisher's Protected LSD at $P = 0.05$ (Saxton, 1998). A treatment by year interaction was observed for final plant heights at harvest, and data are presented separately by year. A treatment by year or treatment by location interaction was not observed for all other box-mapping data, thus means were averaged over 2 yr and four locations. Light penetration data were taken in both years at the Clayton location only, and due to the lack of a treatment by year interaction data were averaged over years. There was not a treatment by year or treatment by location interaction for lint yield and fiber quality characteristics, therefore data are averaged over two locations in 2004 and three locations in 2005. Regression analysis was performed on the 38-cm row treatments only to determine first- and second-order polynomial effects on all data. Analysis of variance indicated a higher-order polynomial effect for light penetration data at 6 and 10 WAP, and as a result a hyperbolic model was fit to data.

RESULTS AND DISCUSSION

Vegetative and reproductive characteristics. In 2004, there were no differences in final plant height among plant populations in the 38-cm rows, however the plants in the 97-cm rows were at least 9 cm taller (Table 2). In 2005, plant height decreased as the plant population increased. Additionally, final plant height in the 97-cm rows was greater than the 38-cm rows with a plant population above 60,300 plants ha^{-1}. These results are similar to those observed by others (Atwell, 1996; Fowler and Ray, 1977; Gwathmey, 1996; Jost and Cothren, 2000; Nichols et al. 2004). The total number of mainstem nodes decreased as the plant population increased, and plants in the 97-cm rows had more total nodes than plants in the 38-cm rows with plant populations greater than or equal to 120,800 plants ha^{-1}. It has been observed that cotton has fewer nodes when planted in ultra-narrow and narrow-row spacings than when planted in wide-row spacings (Jost and Cothren, 2000; Kerby, 1998; Nichols et al. 2004). It is important to note, however, that plant densities in the narrow-rows were greater than that in the wide rows. Additionally, several studies have shown that plant density is inversely related to the number of mainstem nodes, regardless of row spacing (Bednarz et al., 2000; Buxton et al., 1977; Fowler and Ray, 1977; Heitholt, 1995; Jones and Wells, 1998; Kerby et al., 1990).

In general, the number of bolls per plant present at harvest decreased in all portions of the canopy as the plant population increased (Table A-5.6). Conversely, the number of bolls m^{-2} decreased in the lower and middle portions of the canopy as plant population decreased (Table 3). However, the number of bolls m^{-2} in the upper and vegetative portions of the canopy increased as the plant population decreased. Compared to the 97-cm rows, plant populations greater than or equal to 120,800 plants ha^{-1} had an equal or greater amount of bolls m^{-2} in the lower and middle portions of the canopy. The percentage of total bolls on first position sympodial sites increased as plant population increased (Table 4). However, the percentage of total bolls on second positition sympodial sites and vegetative sites increased as plant population density decreased. Vegetative bolls were nonexistent when plant populations were higher than 258,300 plants ha^{-1}. High plant populations in both narrow- and wide-row spacings have been shown to prevent sympodial branches from producing distal sites in cotton (Bednarz et al., 2000; Constable, 1986; Fowler and Ray, 1977). Additionally, seed-cotton weight per boll in all portions of the canopy decreased as plant population increased (Table 4). Our results are in agreement with others who also found that boll size is inversely related to plant populations, regardless of row spacing (Baker, 1976; Bednarz et al., 2000; Fowler and Ray, 1977; Jones and Wells, 1997).

The trends in seedcotton weight distribution throughout the canopy are somewhat similar to boll distribution. The percentage of the total seedcotton weight per plant in the lower portion of the canopy increased as the plant populations increased (Table 5). There was little effect of plant population density in the middle portion of the canopy, and as population density decreased so did the percentage of total of seedcotton weight in the upper portion of the canopy. A considerable amount (16 to 24%) of seedcotton weight per plant was attributed to vegetative portions at the two lowest plant populations.

Increasing plant density has been shown to increase earliness in cotton planted in wide-row spacings (Rao and Weaver, 1976; Smith et al. 1979). Baker (1976) found that plant density and earliness were not related. However, Fowler and Ray (1977) indicated a medium-range population is more consistent in earliness. In our study, plant population density had an effect on earliness. At 15 weeks after planting (WAP), there was a decrease in the number of nodes above white flower (NAWF) as plant population increased (Table 2). Comparatively, plants the 97-cm rows had more NAWF than the 38-cm rows with population densities greater than or equal to 120,800 plants ha^{-1}. The percentage of seedcotton accumulation was greater in the lower portion of the canopy for plant populations greater than or equal to 120,800 plants ha^{-1} compared to the 97-cm rows. Additionally, these plant populations also cause plants to have fewer mainstem nodes and a higher percentage of first position bolls. This indicates that earliness is enhanced in 38-cm spacings, compared to 97-cm spacings, when population densities are greater than or equal to 120,800 plants ha^{-1}.

As expected, plant populations had an effect on the amount of PAR that penetrated through the plant canopy. At 6 WAP, the amount of light penetration decreased as plant population density increased (Figure 1). However, by 10 WAP, only 13 to 16% PAR was penetrating through the canopy when plant population densities ranged from 60,300 to 301,400 plants ha^{-1}. The lowest plant population density allowed 44%, and the 97-cm rows allowed 34%. This is in agreement with Jost and Cothren (2000) who that found canopy closure occurs more rapidly in narrow rows. Additionally, reduced weed resurgence was found in soybean [*Glycine max* (L) Merr.] planted on 23- and 46-cm rows compared to 91-cm rows, due to a reduced amount to PAR intercepted by the soil surface (Yelverton and Coble, 1991). Therefore, the probability of late-season weed resurgence in cotton planted on a 38-cm row spacing should be minimal if population densities are above 60,000 plants ha^{-1}.

Lint yield and fiber characteristics. Lint yields ranged from 1710 to 1820 kg ha^{-1} (Table 6). Lint yields were similar with population densities ranging from 60,300 to 301,400 plants ha^{-1}. However, yield was 9% less for the lowest population density of 34,400 plants ha^{-1}, compared to the average yield (1870 kg ha^{-1}) of the population densities ranging from 60,300 to 301,400 plants ha^{-1}. This can be attributed to the lower number of bolls produced per m^{-2} by cotton at this population density. There was also a trend for yield to decrease when population densities are above 301,379 plants ha^{-1}, and it seems to be associated with the decrease in seedcotton weight per boll inherent within high populations. Lint yield from cotton in 38-cm rows with a population density of 34,400 plants ha^{-1} was 167 kg ha^{-1} greater than yield with the 97-cm rows (Figure 7). Average yields of 38-cm cotton with population densities ranging from 60,300 to 301,400 plants ha^{-1} were 324 kg ha^{-1} greater than that of 97-cm rows.

Population or row spacing had no effect on micronaire and uniformity index (Table 7). There was a tendency for fiber length to decrease as plant populations in 38-cm rows increased. Fiber length at population densities of 60,300 to 301,400 plants ha^{-1} was less than that in 97-cm rows. Trends in fiber strength were not clear, but fiber strength in 38-cm rows with populations of 198,000 plants ha^{-1} or more tended to be less than strength in 97-cm rows. It has been noted by others that row spacing had little or no effect on fiber length, length uniformity, strength, or micronaire regardless of harvesting method (Buxton, 1976; Nichols et al., 2004). However, others have observed lower fiber length, length uniformity, strength, and micronaire in finger-stripped versus spindle-picked cotton (McAllister and Rogers, 2005).

CONCLUSIONS

The results from our study show that decreased population populations in 38-cm cotton resulted in a greater number of mainstem nodes and bolls per plant. Additionally, lower population densities also resulted in a higher seed-cotton weight per boll. However, lower population densities (34,400 to 60,300 plants ha^{-1}) also produced fewer bolls m^{-2}, with a large portion of those bolls arising from vegetative branches. As plant populations increased, the number of mainstem nodes and seedcotton weight per boll decreased. These combined effects resulted in fewer bolls and less seedcotton per plant. Cotton in population densities ranging from 120,800 to 301,400 plants ha^{-1} had a higher percentage of bolls on the first sympodial position than cotton in the 97-cm rows. Cotton in these population densities also produced a higher percentage of seedcotton weight per plant in the lower and middle portion of the canopy than cotton in the 97-cm rows. This indicates that earliness is enhanced in 38-cm spacings, compared to 97-cm spacings, when population densities are $\geq$120,776 plants ha^{-1}.

The amount of PAR penetrating through the plant canopy at 10 WAP was 13 to 15% with plant population densities ranging from 60,277 to 301,379 plants ha^{-1}, and was 18 to 21 percentage points less than what was observed in the 97-cm rows. Lint yields were similar with population densities ranging from 60,300 to 301,400 plants ha^{-1}. However, yields tended to decrease when densities were above and below this range. The average yield in the 38-cm rows was 16% greater than that of the 97-cm rows. This experiment indicates that optimum plant populations in 38-cm rows are similar to that used in 97-cm rows, if the crop is to be spindle-picked. With the cost of transgenic cotton seed, this should allow producers to somewhat reduce input costs in narrow-row cotton production.

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Table 1. Description of soils at trial sites in 2004 and 2005

Year	Location	Soil Series	Soil Texture	Soil pH	Soil humic matter (%)
2004	Clayton	Dothan[w]	Loamy sand	6.1	0.46
	Rocky Mt.	Norfolk[x]	Loamy sand	6.2	0.36
2005	Clayton	Johns[y]	Sandy loam	5.9	1.12
	Rocky Mt.	Norfolk	Loamy Sand	5.3	0.22
	Belhaven	Roanoke[z]	Sandy loam	5.1	0.97

[w] Dothan is a fine-loamy, kaolinitic, thermic Plinthic Kandiudults

[x] Norfolk is a fine-loamy, kaolinitic, thermic Typic Kandiudults

[y] Johns is a fine-loamy, siliceous, semiactive, thermic Aquic Hapludults

[z] Roanoke is a fine, mixed, semiactive, thermic Typic Endoaquults

Table 2. Plant population effect on plant height and number of total nodes at harvest, and nodes above white flower 15 wk after planting in narrow-row cotton[y]

Population (plants ha^{-1})	Plant Height (cm) 2004	Plant Height (cm) 2005	Total Nodes (no. $plant^{-1}$)	NAWF 15 WAP
34400	71 b	89 a	15.6 a	7.7 a
60300	70 b	72 c	15.1 a	6.6 b
120800	69 b	67 c	14.2 b	5.5 d
198000	70 b	61 d	12.8 c	5.2 de
258300	66 b	59 d	12.3 cd	4.9 e
301400	67 b	56 d	11.9 d	4.9 e
115,800 (97-cm rows)	80 a	79 b	15.0 a	6.1 c
Regression[z]				
Linear	NS	**	**	**
Quadratic	NS	*	**	**

[z] Data for final plant heights and total nodes are averaged over two locations per year, and data for NAWF are averaged over two years and two locations per year. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test a *P* = 0.05.

[z] Regression analysis performed on 38-cm rows only. NS, *, and ** denote level of significance for none, *P* = 0.05, and *P* = 0.01, respectively.

