ABSTRACT

CLEWIS, SCOTT BARTON. Weed Management Strategies in Conventional- and Reduced-Tillage Cotton Production Systems. (Under the direction of Dr. David L. Jordan.)

Laboratory and greenhouse studies were conducted to determine the effect of temperature, solution pH, water stress, and planting depth on cutleaf eveningprimrose (*Oenothera laciniata* Hill) germination. Field studies were conducted to measure growth parameters of cutleaf eveningprimrose throughout the fall season. When treated with constant temperature, the optimum germination of cutleaf eveningprimrose occurred at 24 C. Onset, rate, and total germination were greatest in an alternating 20/35 C temperature regime. Germination decreased without increased solution pH and increased water stress. Emergence was optimum when seeds were buried at depths of 0.5 cm. Cutleaf eveningprimrose control was maximized when 2, 4-D was applied in mixture with glyphosate or paraquat.

Five studies were conducted at Clayton, Rocky Mount, and Lewiston-Woodville, NC, in 2001 and 2002, to evaluate weed management, crop tolerance, and yield in strip- and conventional-tillage glyphosate-resistant (GR) cotton. Addition of *S*-metolachlor to glyphosate formulations increased control of broadleaf signalgrass, goosegrass, large crabgrass, and yellow foxtail 14 to 43% compared to control with glyphosate alone. *S*-metolachlor was not beneficial for late-season control of entireleaf morningglory, jimsonweed, pitted morningglory, or yellow nutsedge. Addition of *S*-metolachlor to glyphosate formulations increased control of common lambsquarters, common ragweed, Palmer amaranth, smooth pigweed, and velvetleaf 6 to 46%. Addition of a late postemergence-directed spray (LAYBY) treatment of prometryn plus MSMA increased control to greater than 95% for all weeds regardless of early-postemergence (EPOST)

treatment, and control was similar with or without *S*-metolachlor EPOST. Cotton lint yield was increased 220 kg/ha with the addition of *S*-metolachlor to glyphosate formulations compared to yield from glyphosate alone. Addition of LAYBY treatments increased yields 250 and 380 kg/ha for glyphosate plus *S*-metolachlor and glyphosate systems, respectively.

Field studies were conducted in five states at six locations from 2002 through 2003 to evaluate weed control and cotton response to early-postemergence (EPOST), postemergence (POST)/POST-directed spray (PDS), and late postemergence-directed (LAYBY) systems utilizing glyphosate-DIA (diammonium salt), *S*-metolachlor, trifloxysulfuron-sodium, prometryn, and MSMA. Annual broadleaf and grass control was increased with the addition of *S*-metolachlor to glyphosate-DIA EPOST systems (85 to 98% control) compared with glyphosate-DIA EPOST alone (65 to 91% control), except for sicklepod control where equivalent control was observed. Annual grass control was greater with glyphosate-DIA plus trifloxysulfuron-sodium PDS than with trifloxysulfuron-sodium postemergence (POST) or PDS or trifloxysulfuron-sodium plus MSMA PDS (90 to 94% vs. 75 to 83% control). With few exceptions, broadleaf weed control was equivalent for trifloxysulfuron-sodium applied POST alone, PDS alone, or in combination with glyphosate-DIA PDS or MSMA PDS herbicide treatments (81 to 99% control). Cotton lint yield increased 420 kg/ha with the addition of *S*-metolachlor to glyphosate-DIA EPOST treatments compared to systems without *S*-metolachlor EPOST. Cotton lint yield was increased 330 to 910 kg/ha with the addition of a POST herbicide treatment compared to systems without a POST/PDS treatment. Addition of a LAYBY herbicide treatment increased cotton lint yield by 440 kg/ha compared to systems without a LAYBY.

Studies were conducted at three locations in North Carolina in 2004 to evaluate density-dependent effects of glufosinate-resistant (GUR) corn on GUR cotton growth and lint yield. A GUR corn density of 5.25 plant/m of crop row reduced late season cotton height by 38, 43, and 43% at Clayton, Lewiston-Woodville, and Rocky Mount, respectively, compared to weed-free cotton height. GUR corn dry biomass per m crop row and GUR corn seed biomass per m of crop row decreased linearly with increasing GUR corn density at all locations. Percent GUR cotton lint yield loss increased 4, 5, and 8 percentage points at Clayton, Lewiston-Woodville, and Rocky Mount, respectively, with each 500 g increase in weed biomass per m of crop row.

Weed Management Strategies in Conventional- and Reduced-Tillage Cotton Production Systems

by

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DEDICATION

This thesis is dedicated to my mother,

"Without her never ending love and support, none of

my accomplishments would have been possible."

Delores Ann Harrison

“And to a promise kept”

In memory of:

Juanita and Samuel “Dub” Clewis

Pauline and Curtis Duncan

Dr. John W. Wilcut

BIOGRAPHY

Scott B. Clewis was born in Wilmington, North Carolina on August 8, 1972 to Don Walter Clewis and Delores Ann Harrison. He was raised in Whiteville, North Carolina, a small rural town. He graduated with honors from Whiteville High School in 1990. Following graduation, he enrolled at North Carolina State University where he earned Bachelor of Science degrees in Microbiology and Biology in the fall of 1995. After graduation, he was employed by the Department of Entomology at North Carolina State University as a Research Assistant under Dr. Clyde Sorenson. In April 1999, he accepted a Master's of Science assistantship in Crop Science under the direction of Dr. John Wilcut at North Carolina State University. During his Master's of Science degree program, Scott was employed by North Carolina State University as a Research Specialist beginning in 2000. He graduated as a College of Agriculture and Life Sciences Honor Student. Scott earned a Master of Science in Crop Science and a minor in Entomology from North Carolina State University in December 2001. Following graduation, he pursued a Doctor of Philosophy in Crop Science at North Carolina State University.

While pursuing his degrees, Scott has won awards in the graduate student poster contests at the Southern Weed Science Society and Weed Science Society of North Carolina. He was awarded the Outstanding Master's Graduate Student Award by the Southern Weed Science Society and the Outstanding Ph.D. Student Award by the Weed Science Society of North Carolina. He is a member of the Gamma Sigma Delta Honor Society. He was a member of Weed Science Teams at North Carolina State University and competed at the Northeast Weed Science Society's Contest and Southern Weed Science's

Contest. Scott has authored or co-authored 17 journal articles, 100 abstracts, and 3 research reports from scientific presentations. In July 2007, Scott accepted the position of Research Associate in the Department of Crop Science at North Carolina State University.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
A	acre
ae	acid equivalent
ai	active ingredient
ANOVA	analysis of variance
ANS	as needed spray
C	Celsius
cm	centimeter
d	days
DAP	days after planting
dm	decimeter
fb	followed by
g	grams
GLM	generalized linear models
GR	glyphosate-resistant
GUR	glufosinate-resistant
h	hour
ha	hectare
ht	height
kg	kilogram
kPa	kilopascal
L	leaf
LAYBY	late post-directed
LSD	least significant difference
m	meter
ml	milliliter
mM	millimole
NS	not significant
PDS	postemergence-directed
POST	postemergence
POT	postemergence over-the-top
PPI	pre-plant incorporated
PRE	preemergence
PREBAN	preemergence-banded
SD	standard deviation
SE	standard error
µl	microliter
µmol	micromolar
wk	week
yr	year

Chapter 1. Introduction and Literature Review

Objective 1. Historically, cotton (*Gossypium hirsutum* L.) has been grown in a conventional-tillage environment using primary and secondary tillage. Before the registration of postemergence (POST) herbicides with over-the-top selectivity in cotton, producers were required to use soil-applied herbicide treatments, high use rates of relatively non-selective herbicides, and specialized equipment for POST-directed (PDS) applications (Buchanan 1992; McWhorter and Bryson 1992; Wilcut et al. 1995, 1997). These operations required considerable fuel, labor, and time. Increasing economic inputs, low commodity prices, and concerns for declining soil organic matter, subsoil compaction, and water stress damage have led to interest in alternative tillage options such as strip-tillage production systems (Troeh et al. 1991; Wauchope et al. 1985).

This shift away from fall and winter tillage has allowed the establishment of cool-season weeds, such as cutleaf eveningprimrose (*Oenothera laciniata* Hill). Successful elimination of vegetation prior to planting cotton in reduced-tillage production is critical for adequate stand establishment, eliminating early-season weed interference, and maintaining yields. Poor weed control has been cited as the major limitation to adoption of conservation-tillage in cotton production (McWhorter and Jordan 1985).

Weed management in cotton often requires both soil-applied and POST herbicides for maximum effectiveness (Buchanan 1992; Wilcut et al. 1995). Soil-applied herbicides do not provide season-long weed control in cotton, therefore proper selection of POST herbicides and other inputs are crucial for maximum weed control, cotton yield, and economic returns (Crowley et al. 1979; Culpepper and York 1997; Wilcut et al. 1995, 1997). In the past 9 years, advances in biotechnology and new POST over-the-top (POT) technology have increased cotton growers' options for weed management strategies (Culpepper and York 1997, 1999; Wilcut et al. 1996). POST-applied bromoxynil, glufosinate, glyphosate, pyrithiobac, and trifloxysulfuron-sodium control a broad spectrum of weeds (Askew and Wilcut 1999; Culpepper and York 1997, 1998, 1999; Dotray et al. 1996; Jordan et al. 1993; Porterfield et al. 2003; Scott et al. 2001). Bromoxynil, glufosinate, and glyphosate can only be used in their respective transgenic herbicide-resistant cultivars (York and Culpepper 2005). However, with this technology, farmers have become more reliant on POST herbicide treatments, with only 50% of the North Carolina hectarage receiving soil-applied herbicide treatments (A. C. York, personal communication). These POST technologies have resulted in greater production of reduced tillage cotton and a concomitant reduction in fall, winter, and spring tillage. As a result, establishment of more cool-season species including cutleaf eveningprimrose has occurred. Additionally, the excellent broad spectrum activity of glyphosate on large weeds has resulted in growers making less timely applications to small weeds. These application delays have further promoted the presence of cool season species including cutleaf eveningprimrose at the time of cotton planting (Fairbanks et al. 1995).

Cotton is a poor early season competitor and it is important that weeds be controlled during early cotton growth (McClelland et al. 1993). Preplant weed management is also beneficial for conservation of moisture, nutrients, and time in preparation of difficult-to-manage seedbeds (McClelland et al. 1993). If control efforts, such as using 2, 4-D are delayed until April or May, then cutleaf eveningprimrose can be difficult to control (Reynolds et al. 2000). Cutleaf eveningprimrose can be difficult to manage with herbicides other than 2, 4-D in reduced tillage systems (Fairbanks et al. 1995; Guy 1995). The growth characteristics and development of winter weeds determine the impact they may have on cotton growth. Weeds such as cutleaf eveningprimrose may interfere with cotton the entire growing season (Guy 1995).