Table 3. Plant population effect on number of bolls m^{-2} at harvest in narrow-row cotton[x]

	Total bolls (no. m^{-2})[y]			
Population (plants ha^{-1})	**Nodes 4 to 7**	**Nodes 8 to 11**	**Nodes 12+**	**Vegetative**
34400	18 e	20 d	5 ab	15 a
60300	24 d	23 d	4 bc	10 b
120800	34 c	34 c	4 bc	4 d
198000	44 b	42 ab	3 cd	1 e
258300	56 a	47 a	2 de	0 e
301400	58 a	42 ab	1 e	0 e
115,800 (97-cm rows)	34 c	40 bc	6 a	6 c
Regression[z]				
Linear	**	**	**	**
Quadratic	**	**	*	**

[x] **Data are averaged over two years and two locations per year. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test a *P* = 0.05.**

[y] **All positions.**

[z] **Regression analysis performed on 38-cm rows only. NS, *, and ** denote level of significance for none, *P* = 0.05, and *P* = 0.01, respectively.**

Table 4. Plant population effect on percentage of total bolls per plant and seed cotton weight per boll in first position, second position, and vegetative sites at harvest in narrow-row cotton[x]

	1st position		2nd position		vegetative	
Population (plants ha^{-1})	Bolls (% of total)	Boll size[y] (g $boll^{-1}$)	Bolls (% of total)	Boll size (g $boll^{-1}$)	Bolls (% of total)	Boll size (g $boll^{-1}$)
34400	42 f	5.9 a	24 a	5.0 a	25 a	5.4 a
60300	54 e	5.6 ab	25 a	4.6 ab	16 b	5.4 a
120800	76 c	5.2 b	17 b	3.4 cd	5 c	4.1 b
198000	87 b	4.7 c	11 c	3.0 d	1 d	2.4 c
258300	90 ab	4.6 c	8 cd	2.3 e	0 d	0 d
301400	93 a	3.8 d	5 d	1.3 f	0 d	0 d
115,800 (97-cm rows)	71 d	5.6 ab	19 b	4.0 bc	6 c	4.9 ab
Regression[z]						
Linear	**	**	**	**	*	**
Quadratic	**	**	**	**	**	**

[x] Data are averaged over two years and two locations per year. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test a *P* = 0.05.

[y] Seed cotton weight per boll; averaged over all nodes.

[z] Regression analysis performed on 38-cm rows only. NS, *, and ** denote level of significance for none, *P* = 0.05, and *P* = 0.01, respectively.

Table 5. Plant population effect on seed cotton weight distribution per plant in narrow-row cotton[y]

	Seed cotton weight (% of total)			
Population (plants ha^{-1})	Nodes 4 to 7	Nodes 8 to 11	Nodes 12+	Vegetative
34400	31 f	36 c	9 a	24 a
60300	37 e	40 bc	8 ab	16 b
120800	43 cd	46 a	6 b	5 c
198000	48 bc	47 a	4 c	1 d
258300	52 b	45 a	2 d	0 d
301400	59 a	41 ab	0 e	0 d
115,800 (97-cm rows)	39 de	41 b	6 b	6 c
Regression[z]				
Linear	**	NS	**	*
Quadratic	**	**	**	**

[y] Data are averaged over two years and two locations per year. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test a *P* = 0.05.

[z] Regression analysis performed on 38-cm rows only. NS, *, and ** denote level of significance for none, *P* = 0.05, and *P* = 0.01, respectively.

Table 6. Plant population effect on lint yield and fiber quality characteristics in narrow-row cotton[y]

Population (plants ha^{-1})	Lint yield (kg ha^{-1})	Fiber characteristics Mic	UHM (cm)	UI (%)	Strength (kN mg/kg)
34400	1712 b	4.81 a	2.78 ab	84 a	279 ab
60300	1847 a	4.86 a	2.76 b	83 a	278 ab
120800	1879 a	4.91 a	2.75 bc	83 a	279 ab
198000	1897 a	4.87 a	2.71 d	83 a	274 bc
258300	1903 a	4.82 a	2.75 bc	83 a	278 abc
301400	1820 ab	4.81 a	2.72 cd	83 a	272 c
115,800 (97-cm rows)	1545 c	4.83 a	2.80 a	84 a	282 a
Regression[z]					
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

[y] Data are averaged over two years with two locations in 2004 and three locations in 2005. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test a $P = 0.05$.

[z] Regression analysis performed on 38-cm rows only. NS, *, and ** denote level of significance for none, $P = 0.05$, and $P = 0.01$, respectively.

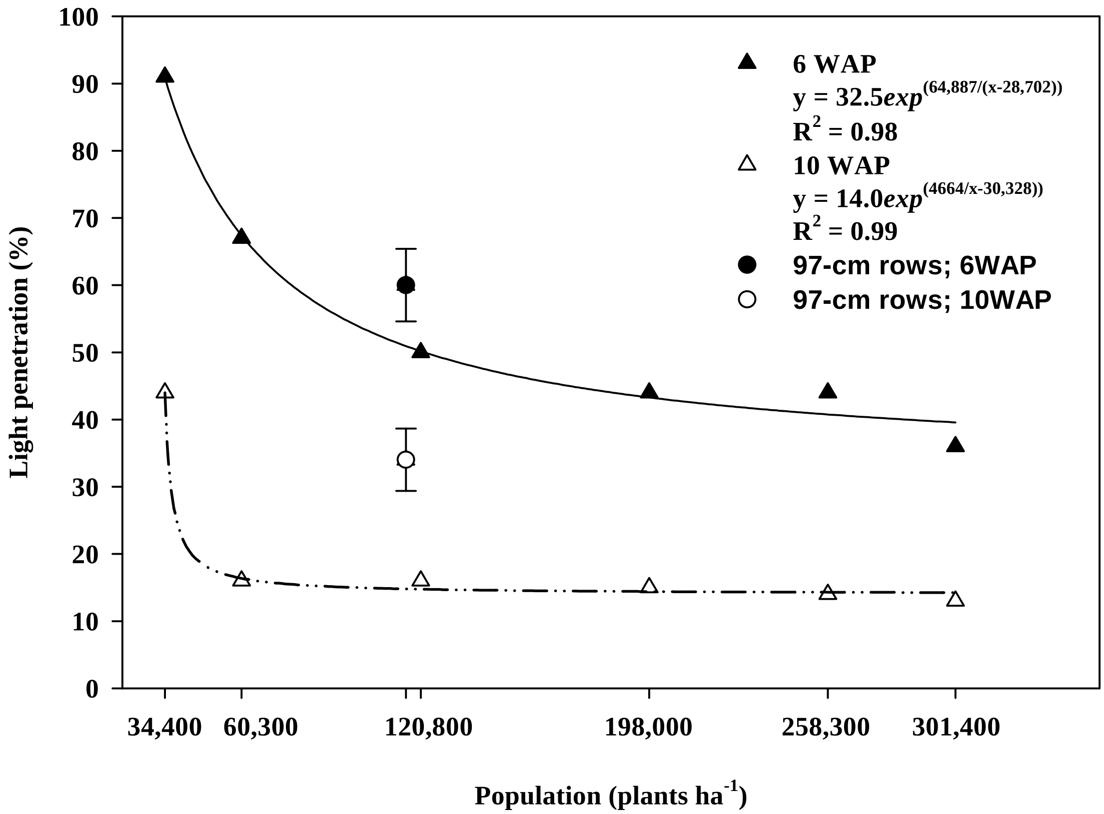

Figure 1. Plant population effect on percentage of photosynthetically active radiation penetrated through the crop canopy 6 and 10 wk after planting at Clayton in 2004 and 2005. Regression analysis performed on 38-cm rows only. Vertical bars denote LSD values at *P* = 0.05 and are present to compare the plant populations in the 38-cm rows to the 97-cm rows.

CHAPTER VI

TITLE: Narrow-row Cotton Response to Mepiquat Chloride

DISCIPLINE: Agronomy and Soils

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ABBREVIATIONS: EB, early bloom; LRM, low rate multiple; MC, mepiquat chloride; MEB, modified early bloom; UNR, ultra-narrow-row.

ABSTRACT

Transgenic, herbicide-resistant cotton and commercialization of equipment to spindle-pick 38-cm rows has renewed interest in narrow-row cotton production. No research has been published relative to mepiquat chloride (MC) use requirements for cotton in 38-cm rows. An experiment was conducted at five locations during 2004 and 2005 to determine if MC application strategies currently recommended for wide-row cotton are valid for cotton planted in 38-cm rows. Cotton planted in 38- and 97-cm rows received MC in three application strategies. The low rate multiple (LRM) strategy consisted of MC at 12 g a.i. ha^{-1} applied three times at 2-wk intervals beginning at the first square stage. The modified early bloom (MEB) strategy consisted of MC at 24 g ha^{-1} applied 2 wk prior to early bloom and repeated at early bloom. The early bloom (EB) strategy consisted of MC at 24 g ha^{-1} applied at early bloom and repeated 2 wk later. Cotton in 38- and 97-cm rows responded similarly to MC, as indicated by lack of a MC application strategy by row spacing interaction for plant height, fruiting characteristics, fruit retention, lint yield, and fiber quality. Cotton in 38-cm rows was shorter, produced more bolls per unit area, had greater boll retention on first position sympodial sites, and yielded 10% more than cotton in wide rows. Except for plant height, which was reduced more by MC in the LRM and MEB strategies than in the EB strategy, cotton response was similar with each MC application strategy. Averaged over row spacings, MC increased lint yield 5%. Minor increases in fiber length were noted in MC-treated cotton, but MC did not affect micronaire, fiber strength, or fiber length uniformity. The results suggest current MC recommendations for wide-row cotton in North Carolina are appropriate for cotton in 38-cm rows. The LRM or MEB strategies would be preferred.

KEY WORDS

Cotton yield, fiber quality, plant growth regulators, 38-cm rows.

Cotton production in narrow rows is not a new concept. Researchers began evaluating the utility of narrow-row cotton production as early as the late 1940's (Waddle, 1971), and work continued until the early 1970's (Hawkins and Peacock, 1973). Although yield responses were often noted, narrow-row production was considered impractical with the technology available at the time, and research efforts were all but abandoned. Interest in narrow-row cotton was renewed in the 1990's with technological advances such as herbicide-resistant cotton, plant growth regulators, and more precise planting equipment (Atwell, 1996; Bader et al., 1999; Brown et al. 1998; Culpepper and York, 2000). This new practice, termed ultra-narrow-row (UNR) production, consisted of seeding cotton with a grain drill in 19- to 25-cm rows and harvesting with a finger-stripper harvester (Atwell, 1996). High plant populations and extensive use of growth regulators were required to create compact plants with short limbs that could be harvested with a finger stripper (Delaney et al., 2002; Gwathmey, 1998; Jones, 2001; Nichols et al., 2003; Perkins, 1998).

One of the attractions of UNR cotton is that finger strippers are more economical to own and operate than spindle-type harvesters (Larson et al., 1997; Parvin et al., 2000; Vories et al., 2001). Greater yields and net returns have sometimes been obtained with UNR cotton relative to cotton in the typical 76- to 101-cm rows, especially on less productive land (Bullen and Brown, 2000; Nichols et al., 2004; Parvin et al., 2000). However, at least two equipment-related problems are associated with UNR cotton. First, erratic stands are sometimes achieved with grain drills. Although there have been significant improvements in grain drills in recent years, precise control of seed placement and coverage is still less with a drill as compared with unit planters (Wiatrak et al., 1998). Second, there have been ginning and fiber quality concerns associated with finger-stripper harvesting. Excess foreign matter, such as carpel walls, peduncles, and short limbs from the cotton plant, increase ginning costs and reduce gin efficiency (Anthony et al., 2000). Fiber quality may also be compromised in finger-stripped cotton (McAllister and Rogers, 2005; Vories et al., 2001). Additionally, there seems to be a stigma associated with UNR cotton. Regardless of grade, buyers pay less for UNR cotton.

The plant growth regulator mepiquat chloride has been widely used on cotton since the 1980s, and its ability to create a more compact plant has been well documented (Kerby, 1985; Stuart et al., 1984; York, 1983a,b). Other responses to MC include increased cotton leaf density, chlorophyll content, and seed weight (Fernandez et al., 1991; Gausman et al., 1979; York, 1983b) . However, yield response to MC has been inconsistent (Biles and Cothren, 2001; Cathey and Meredith, 1988; Kerby, 1985; York, 1983a,b). Earlier research with MC utilized high rates applied once at early bloom (Kerby, 1985; York, 1983a,b). More recent research has focused on MC application rates and timings, with emphases on multiple applications at lower rates beginning earlier in the season. Weir et al. (1991) and Biles and Cothren (2001) reported greater cotton yield responses with multiple, lower-dosage applications of MC as compared with single applications at the early bloom stage. Cultivars with a more indeterminate-type growth habit have responded more positively to MC applied before early bloom (Craig and Gwathmey, 2005). Other research suggests MC applications can be scheduled using plant monitoring techniques rather than basing applications exclusively on crop growth stage. Edmisten (1994) used plant height, height-to-node ratio, and square retention as guidelines for MC application. Less MC was needed when applications were based on plant monitoring techniques, and cotton yield response to MC applied based on plant monitoring techniques was equal to or greater than when applications were based on growth stage.

A harvester capable of spindle-picking cotton planted in 38-cm rows has recently been commercialized (Willcutt et al., 2005). This equipment will facilitate harvest of narrow-row cotton without the foreign matter and other fiber quality concerns associated with finger-stripped cotton (McAllister and Rogers, 2005; Vories et al., 2001). Cotton can be planted in 38-cm rows using unit planters which produce consistently better stands than grain drills (Wiatrak et al., 1998). The production system eliminates the need for high plant populations, a significant expense in transgenic, UNR cotton. Research in North Carolina (Wilson et al., 2005) has demonstrated that optimum plant populations for cotton in 38-cm rows are similar to optimum populations in wide-row cotton. No information has been published relative to MC use requirements for cotton in 38-cm rows. The objective of this study was to determine if MC application strategies currently recommended for wide-row cotton are valid for cotton planted in 38-cm rows.

MATERIALS AND METHODS

The experiment was conducted at five locations in North Carolina during 2004 and 2005. Soil types and locations included the following: Dothan loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) in 2004 and Johns sandy loam (fine-loamy, siliceous, semiactive, thermic Aquic Hapludults) in 2005 on the Central Crops Research Station at Clayton; Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) on the Upper Coastal Plain Research at Rocky Mount in 2004 and 2005; and Roanoke sandy loam (fine, mixed, semiactive, thermic Typic Endoaquults) on a private farm at Belhaven. Soil humic matter content was 0.46, 0.19, 0.60, 0.36, and 0.97% at Clayton in 2004, Clayton in 2005, Rocky Mount in 2004, Rocky Mount in 2005, and Belhaven, respectively.

Glyphosate-tolerant cotton cultivar ST 5599BR (Monsanto Co., St. Louis, MO) was planted into 38- and 97-cm rows in conventionally prepared seed beds on 11 May 2004 and 11 May 2005 at Clayton, 10 May 2004 and 12 May 2005 at Rocky Mount, and 16 May 2005 at Belhaven. This cultivar, commonly planted in the southeastern and mid-south regions of the USA (USDA-AMS, 2005), was chosen for its aggressive vegetative growth. Final plant populations, determined by stand counts at the end of the season, averaged 156,100 and 120,650 plants ha^{-1} in the 38- and 97-cm rows, respectively. Plots were 9 m long by six 38-cm rows or four 97-cm rows.

Ninety and 110 kg ha^{-1} of N, as ammonium nitrate, was broadcast prior to planting at Clayton and Rocky Mount, respectively, in 2004. No additional nitrogen was applied during the season. At Clayton and Rocky Mount In 2005, 45 kg ha^{-1} of N, as ammonium nitrate, was broadcast at the pinhead square stage of cotton and repeated 3 wk later. At Belhaven in 2005, 45 kg ha^{-1} of N, as UAN (urea ammonium nitrate), was broadcast prior to planting and repeated with 45 kg ha^{-1} of N, as ammonium nitrate, when cotton was at the pinhead square stage. Aldicarb (Temik insecticide; Bayer CropScience, Research Triangle Park, NC) was applied in the seed furrow at 0.07 g a.i. m^{-1} of row in 2004 to control thrips (*Frankliniella* spp.) and other early season insects. Seed were treated with imidacloprid (Gaucho Grande insecticide; Bayer CropScience) in 2005 at the rate of 0.375 mg a.i. $seed^{-1}$. Acephate (Orthene 97S; Valent Agricultural Products; Walnut Creek, CA) was applied postemergence as needed for additional early season insect control. Mid- and late-season insect management was standard for cotton production in North Carolina. Cotton was kept weed-free during the growing season by pendimethalin (Prowl 3.3 EC herbicide; BASF Ag Products; Research Triangle Park, NC) at 1110 g a.i. ha^{-1} plus fluometuron (Cotoran 4L herbicide; Griffin LLC; Valdosta, GA) at 1120 g a.i. ha^{-1} applied preemergence, glyphosate potassium salt (Roundup WeatherMAX herbicide; Monsanto Co.; St Louis, MO) at 865 g a.e. ha^{-1} applied to one-leaf cotton, and glyphosate at 865 g ha^{-1} plus *S*-metolachlor (Dual Magnum herbicide; Syngenta Crop Protection; Greensboro, NC) at 1390 g a.i. ha^{-1} applied to four-leaf cotton in both row spacings. Cotton in 97-cm rows also received a postemergence-directed application of glyphosate at 865 g ha^{-1} plus diuron (Direx 4L herbicide; Griffin LLC; Valdosta, GA) at 575 g a.i. ha^{-1} when the crop was 46 cm tall. Harvest preparation consisted of defoliation by a mixture of tribufos (DEF 6 defoliant; Bayer CropScience), thiadiazuron (DROPP SC defoliant; Bayer CropScience), and ethephon (Prep defoliant; Bayer CropScience)..

Treatments, arranged in a randomized complete block and replicated four times, included a factorial arrangement of the two row spacings previously mentioned by four MC application strategies. Mepiquat chloride (Pix Plus, BASF Ag Products, Research Triangle Park, NC) was applied according to the LRM, MEB, and EB strategies described by Edmisten (2006). A no-MC check also was included. The LRM strategy consisted of MC at 12 g ha^{-1} applied three times at 2-wk intervals beginning at the first square stage. The MEB strategy consisted of MC at 24 g ha^{-1} applied 2 wk prior to the early bloom stage and repeated at the early bloom stage (defined as one white bloom per m of row). The EB strategy consisted of MC at 24 g ha^{-1} applied at the early bloom stage and repeated 2 wk later. The MC was applied using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (TeeJet XR11002 nozzles; Spraying Systems Co.; Wheaton, IL) and calibrated to deliver 140 L ha^{-1} at 160 kPa.

After defoliation and prior to mechanical harvest, the following variables were recorded from 10 consecutive plants per plot: plant height, total number of mainstem nodes, number of sympodia with one or more bolls (hereafter referred to as fruited sympodia), node number of the first sympodial branch with a retained boll, total number of bolls and aborted positions on sympodial branches, and number of bolls on monopodial branches. Sympodial and monopodial bolls were summed for presentation and expressed as number m^{-2}. Percent sympodial boll retention was calculated from the total number of sympodial bolls and the total number of sympodial fruiting sites. Percent first position boll retention on sympodial branches was similarly calculated from the total number of first position bolls and the total number of first position fruiting sites.

The center four 38-cm rows and the center two 97-cm rows were harvested using a spindle-type picker modified to harvest multiple row spacings (Lanier et al., 2005). An approximate 200-g sample of mechanically harvested seed cotton was collected from each plot and used to determine lint percentage and fiber quality. Seed cotton was ginned on a laboratory gin without lint cleaning, hence cotton grades are not presented as they would not be representative of cotton ginned commercially. However, fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Data were subjected to analysis of variance using the MIXED procedure in SAS (version 9.1; SAS Institute Inc.; Cary, NC) with treatment sums of squares partitioned to reflect the factorial treatment arrangement. Locations were considered as random effects (McIntosh, 1983). Means of significant main effects and interactions were separated using Fisher's Protected LSD at $P = 0.05$ (Saxton, 1998).

RESULTS AND DISCUSSION

Data were pooled over the five locations as there was no treatment by location interaction for any variable examined (Tables 1 and 2). A row spacing by MC interaction also was not observed. However, main effects of row spacing and MC application strategies were significant for some variables.

Vegetative and fruiting characteristics. Cotton in 38-cm rows was 11% shorter than cotton in 97-cm rows (Table 3). The narrow-row cotton had almost one less mainstem nodes per plant and almost two less fruited sympodia per plant. Shorter plants, fewer mainstem nodes, and fewer fruited sympodia have been observed in 38-cm rows in other studies (Nichols et al., 2004; Wilson et al., 2005). The first fruited sympodia was 0.2 nodes higher on plants in the 38-cm rows compared with plants in the 97-cm rows. Fowler and Ray (1997) noted that the node of the first fruited sympodia increased as plant population increased. However, Nichols et al. (2004) did not observe differences between plants in 38- and 101-cm rows with respect to the lowest fruited sympodia. In the current experiment, no difference in overall boll retention was noted between row spacings, but cotton in 38-cm rows had more total bolls per m^2 and a higher percentage of first position sympodial bolls than did cotton in 97-cm rows. A greater percentage of first position sympodial bolls in 38-cm rows, compared with 97-cm rows, has been observed in other studies in North Carolina with similar plant populations (Wilson et al., 2005).

The greater number of bolls per m^2 in 38-cm rows was due primarily to the higher plant population.

Regardless of application strategy, MC reduced plant height (Table 3). Height was reduced to a greater extent with the LRM and MEB strategies (20 and 15%, respectively) than with the EB strategy (12.5%). In other studies with the same cultivar (Craig and Gwathmey, 2005), MC applied before early bloom also caused greater reductions in plant height than MC applied at the early bloom stage. Regardless of application strategy, MC similarly reduced the number of fruited sympodia per plant (7 to 8%), the total number of mainstem nodes per plant (5 to 7%), and total bolls per m^2 (8 to 11%). The first fruited sympodia was 0.2 nodes lower on plants where MC was applied according to the LRM strategy compared to plants that did not receive MC. Mepiquat chloride applied according to the MEB and EB strategies did not lower the node of the first fruited sympodia. This is likely due to the earlier initial MC application with the LRM strategy. Mepiquat chloride had no effect on the percentage of first position sympodial bolls and only minor effects of percent boll retention. Gerik et al. (1985) noted that MC did not affect on the percentage of first position sympodial bolls or boll retention. With little to no difference in percentage boll retention, the reduction in total number of bolls in our experiment was due primarily to fewer fruited sympodia per plant. It has been widely documented that MC decreases the number of main stem nodes in both wide- and narrow-row cotton (Kerby, 1985; Nichols et al., 2003; York 1983a,b). It follows that the total number of fruited sympodia could also be reduced.

Lint yield and fiber quality characteristics. Lint yield was 10% greater in 38-cm rows relative to 97-cm rows (Table 4). Yield also increased as row spacing decreased in other studies (Jost and Cothren, 2000; Nichols et al., 2004; Wilson et al., 2005). Boll weight was not determined in this study. However, the greater yield with 38-cm rows was likely due to the greater number of bolls per m^2 (Table 3) rather than an effect on boll weight. Boll weight generally decreases as plant population increases (Buxton et al., 1978; Wilson et al., 2005), and the population was 29% greater in the 38-cm rows. Worley et al. (1974) observed that bolls per m^2 is the primary component that determines yield potential of cotton. Heitholt et al. (1992) attributed cotton yield increases with narrow rows to greater light interception by the crop canopy. In their work with okra-leaf cultivars, a greater number of bolls per unit land area correlated with greater light interception by plants in narrow rows. They concluded that the yield increase was due to the greater number of bolls and not due to heavier bolls.

Row spacing did not affect lint percentage or fiber micronaire, length, length uniformity, or strength (Table

4). Other researchers have reported a similar lack of effect of row spacing on these fiber quality parameters (Gerik et al., 1998; Hawkins and Peacock, 1973; Jost and Cothren, 2000; Nichols et al., 2004; Smith et al., 1979).

Mepiquat chloride increased cotton lint yields 5% regardless of application strategy (Table 4). It also caused a minor decrease in lint percentage. A similar effect on lint percentage has been observed previously (Cathey and Meredith, 1988; Pettigrew and Johnson, 2005; Stewart et al., 2001), and it has been attributed to a larger seed fraction (McCarty and Hedin, 1994; York 1983a,b). Yield responses to MC have varied in previous studies; yield increases were noted in some studies (Biles and Cothren, 2001; York, 1983a) while no yield response was noted in others (Jones., 2001; Pettigrew and Johnson, 2005; Prince et al., 1998). In a few cases, MC has decreased yield (Crawford, 1981; York, 1983b). Prince et al. (1998) did not observe a yield response to MC in 38- and 97-cm cotton.