Cutleaf eveningprimrose, a member of the *Onagraceae* family, is an herbaceous winter annual native to eastern North America (Uva et al. 1997). Cutleaf eveningprimrose can be found throughout the southeastern U.S. It often occurs in cultivated fields, sandy waste areas, and roadsides throughout the southeastern U.S. (Uva et al. 1997). Cutleaf eveningprimrose is a common and troublesome weed in soybean [*Glycine max* (L.) Merr.], corn (*Zea mays* L.), and small grain production in areas of the southern U.S. (Webster 2004, 2005), and is one of the most common and troublesome weeds in North Carolina cotton production (Webster 2005). It is a basally prostrate or weakly ascending plant with stems branching at the base and has a fibrous tap root system. In its juvenile stages stems are simple or many branched from the base up to 8 dm long and are hairy (Uva et al. 1997). The leaves are alternating oblong to lanceolate (3 to 8 cm long), coarsely toothed to irregularly lobed, dull green with short hairs present. The hypocotyl is short, smooth and not evident above the soil until the second leaf develops. The cotyledons are kidney-shaped with flat petioles on the upper surface (Uva et al. 1997).

To date only preliminary data on cutleaf eveningprimrose biology exists and no published research concerning cutleaf eveningprimrose growth, development, or the environmental effects that promote these species have been determined (Chapter 1 pp. 22-57).

When treated with constant temperature, cutleaf eveningprimrose germinated over a range of 15 to 32 C, with the optimum germination occurring at 24 C. Onset, rate, and total germination were greatest in an alternating 20/35 C temperature regime. Germination decreased as solution pH increased, with greatest germination occurring at solution pH of 4. Germination decreased when cutleaf eveningprimrose seed was subjected to increased water stress. Emergence was optimum when seed were buried at depths of 0.5 cm. Germination decreased with increasing burial depth and no seed emerged from a depth of 10 cm. Cutleaf eveningprimrose control was maximized when 2, 4-D was applied in mixture with glyphosate or paraquat. These data suggest that cutleaf eveningprimrose can germinate and gain biomass from early-March to late-October. These attributes could contribute to poor control prior to cotton planting if preplant control applications are delayed after early-March.

Objective 2. Weed management in cotton often requires applications of preemergence (PRE), postemergence (POST), and late POST-directed (LAYBY) herbicides for season-long weed control (Culpepper and York 1998; Wilcut et al. 1995). The use of early POST-directed (PDS) herbicide treatments and the requirement of special equipment for such applications to small cotton make this practice a tedious and slow process (Askew and Wilcut 1999; Culpepper and York 1998; Wilcut et al. 1997). Additionally, the need for a height differential between cotton and the weeds (Culpepper and York 1999) along with the possible need for multiple PDS treatments and/or cultivation based on weed populations increases the cost of production often without achieving the desired level of weed control (Snipes and Mueller 1992; Wilcut et al. 1995, 1997). These factors along with the ease of application, have led to many cotton growers opting to apply herbicides strictly POST

(Wilcut et al. 1996). Two options for POST application in cotton are glyphosate and pyrithiobac.

Glyphosate is a non-selective, systemic herbicide that controls many grass and broadleaf weeds common to agronomic crops (Askew and Wilcut 1999; Culpepper and York 1999; Tharp and Kells 1999; VanGessel et al. 2000). Since the commercial introduction of glyphosate-resistant (GR) cotton in 1997 in the U.S., there has been a shift away from soil-applied herbicides (York personal communication). GR cotton offers many benefits to growers including broad-spectrum control of perennial and annual weeds (Bradley 1995), potential to eliminate soil-applied herbicides, ease of POST application (Culpepper and York 1999), and a favorable environmental profile (Culpepper and York 1999, Wachope et al. 1985). However, drawbacks include lack of residual weed control necessitating multiple applications (Askew et al. 2002), marginal control of Florida pusley (*Richardia scabra* L.) and yellow (*Cyperus esculentus* L.) and purple nutsedge (*C. rotundus* L.), and the requirement of timely applications for control of annual morningglories (Faircloth et al. 2001). Glyphosate can only be applied POST up to the 4-leaf (L) stage. After the 4L stage, glyphosate should be applied PDS at the base of the plant to minimize glyphosate contact with the cotton foliage. Research has shown glyphosate uptake after the 4L growth stage can result in glyphosate accumulation in reproductive tissues (Pline et al. 2001, 2002a). Accumulation combined with lower expression of the altered enolpyruvylshikimate-3-phosphate synthase (EPSPS) in male reproductive structures can cause premature fruit abortion, poor seed set, abnormalities in male reproductive structures, and pollen sterility (Jones and Snipes 1999; Pline et al. 2002a, 2002b).

Cotton growers often must apply a residual LAYBY treatment for season-long weed control (Askew et al. 2002; Scott et al. 2001, 2002). Because of the lack of residual activity from glyphosate, weed emergence late in the season can be a problem if cotton has poor canopy closure from early-season weed interference (Wilcut et al. 2003). Cotton has tolerance to *S*-metolachlor early-POST (EPOST) and *S*-metolachlor provides residual control of many annual grass and small-seeded broadleaf weeds including *Amaranthus* spp., Florida pusley, and common lambsquarters (*Chenopodium album* L.) (Grichar et al. 2004). An additional benefit of *S*-metolachlor is that it offers a different site of action for resistance management, and application flexibility (Mallory-Smith and Retzinger 2003).

The recent increase in strip-tillage cotton production on the mid-Atlantic and Southeastern Coastal Plain (Anonymous 2002), and the lack of data concerning weed management in strip-tillage systems necessitates additional research (Chapter 2 pp. 58-89).

Early-season cotton injury was minimal (3%) with glyphosate formulations alone or in mixture with *S*-metolachlor. Weed control and cotton yields were similar for both glyphosate formulations. The addition of *S*-metolachlor to glyphosate formulations increased control of broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash], goosegrass [*Eleusine indica* (L.) Gaertn.], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and yellow foxtail (*Setaria glauca* L.) 14 to 43% compared to control with glyphosate alone. *S*-metolachlor was not beneficial for late season control of entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray.), jimsonweed (*Datura stramonium* L.), pitted morningglory (*Ipomoea lacunosa* L.), or yellow nutsedge. The addition of *S*-metolachlor to glyphosate formulations increased control of common lambsquarters, common ragweed (*Ambrosia artemisiifolia* L.), Palmer amaranth (*Amaranthus palmeri* S. Wats.), smooth pigweed (*Amaranthus hybridus* L.), and velvetleaf (*Abutilon theophrasti* Medicus) 6 to 46%. The addition of a LAYBY treatment of prometryn plus MSMA increased control to greater than 95% for all weed species regardless of EPOST treatment, and control was similar with or without *S*-metolachlor EPOST. Cotton lint yield was increased 220 kg/ha with the addition of *S*-metolachlor to either glyphosate formulation compared to yield from glyphosate alone. The addition of the LAYBY increased yields 250 and 380 kg/ha for glyphosate plus *S*-metolachlor and glyphosate systems, respectively. *S*-metolachlor residual activity allowed for a extended window for more effective LAYBY application to smaller weed seedlings instead of possible larger and harder to control weeds.

Objective 3. GR cotton offers many benefits to growers including broad-spectrum control of annual and perennial grass, sedge, and broadleaf weeds (Clewis et al. 2006; Franz et al. 1997; Tharp and Kells 1999; VanGessel et al. 2000), potential to eliminate soil-applied herbicides, ease of POST application (Culpepper and York 1999), low cost, and a favorable environmental profile (Culpepper and York 1999; Shaner 2000). The wider application window of glyphosate application timing in GR cotton (POST up to 4L and PDS from 5 to 8L) increases the flexibility of POST weed management decisions. However, these advances in biotechnology have shifted weed management programs from traditional multiple herbicide application systems approach to relying on total POST herbicide systems (including PDS and LAYBY applications) (Askew and Wilcut 1999; Culpepper and York 1999; Culpepper et al. 2000; Thomas et al. 2006).

A recent survey conducted by six universities and Marketing Horizons, Inc. showed that a third of 1,195 growers of cotton, corn, and soybean (representing six agricultural states) surveyed relied solely on glyphosate for weed management (Clewis et al. 2007). It is estimated that >95% of all cotton currently grown in Mississippi and North Carolina is glyphosate-resistant (York and Shaw, personal communication). Glyphosate drawbacks include lack of residual weed control necessitating multiple applications (Askew et al. 2002), marginal control of Florida pusley and yellow and purple nutsedge, and the requirement of timely applications for control of annual morningglories (Faircloth et al. 2001). Another more recent concern with glyphosate use is resistance development in weeds such as common ragweed (Brewer et al. 2006), common waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] (Patzoldt et al. 2004; Zelaya and Owen 2002), giant ragweed (*Ambrosia trifida* L.) (Heap 2007), horseweed (*Conyza canadensis* L. Cronq.) (Koger et al. 2004; Mueller et al. 2003; VanGessel 2001), Italian ryegrass (*Lolium multiflorum* Lam.) (Perez-Jones et al. 2005), and Palmer amaranth (Culpepper et al. 2006).

Fundamentals for successful weed management in all crop production systems incorporate timely application, proper herbicide selection, and use of multiple sites of action (Wilcut and Askew 1999). The registration of trifloxysulfuron-sodium provided growers with another POST option for broadleaf weed control in cotton. Trifloxysulfuron-sodium is a sulfonylurea herbicide that inhibits the acetolactate synthase enzyme (ALS, EC 4.1.3.18) and is used for broadleaf and perennial sedge control (Porterfield et al. 2002b; Richardson et al. 2007). Trifloxysulfuron-sodium has low toxicological properties, a favorable environmental profile, and low use rates (Anonymous 2007a). Previous research has shown that trifloxysulfuron-sodium POST controls common lambsquarters, common ragweed, entireleaf morningglory, pitted morningglory, smooth pigweed, Palmer amaranth, sicklepod (*Cassia obtusifolia* L.), tall morningglory (*Ipomoea purpurea* L. Roth.), and yellow nutsedge (Burke and Wilcut 2004; Porterfield et al. 2002b, 2003; Richardson et al. 2007). However, trifloxysulfuron-sodium will not control jimsonweed, prickly sida (*Sida spinosa* L.), spurred anoda (*Anoda cristata* L. Schlecht.), and several annual grasses and only suppresses purple nutsedge and johnsongrass (*Sorghum halepense* L. Pers.) (Corbett et al. 2004; Crooks et al. 2003; Porterfield et al. 2002b, 2003; Richardson et al. 2003). Cotton injury from trifloxysulfuron-sodium has been minimal, with symptoms of chlorosis and stunting; however, cotton at the 5L stage on warm, well-drained soils recovers rapidly (Burke and Wilcut 2004; Crooks et al. 2003; Richardson et al. 2004a; Thomas et al. 2006).