Mepiquat chloride did not affect fiber micronaire, fiber length uniformity, or fiber strength (Tables 2 and 4). In other studies, mepiquat chloride has increased micronaire (Kerby, 1985; York 1983a), decreased micronaire (York 1983b), and had no effect on micronaire (Cathey and Meredith, 1988; Nichols et al., 2003; Pettigrew and Johnson, 2005). Mepiquat chloride caused a minor increase in fiber length. Minor increases in fiber length have previously been observed in MC-treated cotton (York, 1983a).

Lack of interaction between row spacing and MC application strategies indicates cotton in 38-cm rows responds to MC similarly to cotton in traditional wide rows. Thus, current MC recommendations for wide-row cotton in North Carolina (Edmisten, 2006) are appropriate for cotton in 38-cm rows. Regardless of row spacing, MC increased lint yields 5%. The LRM and MEB strategies controlled plant height more effectively than the EB strategy, but cotton yields were similar with all MC application strategies. A 10% yield increase was noted with 38-cm rows. However, increased harvesting costs, due primarily to fewer hectares covered by a picker equipped to harvest 38-cm rows as compared with 97- to 102-cm rows, may negate any economic benefits associated with 38-cm rows (Spurlock et al., 2006).

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Table 1. Analysis of variance for vegetative and fruiting characteristics of cotton as affected by row spacing and mepiquat chloride

		Height		Number of main stem nodes		Node of first fruited sympodia		Number of fruited sympodia		Percent boll retention		Number of total bolls		Percent first position bolls	
Source[x]	df	MS[y]	P > F[z]	MS	P > F	MS	P > F	MS	P > F	MS	P > F	MS	P > F	MS	P > F
Loc	4	197.61	<0.0001	63.09	<0.0001	43.40	<0.0001	16.49	<0.0001	6941.61	<0.0001	8982.85	<0.0001	1684.91	<0.0001
Rep(loc)	14	3.16	0.0004	1.93	0.0001	0.47	0.0004	2.16	<0.0001	295.26	<0.0001	647.25	0.0126	58.36	0.0879
RS	1	58.06	<0.0001	28.92	<0.0001	0.56	0.0198	37.40	<0.0001	27.94	0.2980	4498.25	<0.0001	1660.40	<0.0001
Loc*RS	4	2.41	0.0639	5.11	0.0712	0.71	0.0646	4.62	0.0712	239.76	0.1827	601.35	0.0693	188.05	0.0810
MC	3	28.76	<0.0001	11.18	<0.0001	0.40	0.0302	7.41	<0.0001	71.42	0.0458	1071.83	0.0052	33.84	0.3216
Loc*MC	12	5.05	0.0651	1.44	0.0641	0.22	0.1411	1.33	0.4047	33.87	0.1881	463.62	0.7420	51.65	0.1650
RS*MC	3	0.13	0.9680	0.37	0.7076	0.03	0.7538	0.40	0.5264	9.88	0.7587	290.42	0.3407	12.95	0.8577
Loc*RS*MC	12	1.01	0.4447	0.58	0.3917	0.30	0.0785	0.41	0.6360	26.31	0.3914	309.82	0.3743	38.17	0.4045
Error	98	11.39		0.54		0.15		0.51		24.54		293.00		36.10	

[x] **Abbreviations: Loc, locations; Rep, replications; RS, row spacing; MC, mepiquat chloride strategies.**

[y] **MS, mean square.**

[z] **P > F, probability > F.**

Table 2. Analysis of variance for lint yield, lint percentage, and fiber quality characteristics as affected by row spacing and mepiquat chloride

		Lint yield		Lint percentage		Micronaire		UHM length		Uniformity		Fiber strength	
Source[x]	**df**	**MS[y]**	**P > F[z]**	**MS**	**P > F**	**MS**	**P > F**	**MS**	**P > F**	**MS**	**P > F**	**MS**	**P > F**
Loc	4	2352995	<.0001	19.53	<.0001	1.93	<.0001	0.02	<.0001	22.2	<.0001	89.9	<.0001
Rep(loc)	14	112561	<.0001	0.81	0.5278	0.14	0.0062	0.00	0.1060	1.34	0.0636	1.24	0.6742
RS	1	1153060	<.0001	0.10	0.7180	0.10	0.2310	0.00	0.8049	0.02	0.8158	1.09	0.5506
Loc*RS	4	184120	0.1014	1.28	0.2164	0.20	0.1052	0.00	0.1597	0.92	0.3251	3.33	0.0820
MC	3	89818	0.1027	3.80	0.0038	0.08	0.2685	0.00	0.0011	1.71	0.2514	1.5	0.5093
Loc*MC	12	14926	0.0601	0.95	0.3735	0.05	0.6421	0.00	0.2197	1.51	0.3826	0.99	0.8032
RS*MC	3	6940	0.6088	0.54	0.5286	0.08	0.3334	0.00	0.8230	1.32	0.0794	1.29	0.3590
Loc*RS*MC	12	34421	0.0740	1.15	0.2208	0.08	0.1888	0.00	0.0739	1.88	0.0921	1.91	0.2750
Error	98	28144		0.87		0.05				0.78		1.56	

[x] Abbreviations: Loc, locations; Rep, replications; RS, row spacing; MC, mepiquat chloride strategies.

[y] MS, mean square.

[z] P > F, probability > F.

Table 3. Main effects of row spacing and mepiquat chloride (MC) application strategy on vegetative and fruiting characteristics of cotton[x]

Main effect	Height (cm)	Mainstem nodes (no. plant^{-1})	Node of first fruited sympodia	Fruited sympodia (no. plant^{-1})	Boll retention (%)[y]	Total bolls (no. m^{-2})	First position bolls (% of total)
Row spacing (cm)							
38	33 b	16.3 b	6.3 a	9.1 b	49 a	119 a	77 a
97	37 a	17.1 a	6.1 b	10.9 a	50 a	107 b	70 b
MC strategy[z]							
LRM	32 d	16.4 b	6.1 b	10.1 b	50 ab	111 b	73 a
MEB	34 c	16.3 b	6.2 ab	10.1 b	51 a	112 b	74 a
EB	35 b	16.6 b	6.2 ab	10.2 b	49 b	109 b	73 a
Non-treated	40 a	17.5 a	6.3 a	11.0 a	49 b	122 a	72 a

[x] Data for row spacing averaged over years, locations, and mepiquat application strategies; data for mepiquat chloride application strategies averaged over years, locations, and row spacings. Means within a column and main effect followed by the same letter are not different based on Fisher's Protected LSD test at *P* = 0.05.

[y] Percent boll retention is based on all sympodia and positions.

[z] Mepiquat chloride (MC) application strategies are low rate multiple (LRM), modified early bloom (MEB), and early bloom (EB).

Table 4. Main effects of row spacing and mepiquat chloride (MC) application strategy on lint yield, lint percentage, and fiber quality characteristics of cotton[y]

Main effect	Lint yield (kg ha^{-1})	Lint per-centage (%)	Micro-naire	UHM length (cm)	Uniformity index (%)	Strength (kN mg kg^{-1})
Row spacing (cm)						
38	1880 a	44.1 a	4.9 a	2.81 a	82.5 a	299 a
97	1710 b	44.1 a	4.8 a	2.81 a	82.5 a	301 a
MC strategy[z]						
LRM	1820 a	44.0 b	4.8 a	2.82 a	82.5 a	300 a
MEB	1820 a	43.9 b	4.9 a	2.84 a	82.6 a	302 a
EB	1820 a	44.0 b	4.8 a	2.82 a	82.7 a	300 a
Non-treated	1730 b	44.6 a	4.9 a	2.79 b	82.5 a	298 a

[y] Data for row spacing averaged over years, locations, and mepiquat chloride application strategies; data for mepiquat chloride application strategies averaged over years, locations, and row spacings. Means within a column and main effect followed by the same letter are not different based on Fisher's Protected LSD test at $P = 0.05$.

[z] Mepiquat chloride (MC) application strategies are low rate multiple (LRM), modified early bloom (MEB), and early bloom (EB).

CHAPTER VII

Doveweed (*Murdannia nudiflora*) germination and emergence as affected by temperature and seed burial depth

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Laboratory and greenhouse experiments were conducted to determine the effect of temperature and seed burial depth on doveweed germination and emergence. Germination at constant temperature was well defined by a Gaussian model, which estimated peak germination at 28 C. However, based upon t-tests the effect of temperature treatments between 25 and 30 C did not differ. The mean base temperature for germination (50%) was between 20 and 25 C. Similar maximum percent germination was observed for optimal treatments under both constant and alternating temperatures. Among alternating temperature treatments, 35/25 C regime gave the highest germination (77%). Germination was higher with alternating temperature regimes of 40/30 and 40/35 C (65 and 30%, respectively) than constant temperatures of 36 and 38 C (4 and 0%, respectively). No germination was observed at constant temperature of 38 C and alternating temperature regimes of 20/10 and 25/15. Light did not facilitate germination. In depth of emergence experiments, peak emergence was reached 2 wk after planting regardless of burial depth. Peak emergence was between 0 and 1 cm at 4 weeks after planting, and occurred from as deep as 4 cm. The mean emergence depth was 3.2 cm. Knowledge gained from this research will aid in an integrated weed management strategy for doveweed.

Nomenclature: Doveweed, *Murdannia nudiflora* (L.) Brenan MUDNU.

Key Words: Commelinaceae, dayflower, light, weed biology.

Doveweed (*Murdannia nudiflora*) is an invasive species in the U.S. from Texas to North Carolina, and is native to tropical Asia where it is a conmon weed in rice (Faden 1982; Faden 2000; Thi Tan et al. 2000). It has been considered as one of the top three major weed species worldwide of the family *Commelinaceae*, and occurs in as many as 17 crops in 26 countries (Holm et al. 1977; Wilson 1981). In the U.S. it has historically been a problematic weed in turfgrass systems, but has become increasingly more common in North Carolina row-crop production. This is mostly due to the widespread adoption of glyphosate-resistant (GR) crops, which has allowed producers to eliminate soil-applied herbicides and abandon tillage and cultivation (Culpepper and York 1999, 2000).

Herbicides have become the primary, and sometimes only, method of weed control with some systems receiving applications of only glyphosate alone during the growing season (Culpepper et al. 2004). Although glyphosate is a broad-spectrum herbicide for control of annual grasses and broadleaved weed species, doveweed and other members of the *Commelinaceae* are not adequately controlled with glyphosate programs (Culpepper et al. 2004; York and Culpepper, 2006). In light of all the system changes that have taken place in North Carolina row-crop production since the adoption of GR row crops, doveweed has become a concern for North Carolina producers.

Doveweed has also been observed to be an alternate host for root-knot (*Meloidogyne* spp.) and lesion (*Pratylenchus* spp.) nematodes (Valdez 1968). It also serves as an alternate host for Pythium root rot (*Pythium arrhenomanes*), which occurs in many row crops in the U.S. such as cotton, corn, soybeans, sugarcane, rice, and wheat (Deep and Lipps 1996; Lee and Hoy 1992; Sideris 1931; Wilson 1981). If left uncontrolled, the presence of this weed could potentially pose more of a problem in row-crop production than from just a competition standpoint.

Like most members of the family *Commelinaceae*, doveweed is a perennial of tropical climates, but grows as an annual in temperate climates (Holm et al. 1977). The leaves are linear to lanceolate, and the sheaths are ciliated and tubular (Radford 1968). The stem can be erect or creeping, and always branching. The inflorescence is a cyme which can be terminal or axillary. The flowers are always zygomorphic in symmetry with three free petals and three free sepals (the petals and sepals are not fused). The petals are blue or violet in color, and the fruit is a three-celled capsule with two seeds per cell (Radford 1968).

Studies conducted on related taxa (tropical spiderwort; *Commelina benghalensis*) identified the optimal temperature for vegetative growth and flower production was between 30 and 35 C, but growth occurred over a range of 20 to 40 C (Burton et al. 2003). Doveweed has been observed to emerge late in the growing season in North Carolina, which subjects it to reduced herbicide exposure, especially in cotton production. To date, there is little published research on the biological aspects of doveweed. Therefore, the overall objective of our study was to develop a better understanding of some of the requirements for germination and emergence of doveweed to aid in the development of an integrated management strategy. The specific objectives were to (1) determine temperature and light requirements for germination; and (2) quantify the effects of seed burial depth on emergence from a common soil type found in North Carolina.

Materials and Methods

Doveweed seed was hand-harvested in Wayne county near Goldsboro, NC, on October 18, 2004. The field in which the seed were collected had been in a soybean-corn rotation. Seed was separated from capsules by hand and allowed to dry for 2 weeks at 25 C and then stored at 5 C until use in experiments. Seed was sieved to remove any extraneous plant or foreign matter. The sieved seed were then put into an air-column separator[1] to separate the light and heavy fractions and extra foreign matter not removed by sieving. The heavy fraction, the majority of which were fully developed seed, was used in the germination and emergence experiments. A preliminary study revealed germination to be 7% at 30 C for 14 d (Table A-7.1). Therefore, seed were gently scarified for 25 s using medium-grade emery cloth. A small subsample of approximately 100 seeds were scarified at a time to ensure uniform contact between each seed and the emery cloth. Seed was scarified immediately before use in each experiment.

Effect of Temperature and Light

The effect of constant temperature was evaluated by evenly spacing 50 scarified doveweed seeds in 100 by 80 mm glass dishes[2] with two pieces of filter paper[3] placed on top of 325 g of steam-sterilized gravel and filled with 28 ml of deionized water. Flasks were covered with a watch glass, and sealed using parafilm to retain moisture. The flasks were arranged on a gradient table (Larson 1971) in eight lanes corresponding to a constant temperatures of 15, 20, 25, 28, 30, 33, 36, and 38 C, with four flasks per lane in which each flask served as a replicate. Randomization was not possible as the zones of temperature were fixed in position. Light was provided by fluorescent overhead bulbs set for 14 h light and 10 hr dark. Germination counts were made 2, 4, 6, and 14 d after experiment initiation. Each seed was considered to have germinated when the cotyledonary stalk had protruded 1 mm through the seedcoat, and the seed was removed from the dish. The experiment was conducted three times and the data were combined for analysis.

The effect of alternating temperature and light was evaluated by evenly spacing 50 scarified seed placed on two sheets of filter paper in 9 cm petri dishes. The filter paper was moistened initially with 4 ml of deionized water. If necessary, 1 to 5 ml of deionized water was added to maintain adequate moisture during the course of the experiment. All dishes were placed in polyurethane bags[4] to slow dessication. The experiment was conducted in temperature- and light-controlled growth chambers. Dishes were placed in a completely randomized design within each chamber with four replications, each of which was arranged on a different shelf within each respective chamber. Alternating day/night temperatures of 20/10, 25/15, 30/20, 35/25, 40/30, and 40/35 C were maintained for 12 h each. A 14 h daily photoperiod was maintained in each chamber, with the light period extending from 1 h before to 1 h after exposure to the daily high temperature. Fluorescent lamps produced a photosynthetic photon flux of 150 µmol m^{-2} s^{-1}. Dishes assigned to dark treatments were wrapped in two layers of aluminum foil and remained unopened until the final day of the experiment. Germination counts for seed exposed to light and dark were made at 7 d after experiment initiation. Each seed was considered germinated when the cotyledonary stalk had protruded 1 mm through the seedcoat, and the seeds were removed from the dish. The study was conducted three times and the data were combined for analysis.

Depth of Emergence

The effect of seed burial depth on doveweed germination was conducted in a greenhouse using a steam-sterilized Norfolk loamy sand soil (fine-loamy, siliceous, thermic, Typic Kandiudults; 85% sand, 9% silt, and 6% clay; pH 5.4, and 0.8% OM), which is similar to soils in which row-crops are grown in North Carolina. Fifty scarified seeds were planted in 4.5 L pots containing at depths of 0, 1, 2, 4, 6, and 10 cm. Pots were gravimetrically filled with sieved soil and then placed on the greenhouse bench in a randomized complete block design. Each pot contained approximately 4200 cm^3 of soil. Pots were watered initially by overhead sprinkler, and as needed by sub-irrigation afterwards. This watering method was used to reduce the effect of soil crusting. Greenhouse temperatures averaged 33 ± 2 C during the day and 24 ± 2 C at night. Natural light supplemented with fluorescent lamps at a intensity of 300 ± 20 µmol m^{-2} s^{-1} was used to extend light duration to 14 h to simulate summer field conditions. Emergence was monitored weekly for 4 weeks. Emerged seedlings were counted and then removed. The experiment was conducted three times and data combined for analysis.

Statistical Analysis

Data variance was visually inspected by plotting residuals to confirm homogeneity of variance before statistical analysis. Both nontransformed and arcsine-transformed data were examined, and transformation did improve homogeneity. Data were then subjected to analysis of variance using the MIXED procedure in SAS (2000) to assess all main effects and their interactions based on transformed data. Non-linear equations were used to fit the data for the constant temperature and depth of burial experiments. A coefficient of determination was calculated for the depth of emergence data to assess differences in observed and predicted responses, and standard errors were calculated for observed means. Mean emergence depth (which 50% germination occurs) was calculated from the regression curve that described emergence as a function of depth. Approximate R^2 values for all non-linear models were calculated by subtracting the ratio of the residual sums of squares to the corrected total sums of squares from one (Draper and Smith 1981). There were not run by treatment interactions observed for any experiments, therefore all data are averaged over runs (McIntosh 1983). Additionally, there was no light treatment by temperature regime interaction observed for the alternating temperature study, and thus data were averaged over both light and dark treatments. Untransformed data are presented for the constant temperature and depth of burial experiments. In the alternating temperature experiment, means based on the transformed data were separated using Fisher's Protected LSD at $P = 0.05$ (Saxton, 1998).

Results and Discussion

Effect of Temperature and Light

When exposed to constant temperature treatments ranging from 25 to 33 C, germination was observed 2 days after trial initiation (Figure A-7.1). Tropical spiderwort (*Commelina benghalensis*), a closely related species to doveweed, did not germinate when placed on moist filter paper until after 2 d, irrespective of temperature (Matsuo et al. 2004). Based upon cumulative germination at 14 d, the optimum temperature for germination estimated by a Gaussian model was 27.8 C (Figure 1). Mean percent germination at constant temperatures of 25, 28, and 30 C was 66, 74, and 67%, respectively. However, according to results of t-tests, percent germination did not differ ($P>t = 0.0812$) among these temperatures. Germination declined rapidly with increasing temperature above the optimum of 28 C. At 36 C, germination was only 5% and none was observed at 38 C, indicating that the maximum temperature for germination is between this range. Germination of aerial tropical spiderwort seeds has been observed to occur between 25 and 30 C (Gonzalez and Haddad 1995).

Percent germination was similar after exposure to alternating temperatures for 7 d was similar to that of seeds exposed to constant temperature for 6 d. No germination occurred in alternating temperature regimes of 20/10 or 25/15 C. However, a 5 C increase in the daily maximum and minimum temperature to 30/20 C resulted in at least 71% cumulative germination at 7d (Table 1). Germination was highest at 35/25 C, and decreased as maximum and minimum temperature were further increased. The mean daily temperature for this regime is close to the 28 C optimum that was observed in the constant temperature experiment. However, germination at temperature regimes of 40/30 and 40/35 C (mean of 35 and 38 C, respectively) was higher than at constant temperatures of 36 and 38 C (Table 1 and Figure 1). This is may be due to the daily minimum temperatures being closer to the optima of 28 C (Baskin and Baskin 1998; Thompson and Grime 1983). There were no germination differences within each temperature regime between light and dark ($P = 0.1027$), which suggests that light does not facilitate germination of scarified seed. Also, it has been observed by others that light is not a requirement for closely related taxa (i.e. tropical spiderwort) germination (Gonzalez and Haddad 1995).

Depth of Emergence

Doveweed emergence from continually moist soil was first observed at 1 wk and peaked at 2 wk, with emergence occuring from depths of 0 to 4 cm (Figure A-7.2). Thus, burial depth had minimal effect on the emergence rate of doveweed seeds. The same trend was noted at 4 wk, with emergence ranging from depths of 0 to 6 cm (Figure 2). Doveweed emergence decreased as seed burial depth increased. Total emergence at depths of 0, 1, 2, 4, and 6 cm was 62, 59, 46, 23, and 1%, respectively. The mean (50%) emergence depth was 3.2 cm (Figure 2). No emergence was observed at depths greater than 6 cm. Emergence of tropical spiderwort has been observed from depths from 0 to 5 cm, with no emergence from depths greater than 5 cm (Matsuo et al. 2004). Depth-mediated doveweed emergence inhibition was well described by a logistical model, with the greatest emergence occurring from the soil surface. This trend has been observed in other weed species, in that greater emergence is often from the soil surface when conditions are favorable for germination (Benvenuti et al. 2001). Seedling emergence for some species has been shown to decrease with increasing burial depths (Norsworthy and Oliveira 2005; Shaw et al. 1987; Thomas et al. 2006). Doveweed seed size is small (1.4 to 1.8 mm in length and 1 to 1.3 mm in width), and is very similar to other species of the genus *Commelinaceae* (Faden, 1982). Therefore, as with other small seeded weeds such as *Amaranthus* spp., depth of emergence is likely limited by a small supply of stored resources to support growth (Baskin and Baskin 1998).

Germination of doveweed is strongly influenced by temperature, and the mid-Atlantic, Southeastern, and Mid-Southern U.S. provides an adequate environment for germination to occur. Additionally, light is a not a major germination factor and could occur after canopy closure in most row-crops that are grown in the southeastern and mid-southern U.S. Our data suggest also suggest that for soils common in the coastal plain region of North Carolina, doveweed emergence is severely inhibited by burial. It is likely that greater emergence would occur in a no-tillage or a shallow tillage system compared with a system that employs occasional deep tillage. With the increasing adoption of reduced- and no-tillage systems in the Southeast, coupled with its tolerance to glyphosate, doveweed will likely become more of a problem weed in cotton, soybean, and double-cropped wheat and soybean production.

Sources of Materials

[1] Seed blower, Seedburo Equipment Company, 1022 West Jackson Boulevard, Chicago, IL 60607.

[2] Pyrex brand storage dish, Fisher Scientific, P.O. Box 4829, Norcross, GA 30091.

[3] Whatman #3 filter paper, Fisher Scientific, P.O. Box 4829, Norcross, GA 30091.

[4] Polyurethane bags, Tenneco Packaging Specialty Products Group, 1900 West Field Court, Lake Forest, IL 60045.

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Table 1. Effect of alternating temperatures on germination of doveweed at 7 d after trial initiation.[a]

Temperature	Germination[b]
C	%
20/10	0 g
25/15	0 g
30/20	72 b
35/25	77 a
40/30	65 c
40/35	30 d

[a] Data are averaged over runs. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at *P* = 0.05.

[b] Percent of seed tested.