Weed resistance to the ALS family of herbicides is widespread with ninety-three cases reported worldwide (Heap 2007). Proactive weed resistance management should take priority when developing weed management systems in any crop. Weed resistance management in cotton can be particularly problematic due to the limited POST options (glyphosate, pyrithiobac, and trifloxysulfuron-sodium), widespread weed resistance to the ALS herbicide family and developing glyphosate resistance concerns (Culpepper and York 2005). Multiple herbicide sites of action will be a key for controlling potential resistant biotypes. However, with the decrease in use of soil-applied herbicides due to the overwhelming success of GR cotton, the objective of this research was to evaluate a systems approach for POST control of several annual broadleaf and grass weeds across the Cotton Belt using herbicides with multiple sites of action (Chapter 3 pp. 90-121).

Early-season cotton injury and discoloration was minimal (<1%) with all treatments; mid- and late- season injury was minimal (<2%) except for trifloxysulfuron-sodium POST (11 and 9%, respectively). Annual broadleaf and grass control was increased with the addition of *S*-metolachlor to glyphosate-DIA (diammonium salt) EPOST systems (85 to 98% control) compared with glyphosate-DIA EPOST alone (65 to 91% control), except for sicklepod control where equivalent control was observed. Annual grass control was greater with glyphosate-DIA plus trifloxysulfuron-sodium PDS than with trifloxysulfuron-sodium POST or PDS or trifloxysulfuron-sodium plus MSMA PDS (90 to 94% vs. 75 to 83% control). With few exceptions, broadleaf weed control was equivalent for trifloxysulfuron-sodium applied POST alone or PDS alone or in combination with glyphosate-DIA PDS or MSMA PDS herbicide treatments (81 to 99% control). The addition of a LAYBY herbicide treatment increased broadleaf weed control by 11 to 36 percentage points compared to systems without a LAYBY. Cotton lint yield increased 420 kg/ha with the addition of *S*-metolachlor to glyphosate-DIA EPOST treatments compared to systems without *S*-metolachlor EPOST. Cotton lint yield was increased 330 to 910 kg/ha with the addition of a POST herbicide treatment compared to systems without a POST/PDS treatment. The addition of a LAYBY herbicide treatment increased cotton lint yield by 440 kg/ha compared to systems without a LAYBY.

Objective 4. Field corn is grown on more hectares (ha) than any other crop in the U.S. In 2000 and 2001, there were over 32 million and 31 million ha of corn planted, respectively. North Carolina corn growers have averaged 6,516 kg/ha on 318,892 ha planted per year from 1996 to 2006 (USDA-NASS 2006). In the mid-1990’s, it was reported that U.S. growers applied herbicides to 98% of the nation's field corn hectarage: 39% of the hectarage received a PRE herbicide application only, 21% of the hectarage received a POST application only, while 38% of the hectarage received both a PRE and POST herbicide treatment (USDA-NASS 1994). Herbicide-resistant corn hectarage has steadily increased from 7% in 2000 to 26% in 2005 (USDA-NASS 2000, 2005).

The use of herbicide-resistant cotton has been more widespread with 46 and 61% of the total hectarage planted in 2000 and 2005, respectively (USDA-NASS 2000, 2005). The increased use of herbicide-resistant varieties has led to less than 50% of the North Carolina hectarage receiving any residual PRE herbicide treatment (A. C. York, personal communication). Therefore, there is a potential for presence of herbicide-resistant corn volunteers in rotational crops the following year. The presence of volunteers may lead to many problems including harvesting inefficiency, competition for resources, and ovipositing sites for insect (York et al. 2004).

If an economic threshold is to be realized, data on weed interference must be collected for yield-loss prediction models (Coble and Byrd 1992). Since interference between glufosinate-resistant (GUR) corn and GUR cotton has not been investigated, studies were conducted to determine effects of a range of GUR corn densities on GUR cotton growth and yield and to evaluate growth of GUR corn as affected by plant density (Chapter 4 pp. 124-146).

GUR corn was taller than GUR cotton as early as 11 days (d) after planting, depending on location. A GUR corn density of 5.25 plant/m of crop row reduced late-season cotton height by 38, 43, and 43% at Clayton, Lewiston-Woodville, and Rocky Mount, respectively, compared to weed-free cotton height. GUR corn dry biomass per m crop row and GUR corn seed biomass per m of crop row decreased linearly with increasing GUR corn density at all locations. The relationship between GUR corn density and GUR cotton yield loss was described by the rectangular hyperbola model with the asymptote (*a*) constrained to 100% maximum yield loss. The estimated coefficient *i* (yield loss per unit density as density approaches zero) was 7, 5, and 6 at Clayton, Lewiston-Woodville, and Rocky Mount, respectively. Percent GUR cotton lint yield loss increased 4, 5, and 8 percentage points at Clayton, Lewiston-Woodville, and Rocky Mount, respectively, with each 500 g increase in weed biomass/m of crop row. The examined GUR corn densities had a significant effect on cotton yield, but not as significant as many other problematic grass and broadleaf weeds.

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Chapter 2. Influence of Environmental Factors on Cutleaf Eveningprimrose Germination, Emergence, Development, Vegetative Growth, and Control.

Scott B. Clewis, David L. Jordan, Janet F. Spears, and John W. Wilcut

ABSTRACT. Laboratory and greenhouse studies were conducted to determine the effect of temperature, solution pH, water stress, and planting depth on cutleaf eveningprimrose (*Oenothera laciniata* Hill) germination. Field studies were conducted to measure growth parameters of cutleaf eveningprimrose throughout the fall season. When treated with constant temperature, cutleaf eveningprimrose germinated over a range of 15 to 32 C, with the optimum germination occurring at 24 C. Onset, rate, and total germination were greatest in an alternating 20/35 C temperature regime. Germination decreased as solution pH increased, with greatest germination occurring at solution pH of 4. Germination decreased when cutleaf eveningprimrose seed was subjected to increased water stress. Emergence was optimum when seed were buried at depths of 0.5 cm. Germination decreased with increasing burial depth and no seed emerged from a depth of 10 cm. Cutleaf eveningprimrose control was maximized when 2, 4-D was applied in mixture with glyphosate or paraquat. These data suggest that cutleaf eveningprimrose can germinate

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and gain biomass from early-March to late-October. These attributes could contribute to poor control prior to cotton planting if preplant control applications are delayed after early-March.

Nomenclature: Cutleaf eveningprimrose, *Oenothera laciniata* Hill OEOLA, cotton, *Gossypium hirsutum* L.

Keywords words: Light, temperature, pH, moisture stress, burial depth, growth and development, weed control.

INTRODUCTION

Historically, cotton (*Gossypium hirsutum* L.) has been grown in a conventional-tillage environment using primary and secondary tillage. Before the registration of postemergence (POST) herbicides with over-the-top selectivity in cotton, producers were required to intensively use soil-applied herbicide treatments intensively, high use rates of relatively non-selective herbicides, and specialized equipment for POST-directed (PDS) applications (Buchanan 1992; McWhorter and Bryson 1992; Wilcut et al. 1995, 1997). These operations required considerable fuel, labor, and time. Increasing economic inputs, low commodity prices, and concerns for declining soil organic matter, subsoil compaction, and water stress damage have led to interest in alternative tillage options such as strip-tillage production systems (Troeh et al. 1991; Wauchope et al. 1985).

This shift away from fall and winter tillage has allowed the establishment of cool-season weeds, such as cutleaf eveningprimrose (*Oenothera laciniata* Hill). Successful elimination of vegetation prior to planting cotton in reduced-tillage production is critical for adequate stand establishments, eliminating early-season weed interference, and maintaining yields. Poor weed control has been cited as the major limitation to adoption of conservation-tillage in cotton production (McWhorter and Jordan 1985).

Weed management in cotton often requires both soil-applied and POST herbicides for maximum effectiveness (Buchanan 1992; Wilcut et al. 1995). Soil-applied herbicides do not provide season-long weed control in cotton, therefore proper selection of POST herbicides and other inputs are crucial for maximum weed control, cotton yield, and economic returns (Crowley et al. 1979; Culpepper and York 1997; Wilcut et al. 1995, 1997). In the past 9 years, advances in biotechnology and new POST over-the-top (POT) technology have increased cotton growers' options for weed management strategies (Culpepper and York 1997, 1999; Wilcut et al. 1996). POST-applied bromoxynil, glufosinate, glyphosate, pyrithiobac, and trifloxysulfuron-sodium control a broad spectrum of weeds (Askew and Wilcut 1999; Culpepper and York 1997, 1998, 1999; Dotray et al. 1996; Jordan et al. 1993; Porterfield et al. 2003; Scott et al. 2001). Bromoxynil, glufosinate, and glyphosate can only be used in their respective transgenic herbicide-resistant cultivars (York and Culpepper 2005). However, with this technology, farmers have become more reliant on POST herbicide treatments with only 50% of the North Carolina hectarage receiving soil-applied herbicide treatments (A. C. York, personal communication). These POST technologies have resulted in more cotton being produced in reduced tillage production systems and a concomitant reduction in fall, winter, and spring tillage allowing for establishment of more cool-season species including cutleaf eveningprimrose at planting. Additionally, the excellent broad spectrum activity of glyphosate on large weeds has resulted in growers making less timely applications to small weeds. These application delays have led to the presence of cool season species including cutleaf eveningprimrose at the time of cotton planting (Fairbanks et al. 1995).

Cotton is a poor early season competitor and it is important that weeds be controlled during early cotton growth (McClelland et al. 1993). Preplant burndown weed management is also beneficial for conservation of moisture, nutrients, and time in preparation of difficult-to-manage seedbeds (McClelland et al. 1993). If control efforts, such as 2, 4-D are delayed until April or May, then cutleaf eveningprimrose can be difficult to control (Reynolds et al. 2000). Cutleaf eveningprimrose can be difficult to control with herbicides other than 2, 4-D in reduced tillage systems (Fairbanks et al. 1995; Guy 1995). The growth characteristics and development of winter weeds determine the impact they may have on cotton growth. Weeds such as cutleaf eveningprimrose may interfere with cotton the entire growing season (Guy 1995).

Cutleaf eveningprimrose, a member of the *Onagraceae* family, is an herbaceous winter annual native to eastern North America (Uva et al. 1997). Cutleaf eveningprimrose can be found throughout the southeastern U.S. It is found in cultivated fields, sandy waste areas, and roadsides throughout the southeastern U.S. (Uva et al. 1997). Cutleaf eveningprimrose is a common and troublesome weed in soybean [(*Glycine max* (L.) Merr.)], corn (*Zea mays* L.), and small grain production in areas of the southern U.S. (Webster 2004, 2005), and is one of the most common and troublesome weeds in North Carolina cotton production (Webster 2005). It is a basally prostrate or weakly ascending plant with stems branching at the base and has a fibrous tap root system. In its juvenile stages stems are simple or many branched from the base up to 8 dm long and are hairy (Uva et al. 1997). The leaves are alternating oblong to lanceolate (3 to 8 cm long), coarsely toothed to irregularly lobed, dull green with short hairs present. The hypocotyl is short, smooth and not evident above the soil until the second leaf develops. The cotyledons are kidney-shaped with flat petioles on the upper surface (Uva et al. 1997).

To date there are only preliminary data on cutleaf eveningprimrose biology and no published research concerning cutleaf eveningprimrose growth, development, or the environmental effects that promote these species. Since cultural and chemical control practices targeted at weed management depend on knowledge of the basic growth characteristics and life cycle of weeds, a study was initiated in North Carolina to evaluate the germination requirements, growth, development, and control of cutleaf eveningprimrose in laboratory and field studies. Such information can be used to characterize the competitiveness and the potential infestation range of the weed as well as to enhance management practices, allowing biological, chemical, or mechanical control options to be properly timed (Bhowmik 1997; Dyer 1995; Potter et al. 1984; Wilson 1988).

MATERIALS AND METHODS

Cutleaf eveningprimrose seed was harvested from fallow fields near Rocky Mount, NC in mid-April 2002 and 2003. The seed were allowed to dry to 11% moisture at 25 C for two weeks and stored at 5 C until their use in experiments. The seed were sieved to remove any extraneous plant or floral material. The sieved seed were divided in an air column separator[1] and separated into light and heavy fractions. The heavy fraction, the majority of which were fully developed seed, was used in germination and emergence experiments (Burke et al. 2003). Seed were tested for viability using 1% tetrazolium chloride solution prior to each trial (Peters 2000). Cutleaf eveningprimrose seed tested 96 ± 4% (2002 seed lot) and 94 ± 4% (2003 seed lot) viable by tetrazolium chloride tests (Peters 2000) before each study was initiated (data not shown).

Effect of Temperature. Experiments to evaluate the effects of constant and alternating temperatures on cutleaf eveningprimrose were conducted in 2004. The effect of constant temperature was evaluated by evenly spacing twenty cutleaf eveningprimrose seed in 50 ml Erlenmeyer flasks containing three pieces of filter paper[2] and 8 ml of deionized water (Burke et al. 2003). Experiments performed on the gradient table precluded randomization as the zones of temperature were fixed in position (Larson 1965). The flasks were arranged on a thermogradient table (Larson 1965) in six lanes corresponding to constant temperatures of 15, 19, 24, 28, 32, and 36 C, with six replicate flasks per temperature lane. Each flask was representative of one replication. Flasks were sealed using parafilm to retain moisture. Light was provided by fluorescent overhead bulbs set for an 8 hour (h) light 16 h dark regime with a light intensity of 30 µmol $m^{-2}s^{-1}$. Daily germination counts were made for the first 7 days (d), and then every 3 d until no seed germination was observed for 7 continuous d. Each seedling was removed when a visible radicle could be discerned (Baskin and Baskin 1998). The experiment was conducted twice for each seed lot and the data combined within each year.

Additional experiments were conducted in growth chambers to determine cutleaf eveningprimrose response to diurnal temperature. A randomized complete block design with four replications of treatments was used and the experiment was conducted twice. Each replication was arranged on a different shelf within the respective germination chamber[3]. Blocks were considered study replication over time. Fifty cutleaf eveningprimrose seed were evenly spaced in 110 mm diameter by 20 mm Petri dishes containing 2 pieces of germination paper[4] and 10 ml of deionized water. Four temperature regimes were selected to reflect typical seasonal variation in North Carolina. The regimes 10/25, 15/30, 20/30, 20/35 C, and a constant 20 and 30 C correspond to average mean daily low and high temperatures for the months of April, May, June, July, August, and September in North Carolina (Owenby and Ezell 1992). These regimes also correspond to a range of effective day and night temperatures for April, May, June, July, and August for diverse locations throughout the U.S. (Patterson 1990). The high temperature component of the regime was maintained for 8 h. Light was provided by fluorescent overhead bulbs set for an 8 h light 16 h dark regime with a light intensity of 35 µmol $m^{-2}s^{-1}$. Light quality for germination chambers followed Burke et al. (2003). Daily germination counts were made for 7 d, and then every 3 d until no seed germination was observed for 7 d. Each seedling was removed upon germination as previously described. The experiment was conducted twice and the data combined for analysis.

Effect of Moisture Stress. A study with a randomized complete block design and four replications of treatments was conducted to examine the effects of moisture stress on cutleaf eveningprimrose germination in 2004. Each replication was arranged on a different shelf within the respective germination chamber. Blocks were considered study replication over time. Solutions with osmotic potentials of 0.0, -0.3, -0.4, -0.6, -0.9, and -1.2 MPa were prepared by dissolving 0, 154, 191, 230, 297, or 350 g of polyethylene glycol[5] (PEG) in 1 L of deionized water (Michel 1983). Fifty cutleaf eveningprimrose seed were placed in petri dishes containing 10 ml of appropriate PEG solution and the petri dishes placed in 10/25, 15/30, 20/30, and 20/35 C germination chambers. Germination was determined as previously mentioned. The experiment was conducted twice and data combined for analysis.

Effect of Solution pH. A study using a randomized complete block design with four replications of treatments was conducted to examine the effects of solution pH on cutleaf eveningprimrose germination in 2005. Each replication was arranged on a different shelf within the respective germination chamber. Blocks were considered study replication over time. Buffered pH solutions were prepared according to the method described by Gortner (1949), using potassium hydrogen pthalate in combination with either 0.1 M HCl or 0.1 M NaOH to obtain solution pH levels of 3, 4, 5, and 6. A 25 mM sodium tetraborate decahydrate solution was used in combination with 0.1 M HCl or 0.1 M NaOH to prepare solutions with pH levels of 7, 8, or 9. Fifty cutleaf eveningprimrose seed were placed in petri dishes containing 10 ml of the appropriate pH solution and the petri dishes were placed in 10/25, 15/30, 20/30, and 20/35 C germination chambers. Germination was determined as previously described. The experiment was conducted twice and the data combined for analysis.

Effect of Burial Depth. Studies were conducted in 2004 to examine the effect of burial depth on cutleaf eveningprimrose seed emergence. The study design was a randomized complete block with treatments replicated four times in a glasshouse at an average daily temperature of 33 ± 5 C and a nightly temperature of 23 ± 5 C. Natural light supplemented with fluorescent lamps at a light intensity of 300 ± 20 $\mu Em^{-2}s^{-1}$ were used to extend the daylength to 14 h in glasshouse studies to simulate field conditions.

A Norfolk loamy sand soil (fine-loamy, siliceous, thermic, Typic Paleudults), a typical coastal plain soil in North Carolina, was used in burial studies to simulate field conditions. Twenty cutleaf eveningprimrose seed were placed on the soil surface or covered to depths of 0.5, 1.0, 2.0, 4.0, and 6.0 cm with the same soil. Pots were sub-irrigated initially to field capacity, and then surface irrigated daily to field capacity. Emergence counts were recorded daily for the first 7 d, then every 3 d thereafter. Plants were considered emerged when a cotyledon could be visibly discerned. The experiment was conducted three times and data combined for analysis.

Growth and Development. Field experiments were conducted near Upper Coastal Plain Research Station (Location 1) and the Fountain Research Farm (Location 2) near Rocky Mount, NC in the fall of 2001 and 2002 to evaluate cutleaf eveningprimrose growth throughout the fall season. Soils were a Norfolk loamy sand soil with 0.9% organic matter and a pH 6.0 at location 1 and a Rains fine sandy loam (fine-loamy, siliceous, thermic Typic Paleaquults) with 1.1% organic matter and pH 5.8 at location 2 each season. Approximately 50 emerged cotyledons of cutleaf eveningprimrose plants were flagged and monitored throughout the fall and up to cotton planting. Plant size, growth in diameter, and leaf number was recorded twice a month from fall to early-spring. In addition to these measurements, four plants from each site were harvested during each visit. The roots were removed from these plants and fresh weight determined. The plant's leaf surface area was measured using a leaf surface area meter[6] and plants placed into a dryer for 3 to 5 d. After drying, plants were removed and dry weight measurements were determined.

Weed Control. Field experiments were initiated at the Fountain Research Farm near Rocky Mount, NC in March of 1999 and 2000 to evaluate herbicide treatments for cutleaf eveningprimrose. Soils were a Rains fine sandy loam (fine-loamy, siliceous, thermic Typic Paleaquults) with 0.9 to 1.1% organic matter and pH 5.8 to 6.0 each season. Herbicide applications were broadcast using a CO_2-pressurized backpack sprayer calibrated to deliver 145 L hectare $(ha)^{-1}$ using 8002 regular flat fan nozzles. Cutleaf eveningprimrose size ranged from 3 to 6 in diameter with 6 to 12 leaves at the time of applications.

The experimental design was a randomized complete block design with a factorial treatment arrangement of two non-selective (base) herbicides and four complement herbicides replicated three times. The herbicide treatments consisted of (1) a nontreated control, (2) glyphosate-isopropylamine salt[7] (glyphosate-IP) at 0.84 kg ae ha^{-1} applied POST alone, (3) glyphosate-IP plus 2, 4-D (dimethylamine salt) at 0.47 kg ai ha^{-1} applied POST, (4) glyphosate-IP plus flumioxazin at 90 g ai ha^{-1} applied POST, (5) glyphosate-IP plus a prepackaged mixture of thifensulfuron-methyl plus tribenuron-methyl at 17.4 g ai ha^{-1} applied POST, (6) paraquat plus 2, 4-D applied POST, (7) paraquat plus flumioxazin applied POST, and (8) paraquat plus a prepackaged mixture of thifensulfuron-methyl plus tribenuron-methyl applied POST. Nonionic surfactant[8] at 0.25% (v/v) was included with all treatments. Visual estimates of cutleaf eveningprimrose control were recorded 4 weeks after application (WAP) just prior to cotton planting. Weed control was based on biomass and population reductions and estimated visually on a scale of 0 to 100, where 0 = no control and 100 = death of all plants (Frans et al. 1986).

Statistical Analyses. Data variance was visually inspected by plotting residuals to confirm homogeneity of variance prior to statistical analyses. Both non-transformed and arcsine-transformed data were examined, and transformation did not improve homogeneity. Analyses of variance (ANOVA) were therefore performed on non-transformed percent germination. Trial repetition and linear, quadratic, and higher order polynomial effects of percent germination over time were tested by partitioning sums of squares (Draper and Smith 1981). Nonlinear models were used if ANOVA indicated that higher order polynomial effects of percent germination were more significant than linear or quadratic estimates.