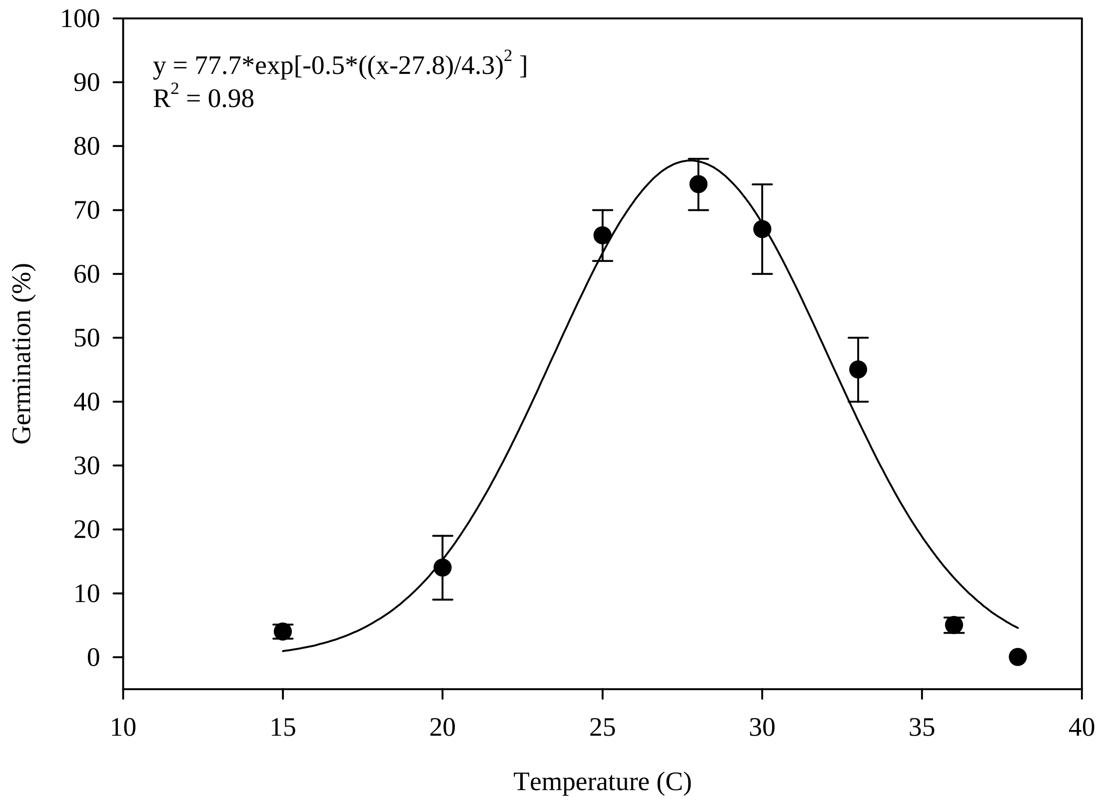

Figure 1. Effect of constant temperature on cumulative germination of doveweed over 14 d. Bars represent standard error of the mean.

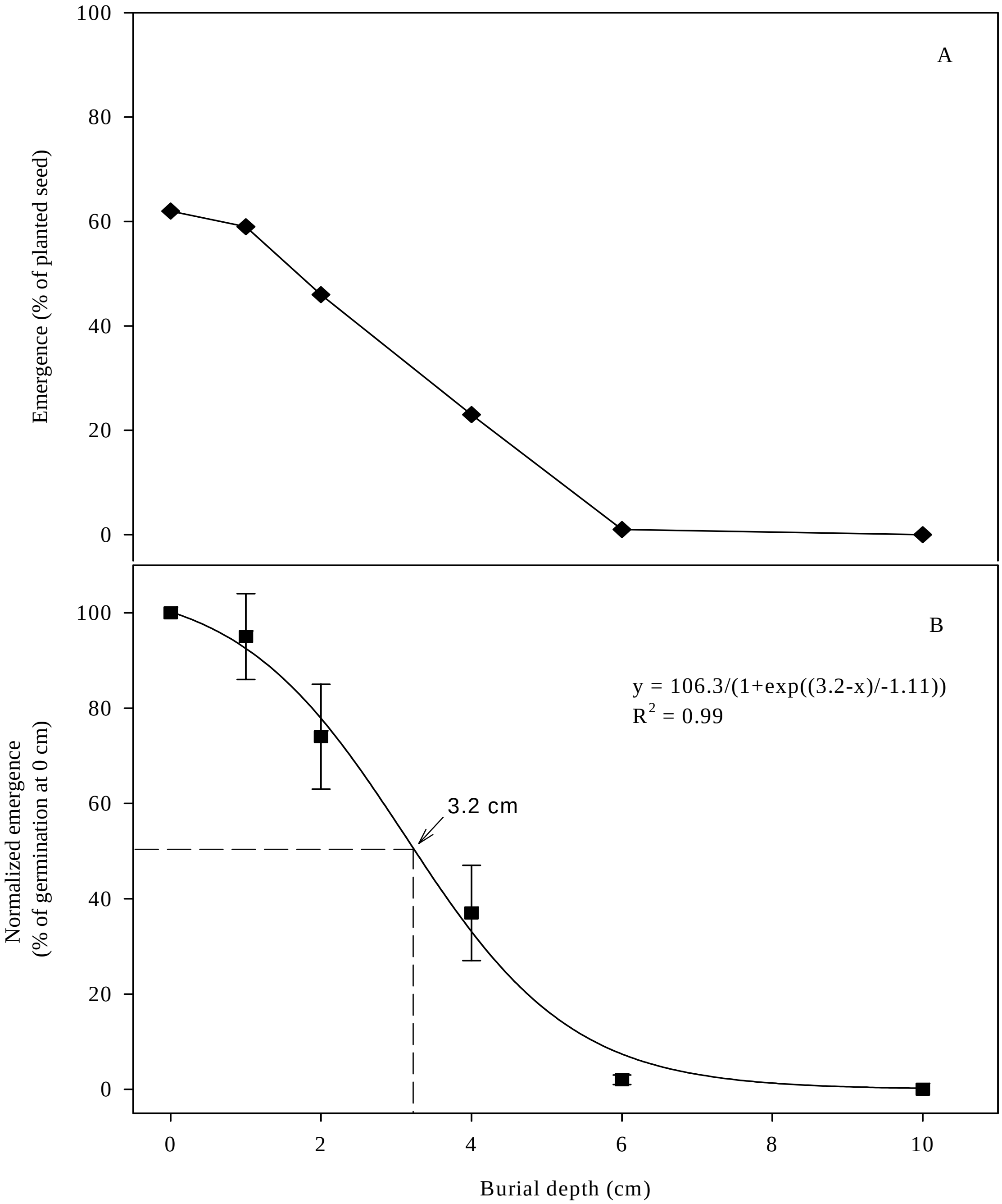

Figure 2. Effect of seed burial depth on cumulative doveweed emergence from the percentage of planted seed (A), and on normalized observed and predicted emergence and the mean emergence depth (B) at 4 wk after planting. Bars represent standard error of the mean.

APPENDIX

Table A-2.1. Late-season control in 2005 of *Amaranthus* spp. in glufosinate-resistant cotton.[a]

Preemergence herbicides[b]	Mid-postemergence herbicides[c]	*Amaranthus* spp.[d] 2005 38-cm rows	97-cm rows
		%	
None	Glufosinate	88 b	96 a
Pendimethalin	Glufosinate	100 a	100 a
Pendimethalin + fluometuron	Glufosinate	100 a	100 a
Pendimethalin + pyrithiobac	Glufosinate	100 a	100 a
Pendimethalin	Glufosinate + *S*-metolachlor	100 a	100 a
Pendimethalin	Glufosinate + pyrithiobac	100 a	100 a

[a] All treatments received glufosinate applied early postemergence at 468 g/ha to two-leaf cotton. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at P = 0.05.

[b] Pendimethalin, fluometuron, and pyrithiobac applied preemergence at 1110, 1120, and 48 g/ha, respectively.

[c] Glufosinate, *S*-metolachlor, and pyrithiobac applied mid-postemergence to six-leaf cotton at 468, 1387, and 48 g/ha, respectively.

[d] Data averaged over two locations, with Palmer amaranth at one location and smooth pigweed at the second location.

Table A-2.2. Mid- and late-season crop injury as influenced by herbicide applications in glufosinate-resistant cotton.[a]

Herbicides		Injury	
Preemergence[b]	Mid-postemergence[c]	2 wk MPOST	Late-season
		%	
None	Glufosinate	0 c	0
Pendimethalin	Glufosinate	0 c	0
Pendimethalin + fluometuron	Glufosinate	0 c	0
Pendimethalin + pyrithiobac	Glufosinate	0 c	0
Pendimethalin	Glufosinate + *S*-metolachlor	5 b	0
Pendimethalin	Glufosinate + pyrithiobac	13 a	0

[a] Data averaged over two row spacings, years, and locations. All treatments received glufosinate applied early postemergence at 468 g/ha to two-leaf cotton. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] Pendimethalin, fluometuron, and pyrithiobac applied preemergence at 1120, 1120, and 48 g ai/ha, respectively.

[c] Glufosinate, *S*-metolachlor, and pyrithiobac applied mid-postemergence to six-leaf cotton at 468, 1420, and 48 g ai/ha, respectively.

Table A-2.3. Fiber characteristics as influenced by herbicide systems in glufosinate-resistant cotton.

Herbicides[b]		Lint	Fiber characteristics[c]			
Preemergence[d]	Mid-postemergence[e]	percentage	Mic	UHM	UI	Strength
						kN
		%		cm	%	mg/kg
None	Glufosinate	41.2 a	4.86 a	2.85 a	83 a	307 a
Pendimethalin	Glufosinate	42.2 a	4.95 a	2.85 a	83 a	310 a
Pendimethalin + fluometuron	Glufosinate	42.1 a	5.00 a	2.86 a	83 a	311 a
Pendimethalin + pyrithiobac	Glufosinate	41.6 a	4.98 a	2.86 a	83 a	311 a
Pendimethalin	Glufosinate + *S*-metolachlor	41.8 a	4.96 a	2.87 a	83 a	311 a
Pendimethalin	Glufosinate + pyrithiobac	41.5 a	4.92 a	2.84 a	83 a	309 a
Mean		41.7	4.95	2.85	83	310

[a] Data averaged over two row spacings, two years, and four locations. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] All treatments included glufosinate applied early postemergence at 468 g ai/ha to two-leaf cotton. All treatments to cotton in 97-cm rows included trifloxysulfuron + prometryn + MSMA at 1098 + 9.8 + 2220 g ai/ha applied postemergence-directed to 46-cm cotton. Data for cotton in 38-cm rows averaged over 0 and 5.3 g ai/ha of trifloxysulfuron applied late-postemergence to 11-leaf cotton.

[c] Mic, micronaire; UHM, upper-half mean length; UI, uniformity index.

[d] Pendimethalin, fluometuron, and pyrithiobac applied preemergence at 1120, 1120, and 48 g ai/ha, respectively.

[e] Glufosinate, *S*-metolachlor, and pyrithiobac applied mid-postemergence to six-leaf cotton at 468, 1420, and 48 g ai/ha, respectively.

Table A-3.1. Weed density in nontreated checks at experiment sites.

	2004	2005
Locations and weed species	Weed density	Weed density
	No./m^2	No./m^2
Clayton		
goosegrass	10	48
broadleaf signalgrass	5	12
fall panicum	2	13
tall morningglory	11	8
pitted morningglory	4	10
Palmer amaranth	6	8
Rocky Mount		
goosegrass	14	16
broadleaf signalgrass	12	15
large crabgrass	5	3
tall morningglory	8	28
pitted morningglory	4	18
smooth pigweed	10	28

Table A-3.2. Control of annual grasses, *Ipomoea* spp., and *Amaranthus* spp. 3 wk after MPOST applications in 38 cm glyphosate-resistant cotton.[a]

Herbicides[c, d]		Control[b]				
		Annual grasses		*Ipomoea* spp.		*Ipomoea* spp.
PRE	MPOST	2004	2005	2004	2005	
		%				
None	Glyp	85 d	99 a	92 b	97 a	97 a
	Glyp + Metol	100 a	100 a	95 ab	97 a	100 a
	Glyp + Pyri	94 c	99 a	96 a	97 a	99 a
Pend + Fluo	Glyp	94 c	100 a	94 ab	95 a	100 a
	Glyp + Metol	99 a	100 a	95 ab	97 a	100 a
	Glyp + Pyri	98 ab	100 a	96 a	98 a	100 a
Pend + Pyri	Glyp	94 c	100 a	94 ab	98 a	100 a
	Glyp + Metol	100 a	100 a	94 ab	96 a	100 a
	Glyp + Pyri	95 bc	100 a	97 a	98 a	100 a

[a] Data are pooled over like treatments. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] Data for annual grasses and morningglories are pooled over locations. Data for pigweed species are pooled over years and locations. Annual grasses consisted of a mixture of goosegrass, broadleaf signalgrass, and fall panicum at Clayton, and goosegrass, broadleaf signalgrass, and large crabgrass at Rocky Mount. Pigweed species consisted of Palmer amaranth at Clayton, and smooth pigweed at Rocky Mount. Morningglory species consisted of a mixture of tall morningglory and pitted morningglory at both locations.

[c] Systems not including a PRE herbicide received an early POST application of glyphosate at 1.1 kg ai/ha when cotton was in the 1-leaf stage.