ANOVA indicated higher order polynomial effects for germination resulting from constant and alternating temperature treatments, solution pH treatments, and water potential treatments. Thus, the germination response for each treatment was modeled using the logistic function:

$$y = M\,[1 + \exp(-K(t - L))]^{-1} \qquad [1]$$

and where y is the cumulative percentage germination at time t, M is the asymptote or theoretical maximum for y, L is the time scale constant or lag to onset of germination, and K is the rate of increase (Roché et al. 1997). Estimation used the Gauss-Newton algorithm, a nonlinear least squares technique. When a non-linear equation was fit to the data, an approximate R^2 value was obtained by subtracting the ratio of the residual sum of squares to the corrected total sum of squares from one (Askew and Wilcut 2001; Draper and Smith 1981).

Emergence data were subjected to an ANOVA using the generalized linear models (GLM) procedure in SAS (SAS 1998). No cutleaf eveningprimrose plants emerged from 10 cm, and consequently these data were not included in the analysis. Sums of squares were partitioned to evaluate planting depth and trial repetition. Both study replication and repetition were considered random variables and main effects and interactions were tested by the appropriate mean square associated with the random variable (McIntosh 1983).

Growth and development data were subjected to an ANOVA using sums of squares partitioned to evaluate linear and nonlinear effects of time. Location was considered random and time effects were tested by the appropriate interaction with the random variable (McIntosh 1983). The nontreated check was not included in the control analyses to stabilize variance. Regression analysis was used to describe the growth trends over time for the growth and development data.

Weed control data were tested for homogeneity of variance by plotting residuals. To recognize treatment structure in the factorial arrangement, ANOVA was conducted using GLM procedure in SAS to evaluate the effects of base herbicides (2 levels) and complement herbicides (4 levels) on weed control. Sums of squares were partitioned to evaluate year effects, which were considered separate random variables. Main effects and interactions were tested by appropriate mean square associated with the random variables (McIntosh 1983). Mean separations were performed on non-transformed weed control data using Fisher's protected LSD at $P \leq 0.05$. When interactions were significant, least significant difference (LSD) tests were performed separately across the levels of a given factor within the levels of the other factor.

RESULTS AND DISCUSSION

Effect of Temperature. ANOVA indicated a significant constant temperature regime by year interaction, so cutleaf eveningprimrose germination is presented for each temperature regime by year (Figure 1; Table 1). When exposed to constant temperature regimes, cutleaf eveningprimrose seed germinated over at temperature range of 15 to 36 C for both 2002 and 2003 seed lots (Figures 1; Table 1). Constant temperature resulted in a maximum germination of 62% and 52% at 24 C for 2002 and 2003, respectively. Observed germination at 15, 19, 28, and 32 C was 17, 28, 44, and 31%, respectively, with less than 1% germination at 36 C for 2002 (Figure 1; Table 1). Observed germination at 15, 19, 28, 32, and 36 C was 17.5, 40, 46, 17.5, and 2.6%, respectively for 2003 (Figure 1; Table 1).

ANOVA indicated a significant alternating temperature regime by year interaction, so cutleaf eveningprimrose germination is presented for each temperature regime by year (Figure 2; Table 2). Maximum cumulative germination (73 and 70%, parameter *M* for 2002 and 2003 respectively) of cutleaf eveningprimrose occurred when seed were exposed to a 20/35 C regime (Figure 2; Table 2). The germination rate (parameter *K*) in response to the 20/35 C regime was similar to rates at 20/30, 20, and 30 C regimes in 2002 (Figure 2; Table 2). Time to 50% germination (parameter *L*) ranged from 7.2 d in the 15/30 C regime to 14.2 d in the 30 C regime in 2002 (Figure 2; Table 2). The germination rate in response to the 20/35 C regime was similar to rates at 15/30, 20/30, 10/25, and 20 C regimes in 2003 (Figure 2; Table 2). Time to 50% germination ranged from 4.2 d in the 30 C regime to 19.9 d in the 20 C regime in 2003 (Figure 2; Table 2). Total percent cumulative germination was lowest in the 10/25 C regime for both 2002 and 2003. The greater response to warm fluctuating temperatures may be the cause of weeds, like cutleaf eveningprimrose, to emerge on fallow ground where the greatest diurnal fluctuations would be expected (Gupta 1973). These germination data suggest that cutleaf eveningprimrose can germinate over a considerable part of the growing season (Figure 3) which may lead to problematic control of cutleaf eveningprimrose in North Carolina and the Southeastern U.S.

Effect of Solution pH. ANOVA indicated a significant main effect of solution pH treatment, so cutleaf eveningprimrose germination is presented by solution pH treatment averaged over temperature regimes and years (Figure 4; Table 3). Cutleaf eveningprimrose seed had the highest cumulative germination at solution pH of 4, and cumulative germination decreased with increasing solution pH. Cumulative seed germination and rate (*K*) was greater at solution pH 4 and 5 than at all other solution pHs, indicating that cutleaf eveningprimrose germination is sensitive to changes in solution pH. Germination for each solution pH began within 2 to 6.2 d of exposure of seed to the treatment solution. These data suggest that cutleaf eveningprimrose prefers acidic soil conditions, which are common throughout the major crop production regions of the North Carolina Piedmont and Coastal Plain (Tucker et al. 1997). Highly weathered soils are common throughout the Southeastern United States and soil pH values for these weathered soils are usually acidic (Singer and Munns 1999). Based on this soil characteristic and these germination data, it seems probable that cutleaf eveningprimrose will germinate in many soil types found in the southeastern portions of the United States.

Effect of Moisture Stress. ANOVA indicated a significant main effect of water stress treatment, thus cutleaf eveningprimrose germination is presented by water stress treatment averaged over temperature regime and years (Figure 4; Table 4). As water stress increased, cumulative cutleaf eveningprimrose seed germination decreased. No germination occurred when the water potential was -0.8 or -1.2, regardless of the germination temperature (data not shown). When water potential was 0.0 (seed in deionized water), maximum germination was 60% averaged across the four temperature regimes. Water-stressed seed had delayed germination onset, causing the time to 50% germination (*L*) to increase for -0.3, -0.4, and -0.6 mPa compared to 0.0 mPa in seed with adequate water. The requirement for low water stress suggests that cutleaf eveningprimrose may be dependent upon a precipitation or an irrigation event for germination in the field.

Effect of Burial Depth. Cutleaf eveningprimrose emergence decreased with increased planting depth; with maximum of 36% occurring at 14 days after planting (DAP) from the 0.5 cm depth (Figure 5). At 7 DAP, cutleaf eveningprimrose emergence was greater from burial depths of 0.5 and 1 cm than any other depth of burial. Seed on the soil surface had reduced emergence compared to seed placed just below the surface. Limited soil to seed contact, light conditions on the surface, and water availability are some environmental conditions that may limit germination of seed on the soil surface (Ghorbani et al. 1999). Seed placed just below the surface receive adequate water to emerge using the limited carbohydrate reserves of this small-seeded broadleaf (Ghorbani et al. 1999; Webb et al. 1987). Emergence was similar when seeds were planted on the surface, at 0.5 or 1 cm depths 14 DAP. Emergence on the surface or from a depth of 8 cm increased from 7 DAP to 14 DAP. Delayed emergence from depths of 4 cm or greater could be due to the larger distance to extend the coleoptile to the soil surface. Larger seed with greater carbohydrate reserves can emerge from greater depths of burial (Baskin and Baskin 1998). Cutleaf eveningprimrose seed is small at 1.2 to 1.4 mm in diameter, therefore having less carbohydrate reserves needed for emergence at greater depths. Only 5% of cutleaf eveningprimrose seed emerged from a planting depth of 4 cm 14 DAP.

Growth and Development. Cutleaf eveningprimrose leaf number increased exponentially over time (Figure 6). Lack of location effect ($P \geq 0.05$) indicates that cutleaf eveningprimrose leaf number was not location dependent. Cutleaf eveningprimrose diameter increased exponentially over time, but variation existed between locations (Figure 6). Location 1 was adjacent to a swine farm and was sprayed by lagoon effluent leading to a higher soil fertility rate (data not shown). Cutleaf eveningprimrose leaf area increased exponentially over time (Figure 6). Although leaf number per plant was not environment dependent (Figure 6), the rate of leaf expansion was much greater in the location of higher fertility after 75 d (Figure 6). Cutleaf eveningprimrose above-ground dry biomass also exhibited an exponential trend similar to leaf area (Figure 6). Trends indicate that most of the above-ground biomass can be attributed to leaf material. This is not uncommon for rosette-forming plants, like cutleaf eveningprimrose, in the vegetative stage (Uva et al. 1997). Cutleaf eveningprimrose growth exhibited an exponential trend from October to early April.

The normal sigmoidal growth trend likely did not occur because field preparation during April of each year halted growth during the linear phase and prevented an asymptotic response. The growth rate is slow between October and mid-February and the rapid linear phase of growth occurs after this period. Thus, reduced-tillage fields planted late are more likely to have increased problems with large cutleaf eveningprimrose plants. This growth rate also indicates that herbicides need to be applied either before or shortly after the linear growth phase initiates. Leaf area, whole-plant diameter, and above-ground dry biomass did exhibit location dependency, but leaf number was not affected by location effects. Even though one location was a swine waste management area and had a higher fertility, trends in leaf number per plant were similar for both experiments.

Weed Control. Due to a significant year by treatment factor interactions for cutleaf eveningprimrose, data are presented by year (Table 5). For all control data, a significant ($P \leq 0.05$) base herbicide by complement herbicide interaction was detected.

Glyphosate-IP alone controlled cutleaf eveningprimrose 83 and 84% in 1999 and 2000, respectively. A prepackaged mixture of thifensulfuron-methyl plus tribenuron methyl did not improve cutleaf eveningprimrose control when applied in mixture with glyphosate-IP during either year. Glyphosate-IP applied in mixture with 2, 4-D or flumioxazin provided the highest level of control for 6- to 12-leaf cutleaf eveningprimrose during 1999 and 2000. Flumioxazin does provide residual activity but also requires a 30 d interval prior to cotton planting with rates less than 70 g ai ha^{-1}. Paraquat alone did not effectively control cutleaf eveningprimrose during 1999 and 2000. A prepackaged mixture of thifensulfuron-methyl plus tribenuron methyl improved cutleaf eveningprimrose control only marginally when applied in mixture with paraquat in 1999 and 2000. Flumioxazin was also of limited value when applied in mixture with paraquat, whereas cutleaf eveningprimrose control was maximized when paraquat, like glyphosate, were applied with 2, 4-D with at least 90% control.

Cutleaf eveningprimrose can be difficult to control in reduced tillage systems when timely applications are not made (Fairbanks et al. 1995; Guy 1995). Based on our germination data, cutleaf eveningprimrose can germination from late-February to mid-October (Figure 3) in North Carolina. Herbicide applications made in late-February and early-March are more effective on cutleaf eveningprimrose because of the weed's small size and slowed growth (York and Culpepper 2005). When the interval between herbicide application and planting cotton (at least 30 d, York and Culpepper 2005) is sufficiently long to prevent crop injury, 2, 4-D is the most effective and economical herbicide available to control cutleaf eveningprimrose (Guy 1995; Johnson and Kendig 1997; York and Culppeper 2005). However, predicting when residues of 2, 4-D have dissipated in relation to herbicide application and crop planting can be difficult. This 30 d interval puts the ideal application timing at early March for the North Carolina cotton growing region.

These data also suggest that cutleaf eveningprimrose has capability of emerging in a variety of environmental conditions. Cutleaf eveningprimrose germinated at constant temperatures between 15 and 32 C and in all evaluated alternating temperature regimes. Germination occurred in all solution pH treatments, but was optimum with solution pH values between 4 and 6. In the piedmont and coastal plain regions of North Carolina, agricultural fields range from a maximum pH of 6.5 or less (Edwards 1999), providing a favorable environment for cutleaf eveningprimrose germination. Based on these data, cutleaf eveningprimrose germination may be optimum from shallow soil depths (0 to 1 cm) in moist cool or warm conditions generally found in March to October (Figure 3) in southeastern United States especially North Carolina. Cutleaf eveningprimrose grows slowly until late- or mid-March and then growth is linear providing a broad time window to control cutleaf eveningprimrose. Control treatments need to be applied early in March when cutleaf eveningprimrose plants are already present and before another flush of germinating plants occur before cotton planting.

SOURCES OF MATERIALS

[1]Seed Blower, Seedburo Equipment Company. 1022 W. Jackson Blvd., Chicago, IL 60607.

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

[3]SG8S Germinator. Hoffman Manufacturing Inc. International Agri-Supply. Albany, OR 97321.

[4]9.0 cm germination paper, Anchor Paper Company, 480 Broadway, St. Paul, MN 55165-0648.

[5]PEG 8000, Sigma Chemicals, P. O. Box 14508, St. Louis, MO 63178.

[6]LI-3100C Area Meter. LI-COR Biosciences, 4421 Superior St., Lincoln, NE 68504.

[7]Roundup UltraMax® herbicide product label. Monsanto Co., 800 North Lindbergh Boulevard, St. Louis, MO 63167.

[8]Induce nonionic low foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylarylpolyoxyalkane ether and isopropanol), free fatty acids, and 10% water. Helena Chemical Company, Suite 500, 6075 Popular Avenue, Memphis, TN 38137.

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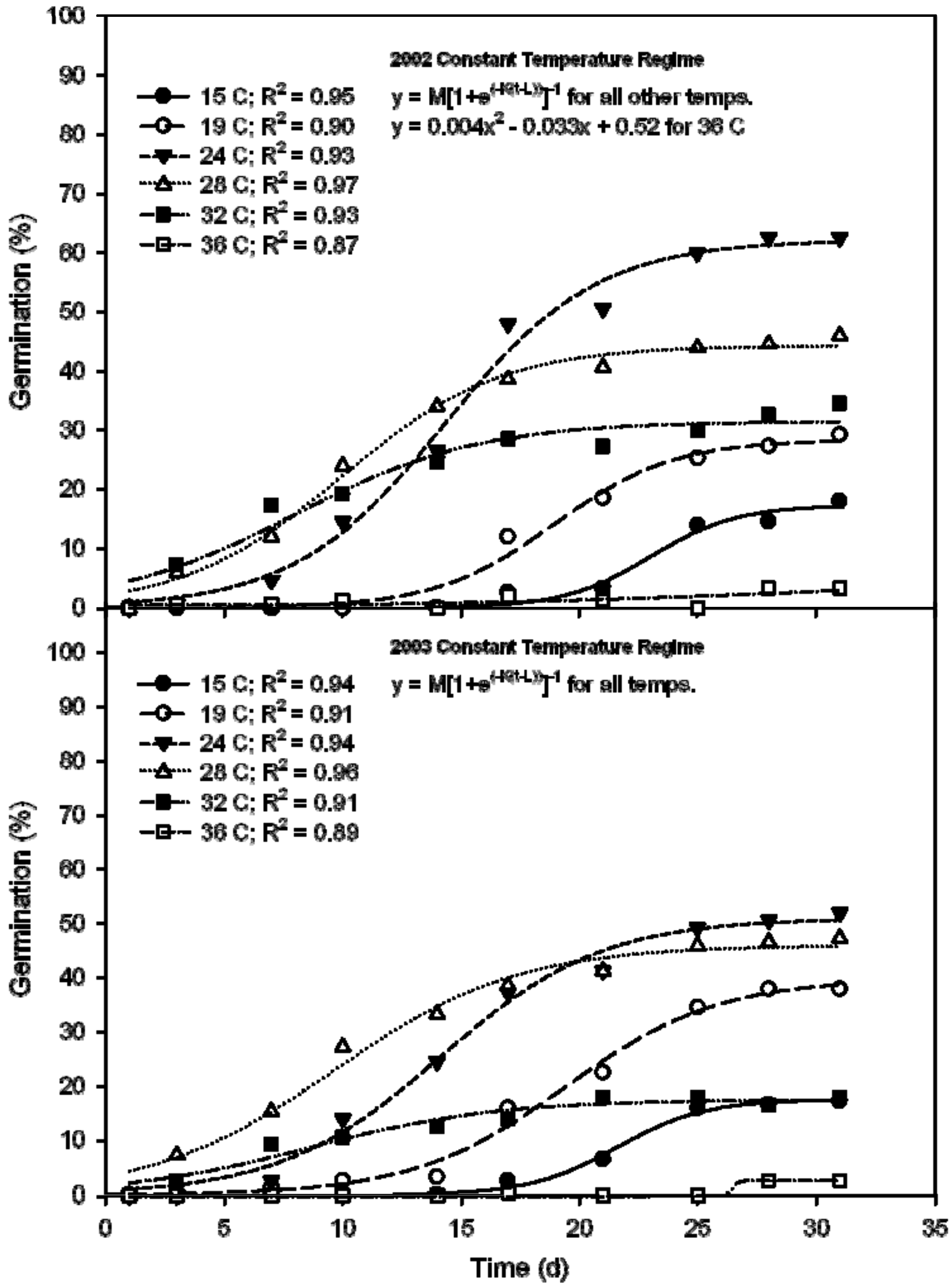

Figure 1. Influence of the main effects of six constant temperature regimes on cutleaf eveningprimrose germination in 2002 and 2003.

Table 1. Influence of the main effects of six constant temperature regimes on cutleaf eveningprimrose germination in 2002 and 2003, modeled using equation $y = M[1 + \exp(-K(t - L))]^{-1}$ with estimated parameters (and standard errors), where *y* is the cumulative percentage germination at time *t*, *M* is the asymptote or theoretical maximum for *y*, *L* is the time scale constant or lag to onset of germination, and *K* is the rate of increase.

Year	Temperature (C)	*M*	*K*	*L*	R^2
2002	15	17.30 (1.18)	1.828 (0.44)	23.02 (0.60)	0.98
	19	28.37 (1.53)	2.513 (0.53)	18.96 (0.66)	0.98
	24	62.16 (1.98)	3.198 (0.42)	14.33 (0.49)	0.99
	28	44.31 (0.99)	3.343 (0.34)	9.962 (0.40)	0.99
	32	31.49 (1.63)	3.901 (0.91)	7.989 (1.01)	0.98
	36	0.515 (0.84)	-0.033 (0.13)	0.004 (0.004)	0.87
2003	15	17.55 (0.59)	1.851 (0.28)	21.62 (0.32)	0.99
	19	39.83 (2.06)	3.223 (0.49)	19.43 (0.66)	0.99
	24	51.01 (1.61)	3.395 (0.42)	14.17 (0.50)	0.99
	28	46.01 (1.50)	3.842 (0.53)	9.679 (0.61)	0.99
	32	17.51 (0.95)	3.952 (0.93)	8.685 (1.05)	0.98
	36	2.600 (0.23)	0.101 (0.96)	2.652 (0.15)	0.96

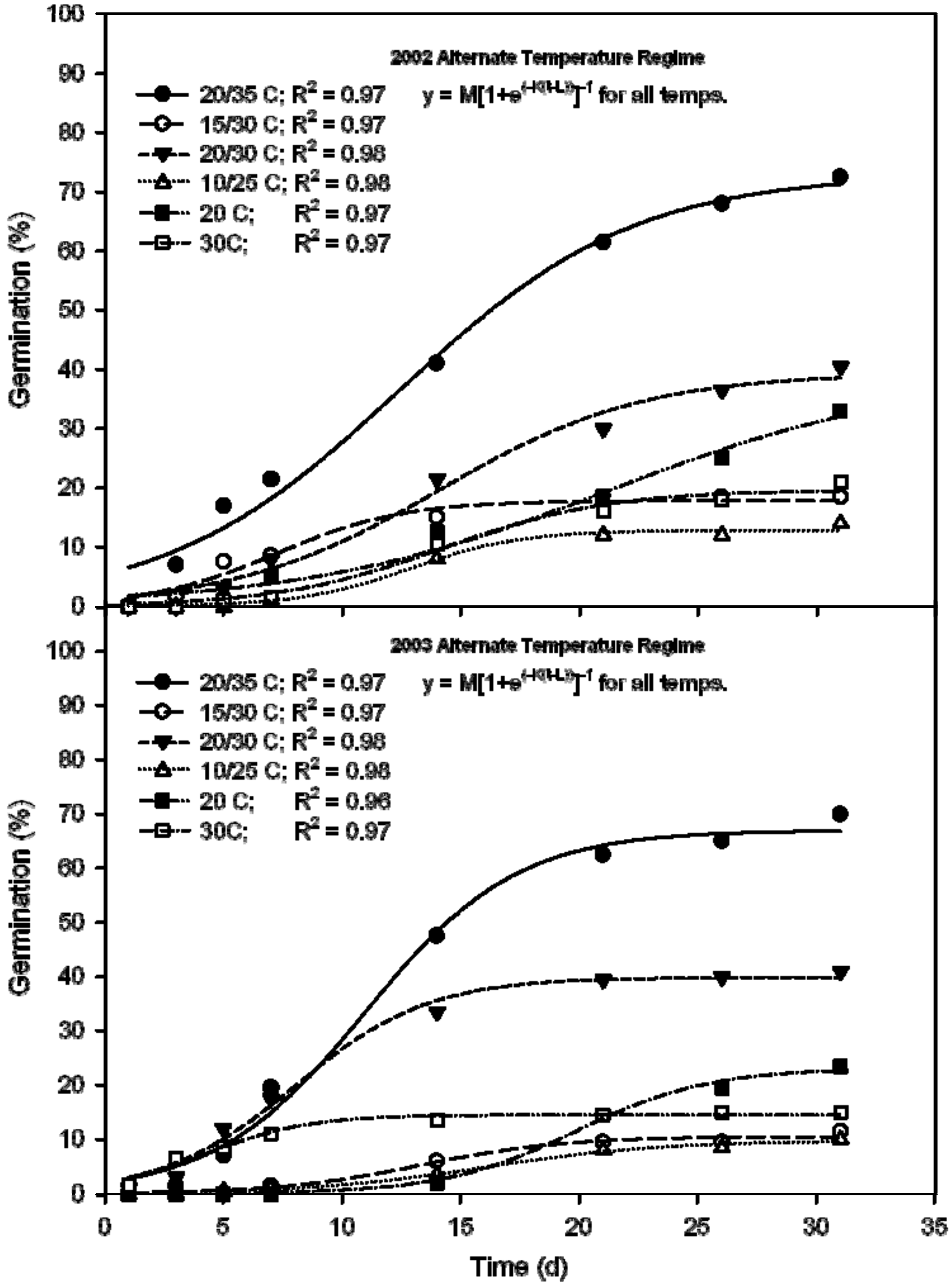

Figure 2. Influence of the main effects of four alternating temperature regimes and two constant temperature regimes on cutleaf eveningprimrose germination in 2002 and 2003.