[d] Abbreviations and herbicide rates: Pend., pendimethalin (1.1 kg ai/ha); fluo., fluometuron (1.1 kg ai/ha); glyp, glyphosate (1.1 kg ai/ha), pyri., pyrithiobac (48 g ai/ha, PRE and POST); metol, *S*-metolachlor (1.4 kg ai/ha).

Table A-3.3. Row spacing and herbicide system effect on control of annual grasses, *Ipomoea* spp., and *Amaranthus* spp. 3 wk after MPOST applications in 38 and 97 cm glyphosate-resistant cotton.[a]

Herbicides[c, d]			Control[b]				
			Annual Grasses		*Ipomoea* spp.		
Row Spacing (cm)	PRE	MPOST	2004	2005	2004	2005	*Amaranthus* spp.
			%				
38	None	Glyp	85 c	99 a	92 bc	97 a	97 a
	None	Glyp + Metol	100 a	100 a	96 a	97 a	100 a
	None	Glyp + Pyri	94 b	99 a	96 a	97 a	99 a
	Pend + Fluo	Glyp	94 b	100 a	94 abc	95 a	100 a
	Pend + Pyri	Glyp	94 b	100 a	94 abc	98 a	99 a
97	None	Glyp	83 c	100 a	90 c	96 a	97 a
	None	Glyp + Metol	100 a	100 a	93 bc	97 a	100 a
	None	Glyp + Pyri	93 b	100 a	96 a	98 a	100 a
	Pend + Fluo	Glyp	94 b	100 a	94 abc	95 a	99 a
	Pend + Pyri	Glyp	95 b	100 a	93 bc	96 a	99 a

[a] Data are pooled over like treatments. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at P = 0.05.

Table A-3.3. Continued

[b] Data for annual grasses and morningglories are pooled over locations. Data for pigweed species are pooled over years and locations. Annual grasses consisted of a mixture of goosegrass, broadleaf signalgrass, and fall panicum at Clayton, and goosegrass, broadleaf signalgrass, and large crabgrass at Rocky Mount. Pigweed species consisted of Palmer amaranth at Clayton, and smooth pigweed at Rocky Mount. Morningglory species consisted of a mixture of tall morningglory and pitted morningglory at both locations.

[c] Systems not including a PRE herbicide received an EPOST application of glyphosate at 1.1 kg ai/ha when cotton was in the 1-leaf stage.

[d] Abbreviations and herbicide rates: Pend., pendimethalin (1110 g ai/ha); fluo., fluometuron (1120 g ai/ha); glyp, glyphosate (1120 g ai/ha), pyri., pyrithiobac (48 g ai/ha, PRE and POST); metol, *S*-metolachlor (1387 g ai/ha).

Table A-3.4. Late-season control of *Amaranthus* spp. in 38- and 97-cm glyphosate-resistant cotton.[a]

	Herbicides[b,c]		Control[d]
Row spacing (cm)	PRE	MPOST	*Amaranthus* spp.
			%
38	None	Glyp	98 a
	None	Glyp + Metol	99 a
	None	Glyp + Pyri	99 a
	Pend + Fluo	Glyp	99 a
	Pend + Pyri	Glyp	99 a
96	None	Glyp	98 a
	None	Glyp + Metol	98 a
	None	Glyp + Pyri	99 a
	Pend + Fluo	Glyp	99 a
	Pend + Pyri	Glyp	99 a

[a] Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[b] Systems not including a PRE herbicide received an EPOST application of glyphosate at 1120 g ai/ha when cotton was in the 1-leaf stage. All systems in both row spacings received a LPOST application of trifloxysulfuron (38-cm rows; topical) or trifloxysulfuron plus prometryn plus MSMA (97-cm rows; directed).

[c] Abbreviations and herbicide rates: Pend., pendimethalin (1110 g ai/ha); fluo., fluometuron (1120 g ai/ha); glyp, glyphosate (1120 kg ai/ha), pyri., pyrithiobac (48 g ai/ha, PRE and POST); metol, *S*-metolachlor (1387 g ai/ha); Trif, trifloxysulfuron (5.3 g ai/ha).

[d] Data for pigweed species are pooled over years and locations. Species consisted of Palmer amaranth at Clayton, and smooth pigweed at Rocky Mount.

Table A-3.5. Crop injury as affected by mid-POST herbicide applications 3 wk after treatment in 38 and 97 cm glyphosate-resistant cotton.[a]

	Herbicides[b, c]		
Row Spacing (cm)	PRE	Mid-POST	Injury[d]
			%
38	None	Glyp	0 c
	None	Glyp + Metol	1 b
	None	Glyp + Pyri	5 a
	Pend + Fluo	Glyp	0 c
	Pend + Fluo	Glyp + Metol	1 b
	Pend + Fluo	Glyp + Pyri	7 a
	Pend + Pyri	Glyp	0 c
	Pend + Pyri	Glyp + Metol	1 b
	Pend + Pyri	Glyp + Pyri	8 a
97	None	Glyp	0 c
	None	Glyp + Metol	1 b
	None	Glyp + Pyri	6 a
	Pend + Fluo	Glyp	0 c
	Pend + Pyri	Glyp	0 c

[a] Data are pooled over like treatements, years, and locations. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[c] Systems not including a PRE herbicide received an EPOST application of glyphosate at 1.1 kg ai/ha when cotton was in the 1-leaf stage.

[d] Abbreviations and herbicide rates: Pend., pendimethalin (1110 g ai/ha); fluo., fluometuron (1120 g ai/ha); glyp, glyphosate (1120 g ai/ha), pyri., pyrithiobac (48 g ai/ha, PRE and POST); metol, *S*-metolachlor (1387 g ai/ha).

Table A-3.6. Row spacing influence on fiber characteristics.[a, b]

Row spacing (cm)	Micronaire	Length	Length Uniformity	Strength
		cm	%	kN m/kg
38	4.65 a	2.82 a	83.1 a	301 a
97	4.73 a	2.82 a	82.9 a	307 a
Mean	4.69	2.82	83	304

[a] Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test at $P = 0.05$.

[b] Data are pooled over years, locations, and herbicide systems.

Table A-4.1. Weekly rainfall for 12 wk after planting of cotton in 2004 and 2005.

	Rainfall (cm)			
	Clayton		Rocky Mount	
	2004	2005	2004	2005
Week 1	1.1	3.4	1.9	3.5
Week 2	1.3	1.1	2.4	0.7
Week 3	1.4	1.9	0.6	1.4
Week 4	5.1	2.4	1.3	3.9
Week 5	1.3	0	4	2.3
Week 6	0.4	0.3	1.6	0
Week 7	5.9	1.9	6.3	0
Week 8	0.7	0	1.3	2
Week 9	3.6	0.2	2.1	0.4
Week 10	0.4	5.4	0	1.7
Week 11	2.5	0.8	1.4	2.1
Week 12	6.5	5.9	0.5	1.3

Table A-4.2. Crop injury as affected by herbicide systems at 8 and16 weeks after planting (WAP).[x]

Herbicides[y]					Injury (%)	
PRE[z]	4-leaf	6-leaf	12-leaf	14-leaf	8 WAP	16 WAP
None	None	Glyp	None	None	0	0
None	None	Glyp	Glyp	None	0	0
None	None	Glyp	Glyp	Glyp	0	0
None	None	Glyp	Trif	None	0	0
None	None	Glyp + metol	Glyp	None	4 b	0
None	None	Glyp + metol	Trif	None	5 b	0
None	None	Glyp + pyri	Glyp	None	12 a	0
None	None	Glyp + pyri	Glyp + pyri	None	11 a	0
Pend + fluo	Glyp	None	Glyp	None	0 c	0
Pend + fluo	Glyp	None	Glyp	Glyp	0 c	0
Pend + pyri	Glyp	None	Glyp	None	0 c	0
Pend + pyri	Glyp	None	Glyp	Glyp	0 c	0

[x] Data are averaged over years and locations. Means followed by the same letter are not significantly different based on Fisher's Protected LSD test at P = 0.05.

[y] Abbreviations and herbicide rates: Pend, pendimethalin (1.1 kg ai/ha); fluo, fluometuron (1.1 kg ai/ha); glyp, glyphosate (1.1 kg ai/ha); pyri, pyrithiobac (48 g ai/ha PRE and POST; 0.24 g ai/ha sequential POST); trif, trifloxysulfuron (5.3 g ai/ha).

[z] Systems not including a PRE herbicide received an early POST application of glyphosate at 1.1 kg ai/ha when cotton was in the 1-leaf stage.

Table A-4.3. Cotton fiber characteristics as affected by herbicide systems in narrow row glyphosate-resistant cotton.[w]

Herbicides[x]					Fiber characteristics[y]			
PRE[z]	4-leaf	6-leaf	12-leaf	14-leaf	Micronaire	UHM	UI	Strength
						cm	%	kN mg/kg
None	None	Glyp	None	None	4.21 a	2.86 a	84 a	287
None	None	Glyp	Glyp	None	4.21 a	2.87 a	84 a	288
None	None	Glyp	Glyp	Glyp	4.35 a	2.86 a	84 a	286
None	None	Glyp	Trif	None	4.21 a	2.85 a	83 a	289
None	None	Glyp + metol	Glyp	None	4.25 a	2.83 a	84 a	284
None	None	Glyp + metol	Trif	None	4.22 a	2.86 a	84 a	285
None	None	Glyp + pyri	Glyp	None	4.25 a	2.86 a	83 a	287
None	None	Glyp + pyri	Glyp + pyri	None	4.22 a	2.84 a	84 a	287
Pend + fluo	Glyp	None	Glyp	None	4.29 a	2.85 a	84 a	288
Pend + fluo	Glyp	None	Glyp	Glyp	4.25 a	2.87 a	83 a	288
Pend + pyri	Glyp	None	Glyp	None	4.23 a	2.85 a	84 a	288
Pend + pyri	Glyp	None	Glyp	Glyp	4.28 a	2.84 a	84 a	287
Mean					4.25	2.85	83.75	287

[w] Data are averaged over years and locations. Means followed by the same letter are not significantly different based on Fisher's Protected LSD test at $P = 0.05$.

[x] Abbreviations and herbicide rates: Pend, pendimethalin (1.1 kg ai/ha); fluo, fluometuron (1.1 kg ai/ha); glyp, glyphosate (1.1 kg ai/ha); pyri, pyrithiobac (48 g ai/ha PRE and POST; 0.24 g ai/ha sequential POST); trif, trifloxysulfuron (5.3 g ai/ha).

[y] UHM = upper-half mean length; UI = uniformity index.

[z] Systems not including a PRE herbicide received an early POST application of glyphosate at 1.1 kg ai/ha when cotton was in the 1-leaf stage.

Table A-5.1. *P*-Values for final plant heights, total number of mainstem nodes, and nodes above white flower at 15 weeks after planting as affected by various plant populations.

Source	df	Final Plant Height	Total Nodes	NAWF
		cm	#/plant	
Year	1	0.1551	0.2214	0.3652
Loc	1	0.9012	<.0001	<.0001
Year*Loc	1	<.0001	0.2900	0.0019
Rep(Year*Loc)	11	0.2149	0.0164	0.0013
Treatment	6	<.0001	<.0001	<.0001
Year*Treatment	6	<.0001	0.1032	0.2632
Loc*Treatment	6	0.1521	0.5448	0.1044
Year*Loc*Treatment	6	0.2951	0.4045	0.5696

Table A-5.2. *P*-Values for number of bolls per plant as affected by population density.

		Number of bolls (all positions)			
Source	df	Nodes 4 to 7	Nodes 8 to 11	Nodes 12+	Vegetative
		no. plant^{-1}			
Year	1	<.0001	0.0001	0.9172	0.1016
Loc	1	<.0001	<.0001	<.0001	0.0006
Year*Loc	1	0.4093	0.0012	0.8134	<.0001
Rep(Year*Loc)	11	<.0001	0.0230	0.3649	0.0133
Treatment	6	<.0001	<.0001	<.0001	<.0001
Year*Treatment	6	0.1461	0.0733	0.0825	0.1236
Loc*Treatment	6	0.1363	0.1776	0.0754	0.4526
Year*Loc*Treatment	6	0.0944	0.6227	0.9954	0.3489

Table A-5.2. Continued. *P*-Values for percentage of total bolls per plant in first position, second position, and vegetative sites as affected by population density.