Table 2. Influence of the main effects of four alternating temperature regimes and two constant temperature regimes on cutleaf eveningprimrose germination in 2002 and 2003, modeled using equation $y = M[1 + \exp(-K(t - L))]^{-1}$ with estimated parameters (and standard errors), where *y* is the cumulative percentage germination at time *t*, *M* is the asymptote or theoretical maximum for *y*, *L* is the time scale constant or lag to onset of germination, and *K* is the rate of increase.

Year	Temperature (C)	*M*	*K*	*L*	R^2
2002	20/35	72.98 (3.96)	4.929 (0.75)	12.43 (1.14)	0.99
	15/30	17.82 (0.90)	2.672 (0.80)	7.242 (0.89)	0.98
	20/30	39.34 (2.45)	4.295 (0.78)	14.11 (1.20)	0.98
	10/25	12.84 (0.44)	2.326 (0.52)	12.92 (0.55)	0.99
	20	39.01 (7.37)	6.424 (1.45)	21.22 (3.23)	0.98
	30	19.60 (0.99)	3.478 (0.68)	14.25 (0.91)	0.99
2003	20/35	66.97 (2.32)	3.185 (0.43)	10.99 (0.68)	0.99
	15/30	10.52 (0.51)	3.017 (0.67)	13.34 (0.85)	0.99
	20/30	39.84 (1.25)	2.797 (0.47)	8.034 (0.60)	0.99
	10/25	9.771 (0.41)	3.739 (0.51)	16.04 (0.73)	0.99
	20	14.52 (0.47)	2.191 (0.41)	4.201 (0.38)	0.99
	30	23.11 (0.87)	2.814 (0.39)	19.87 (0.46)	0.99

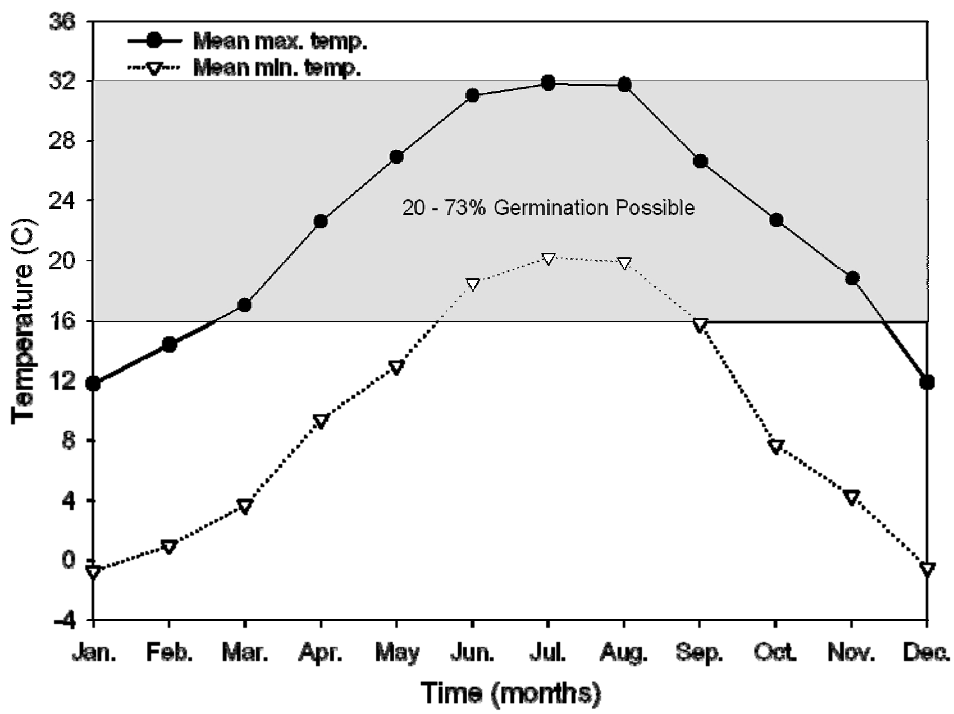

Figure 3. 30-year mean maximum and minimum temperatures for North Carolina over a calendar year.

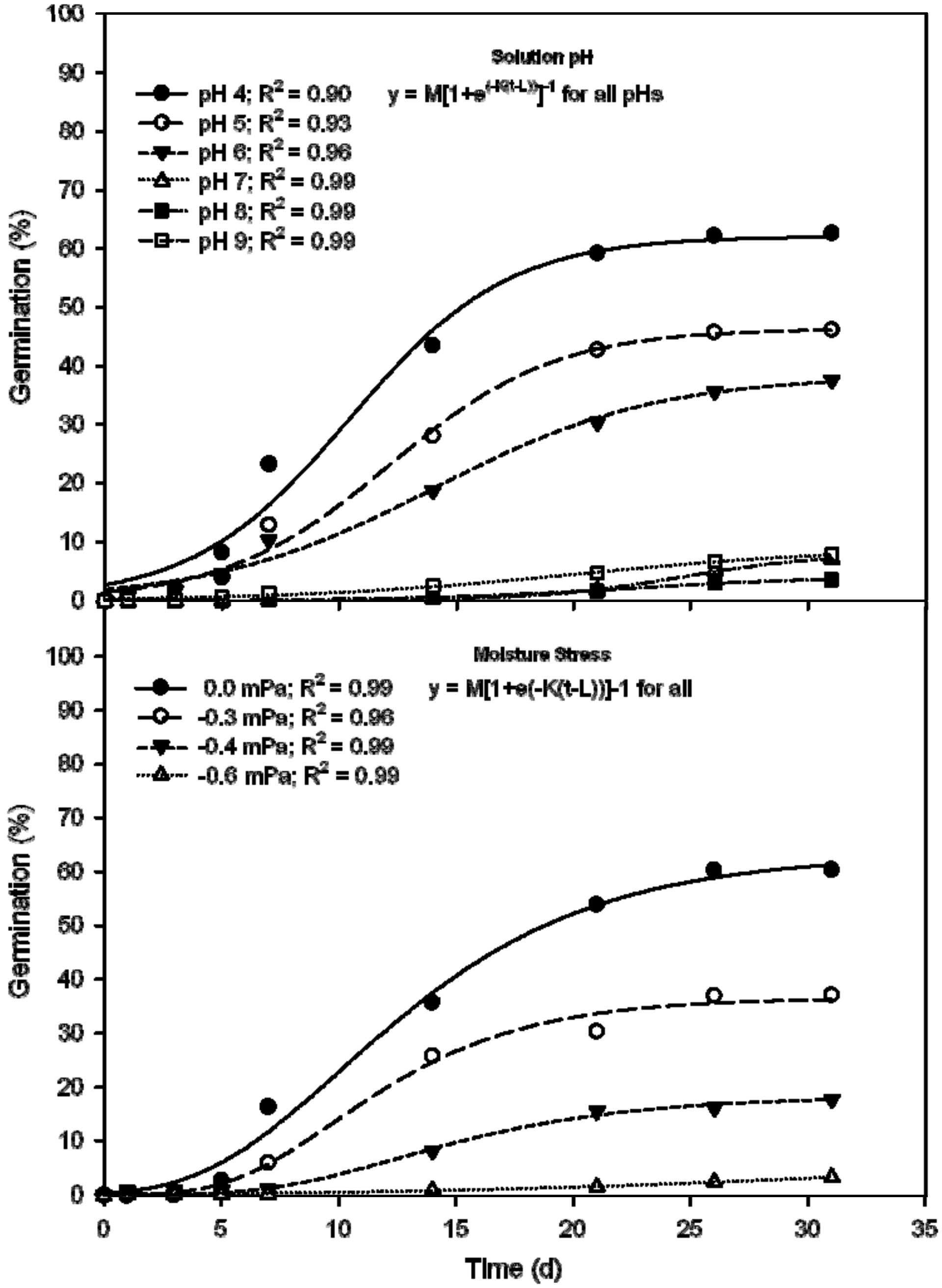

Figure 4. Influence of the main effects of solution pH and moisture stress on cutleaf eveningprimrose germination averaged across temperature regimes and years.