		Bolls		
Source	df	1st position	2nd position	vegetative
		% of total		
Year	1	<.0001	<.0001	0.0529
Loc	1	0.0006	0.5405	<.0001
Year*Loc	1	<.0001	0.6586	<.0001
Rep(Year*Loc)	11	0.0002	0.3535	0.0894
Treatment	6	<.0001	<.0001	<.0001
Year*Treatment	6	0.2106	0.8401	0.1046
Loc*Treatment	6	0.5816	0.4745	0.2365
Year*Loc*Treatment	6	0.3541	0.2946	0.3258

Table A-5.3. *P*-Values for seed cotton weight distribution throughout the plant as affected by population density.

		Seed cotton weight			
Source	df	Nodes 4 to 7	Nodes 8 to 11	Nodes 12+	Vegetative
		% of total			
Year	1	0.5596	0.6238	0.7697	0.9828
Loc	1	<.0001	<.0001	<.0001	<.0001
Year*Loc	1	<.0001	0.0510	0.2453	<.0001
Rep(Year*Loc)	11	0.599	0.4416	0.1204	0.2975
Treatment	6	<.0001	<.0001	<.0001	<.0001
Year*Treatment	6	0.0971	0.5449	0.1256	0.3652
Loc*Treatment	6	0.0715	0.1069	0.2365	0.2469
Year*Loc*Treatment	6	0.6692	0.7714	0.5077	0.0921

Table A-5.4. *P*-Values for seed cotton weight per boll by position and node zone as affected by plant population density.

		Seed cotton weight per boll (grams)						
Source	df	Nodes 4 to 7		Nodes 8 to 11		Nodes 12+		Veg.
		Pos. 1	Pos. 2	Pos. 1	Pos. 2	Pos. 1	Pos. 2	
Year	1	0.0065	0.0023	<.0001	0.0025	0.0143	0.3168	0.4180
Loc	1	<.0001	0.4903	<.0001	<.0001	<.0001	<.0001	0.0007
Year*Loc	1	<.0001	0.2495	0.1094	0.6567	0.8164	0.2426	0.0284
Rep(Year*Loc)	11	0.0077	0.1316	0.7809	0.1730	0.5103	0.3123	0.3451
Treatment	6	0.0006	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Year*Treatment	6	0.1042	0.1301	0.5771	0.7001	0.5357	0.5352	0.9415
Loc*Treatment	6	0.3846	0.7885	0.5231	0.0812	0.2209	0.5162	0.6642
Year*Loc*Treatment	6	0.4150	0.1480	0.4717	0.3104	0.3238	0.4216	0.0143

Table A-5.4. Continued. *P*-values for the effect of plant population density on percentage of total bolls per plant and seed cotton weight per boll in first position, second position, and vegetative sites at harvest in narrow-row cotton.[z]

		Seed cotton weight per boll		
Source	df	1st position	2nd position	vegetative
		g/boll		
Year	1	0.0002	0.0005	0.0529
Loc	1	0.0060	<.0001	<.0001
Year*Loc	1	0.0023	0.7580	<.0001
Rep(Year*Loc)	11	0.4304	0.0379	0.0894
Treatment	6	<.0001	<.0001	<.0001
Year*Treatment	6	0.5530	0.0970	0.1046
Loc*Treatment	6	0.0810	0.2084	0.2365
Year*Loc*Treatment	6	0.3402	0.0898	0.4180

Table A-5.5. *P*-Values for lint yield and fiber quality characteristics as affected by plant population density.

Source	df	Lint yield	Fiber quality			
			Mic	UHM	UI	Strength
		Kg/ha		cm	%	kN mg/kg
Loc	4	<.0001	<.0001	<.0001	<.0001	<.0001
Rep(Loc)	14	0.1023	0.0781	0.0227	0.0815	0.3209
Treatment	6	<.0001	0.7272	<.0001	0.0007	0.0243
Loc*Treatment	24	0.1817	0.0912	0.6526	0.5464	0.5256

Table A-5.6. Plant population effect on boll distribution per plant at harvest in narrow-row cotton.[x]

	Total bolls[z]			
Population	Nodes 4 to 7	Nodes 8 to 11	Nodes 12+	Vegetative
plants/ha^{-1}	no./ plant^{-1}			
34443	5.2 a	5.8 a	1.5 a	4.4 a
60277	4.0 b	4.0 b	0.8 b	1.7 b
120776	2.9 c	2.8 d	0.4 cd	0.3 cd
198048	2.2 d	2.1 e	0.2 de	0.1 d
258349	2.2 d	1.8 e	0.1 e	0 d
301379	1.9 d	1.4 f	0.1 e	0 d
115,789 (97-cm rows)	3.0 c	3.5 c	0.6 bc	0.5 c

[x] Data are averaged over two years and two locations per year. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test a $P = 0.05$.

[z] All positions.

Table A-5.7. Seed cotton weight per boll as affected by plant population density in narrow-row cotton.[z]

	Seed cotton weight per boll						
	Nodes 4 to 7		Nodes 8 to 11		Nodes 12+		
Population	Pos. 1	Pos. 2	Pos. 1	Pos. 2	Pos. 1	Pos. 2	Veg.
plants/ha^{-1}	grams						
34443	5.4 a	5.6 a	6.2 a	5.7 a	6.0 a	3.7 a	5.4 a
60277	5.3 ab	5.2 a	6.1 a	5.5 ab	5.3 ab	2.9 ab	5.4 a
120776	5.1 bc	5.2 a	5.9 a	4.6 bc	4.6 bc	0.6 c	4.1 b
198048	5.0 c	4.0 b	5.3 b	4.5 c	3.8 c	0.6 c	2.4 c
258349	4.9 c	3.6 bc	5.3 b	2.9 d	3.6 c	0.4 cd	0 d
301379	5.0 bc	3.0 c	4.9 c	1.0 e	1.3 d	0 d	0 d
115,789 (97-cm rows)	5.4 a	5.1 a	6.1 a	5.2 abc	5.2 ab	1.8 b	4.9 ab

[z] Data are averaged over two years and two locations per year. Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test a *P* = 0.05.

Table A-7.1. Effect of constant temperature on cumulative germination of unscarified doveweed seed.

	Germination	
Temperature	7 d	14 d
C	%	
15	0	0
20	0	0
25	0.3	1.3
28	3.3	7
30	5	7.3
33	3.3	4
36	0.3	1.3
38	0	0.3
Mean (28 to 33 C)	3.9	6.1

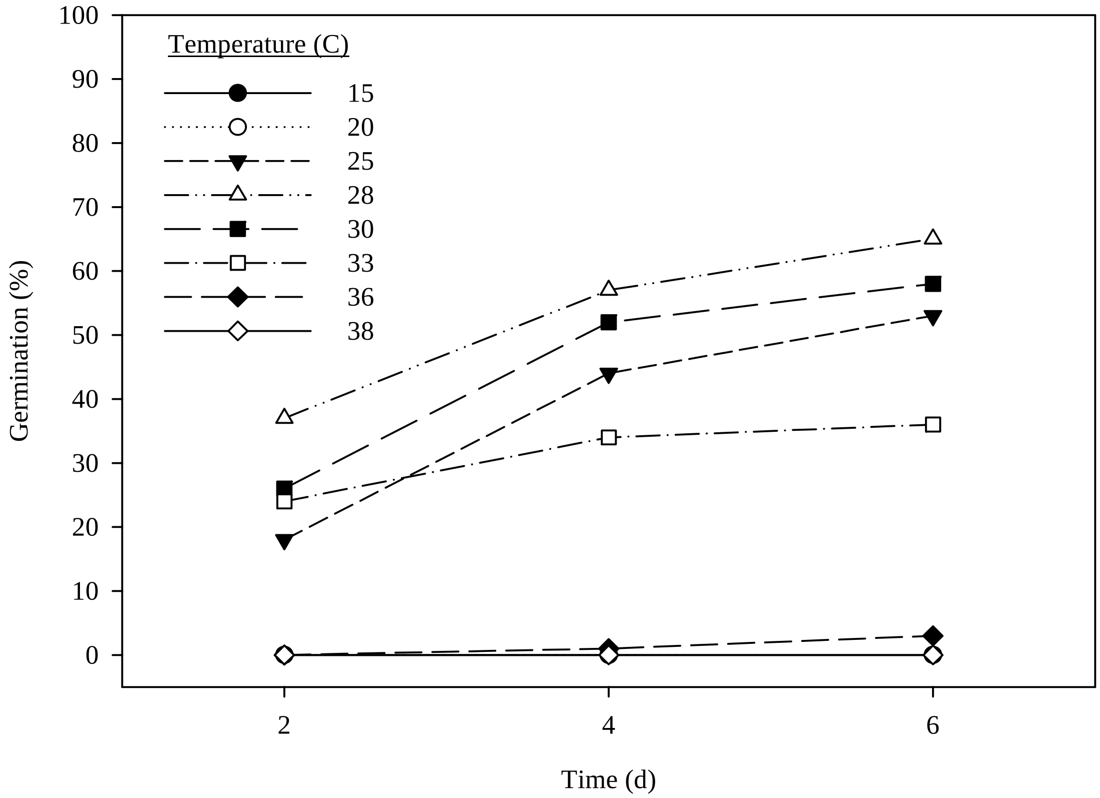

Figure A-7.1. Effect of constant temperature on doveweed germination over 6 days.

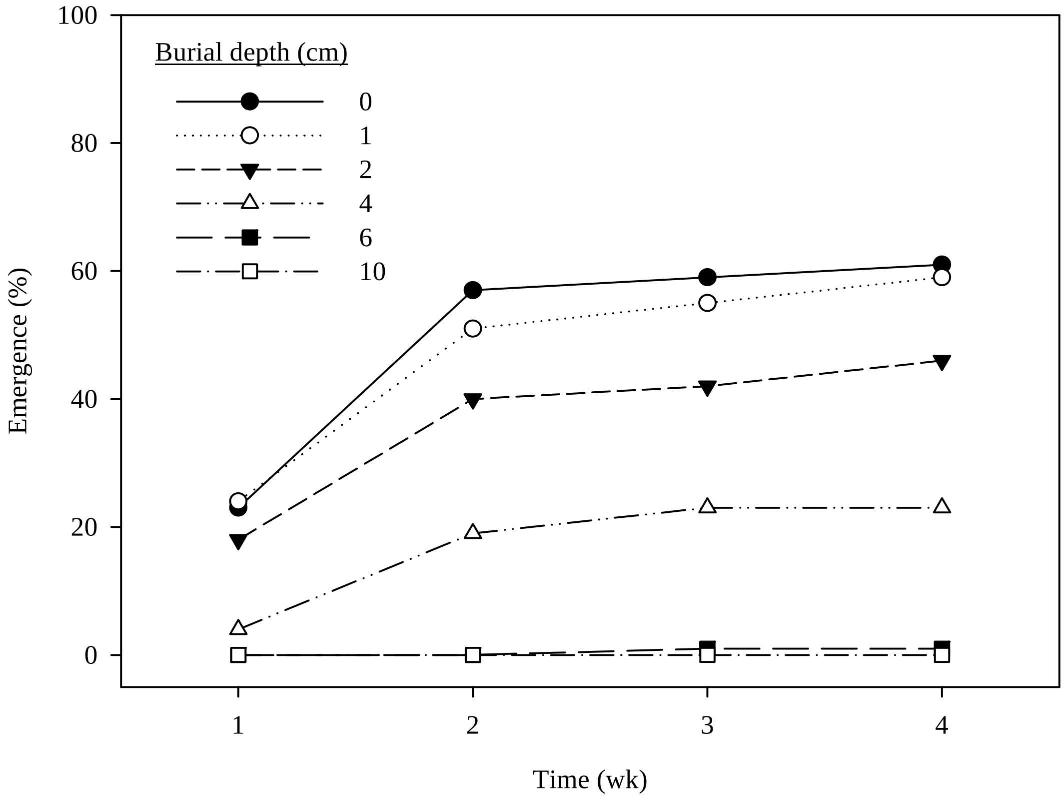

Figure A-7.2. Effect of seed burial depth on doveweed emergence over 4wk.