Table 3. Influence of the main effects of solution pH on cutleaf eveningprimrose germination averaged across temperature regimes and years, modeled using equation $y = M[1 + \exp(-K(t - L))]^{-1}$ with estimated parameters (and standard errors), where *y* is the cumulative percentage germination at time *t*, *M* is the asymptote or theoretical maximum for *y*, *L* is the time scale constant or lag to onset of germination, and *K* is the rate of increase.

pH	*M*	*K*	*L*	R^2
4	62.11 (2.60)	3.343 (0.53)	10.47 (0.84)	0.99
5	46.35 (1.69)	3.517 (0.46)	12.17 (0.71)	0.99
6	38.29 (1.94)	4.719 (0.61)	14.06 (1.01)	0.99
7	7.925 (0.30)	2.977 (0.23)	24.56 (0.34)	0.99
8	4.129 (0.25)	4.381 (0.46)	22.42 (0.76)	0.99
9	8.983 (0.62)	5.871 (0.57)	20.14 (1.17)	0.99

Table 4. Influence of the main effects of moisture stress on cutleaf eveningprimrose germination averaged across temperature regimes and years, modeled using equation $y = M[1 + \exp(-K(t - L))]^{-1}$ with estimated parameters (and standard errors), where *y* is the cumulative percentage germination at time *t*, *M* is the asymptote or theoretical maximum for *y*, *L* is the time scale constant or lag to onset of germination, and *K* is the rate of increase.

mPa	*M*	*K*	*L*	R^2
0.0	60.47 (2.58)	3.505 (0.55)	12.59 (0.82)	0.99
-0.3	35.37 (1.36)	2.574 (0.45)	11.65 (0.70)	0.99
-0.4	17.30 (0.40)	3.159 (0.32)	14.39 (0.40)	0.99
-0.6	5.238 (0.90)	7.300 (0.78)	27.47 (2.66)	0.99

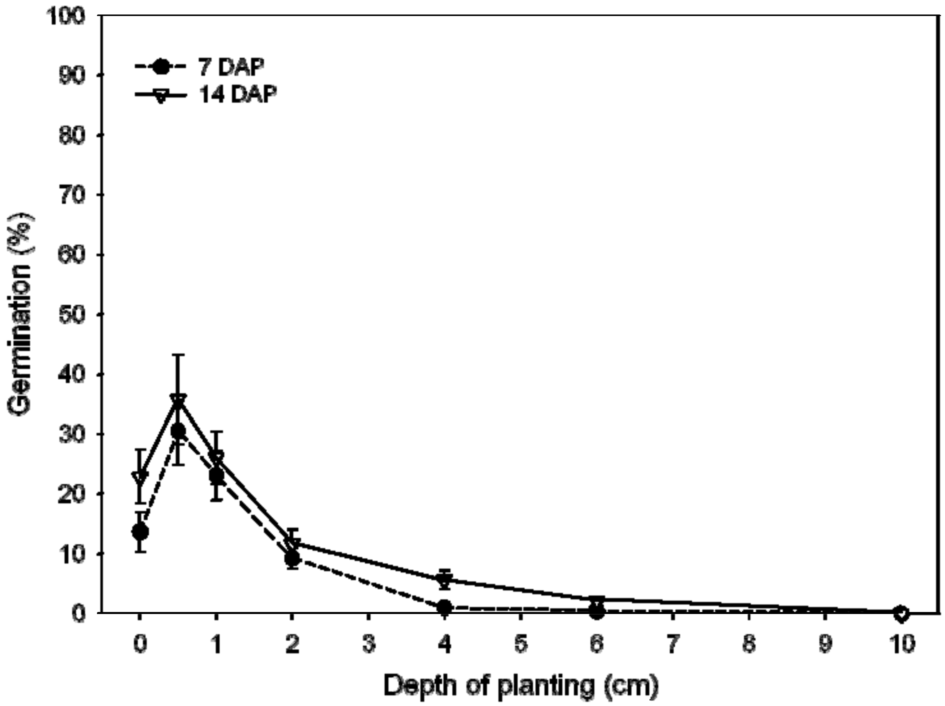

Figure 5. Cumulative emergence of cutleaf eveningprimrose seed buried 0, 0.5, 1, 2, 4, or 6 cm 7 and 14 days after planting (DAP). Vertical bars represent standard errors (SE) of the mean.

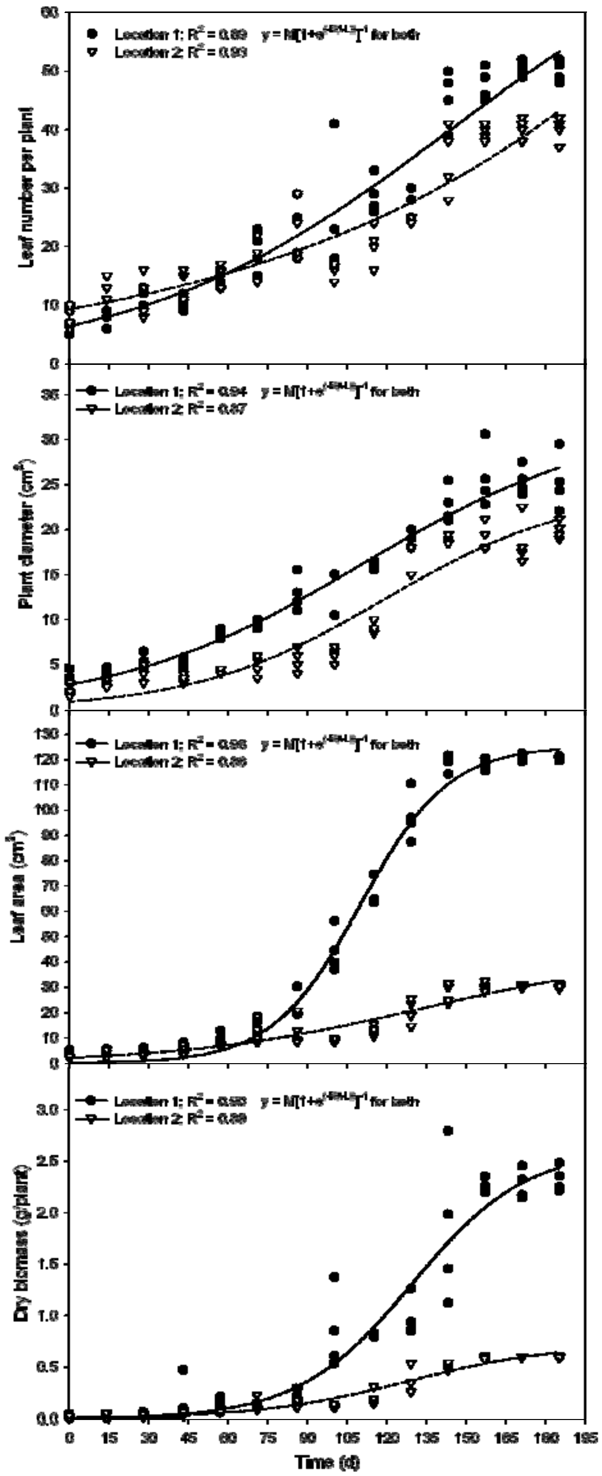

Figure 6. Cutleaf eveningprimrose leaf number per plant, plant diameter, leaf area, and dry biomass over time at two locations in 2001 and 2002.

Table 5. Cutleaf eveningprimrose control with glyphosate-IP or paraquat alone or with 2,4-D, flumioxazin, and thifensulfuron-methyl plus tribenuron methyl during 1999 and 2000[a].

Herbicide treatments[b]		Cutleaf eveningprimrose	
Base herbicide	Complement herbicide	1999	2000
		——% control——	
Glyphosate-IP	None	84 c	83 c
Glyphosate-IP	2,4-D	99 a	97 a
Glyphosate-IP	Flumioxazin	97 ab	99 a
Glyphosate-IP	Thifensulfuron-methyl plus tribenuron methyl	84 c	78 c
Paraquat	None	26 e	32 e
Paraquat	2,4-D	90 bc	91 b
Paraquat	Flumioxazin	36 d	43 d
Paraquat	Thifensulfuron-methyl plus tribenuron methyl	34 de	47 d

[a]Roundup UltraMax® herbicide product label. Monsanto Co., 800 North Lindbergh Boulevard, St. Louis, MO 63167. Means within a year followed by the same letter are not significantly based on Fisher's Protected LSD test at $P \leq 0.05$.

[b]The herbicide rates were glyphosate-IP (glyphosate-isopropylamine salt) at 0.84 kg ae ha^{-1}, paraquat at 0.70 kg ai ha^{-1}, 2,4-D (dimethylamine salt) at 0.47 kg ai ha^{-1}, flumioxazin at 90 g ai ha^{-1}, and a prepackaged mixture of thifensulfuron-methyl plus tribenuron-methyl at 17.4 g ai ha^{-1}. Nonionic surfactant at 0.25% (v/v) was included with all treatments.

Chapter 3. Weed Management with *S*-Metolachlor and Glyphosate Mixtures in Glyphosate-Resistant Strip- and Conventional-Tillage Cotton

Scott B. Clewis, John W. Wilcut, and Dunk Porterfield*

ABSTRACT. Five studies were conducted at Clayton, Rocky Mount, and Lewiston-Woodville, NC, in 2001 and 2002, to evaluate weed management, crop tolerance, and yield in strip- and conventional-tillage glyphosate-resistant (GR) cotton (*Gossypium hirsutum* L.). Cotton was treated with two glyphosate formulations; glyphosate-IP (isopropylamine salt) or glyphosate-DIA (diammonium salt), early postemergence (EPOST) alone or with *S*-metolachlor. Early-season cotton injury was minimal (3%) with either glyphosate formulation alone or in mixture with *S*-metolachlor. Weed control and cotton yields were similar for both glyphosate formulations. The addition of *S*-metolachlor to either glyphosate formulation increased control of broadleaf signalgrass *(Brachiaria platyphylla* (Griseb.) Nash.), goosegrass (goosegrass, *Eleusine indica* (L.) Gaertn.), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), and yellow foxtail (*Setaria glauca* (L.) Beauv.) 14 to 43% compared to control with glyphosate alone. *S*-metolachlor was not beneficial for late season control of entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray.), jimsonweed (*Datura*

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stramonium L), pitted morningglory (*Ipomoea lacunosa* L.), or yellow nutsedge (*Cyperus esculentus* L.). The addition of *S*-metolachlor to either glyphosate formulation increased control of common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), Palmer amaranth (*Amaranthus palmeri* S. Wats.), smooth pigweed (*Amaranthus hybridus* L.), and velvetleaf (*Abutilon theophrasti* Medicus) 6 to 46%. The addition of a late postemergence-directed (LAYBY) treatment of prometryn plus MSMA increased control to greater than 95% for all weed species regardless of EPOST treatment, and control was similar with or without *S*-metolachlor EPOST. Cotton lint yield was increased 220 kg/ha with the addition of *S*-metolachlor to either glyphosate formulation compared to yield from glyphosate alone. The addition of the LAYBY increased yields 250 and 380 kg/ha for glyphosate plus *S*-metolachlor and glyphosate systems, respectively. *S*-metolachlor residual activity allowed for a extended window for more effective LAYBY application to smaller weed seedlings instead of possible larger and harder to control weeds.

Nomenclature: glyphosate-IP, (isopropylamine salt); glyphosate-DIA, (diammonium salt); *S*-metolachlor; MSMA; prometryn; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash. #[3] BRAPP; common lambsquarters, *Chenopodium album* L. # CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; entireleaf morningglory, *Ipomoea hederacea* var. *integriuscula* Gray. # IPOHG; goosegrass, *Eleusine indica* (L.) Gaertn. # ELEIN; jimsonweed, *Datura stramonium* L. # DATST; 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; velvetleaf, *Abutilon theophrasti* Medicus # ABUTH; yellow foxtail, *Setaria*

glauca (L.) Beauv. # SETLU; yellow nutsedge, *Cyperus esculentus* L. # CYPES; cotton, *Gossypium hirsutum* L.

Additional index words: Economic returns, herbicide-resistant crops, tillage systems.

Abbreviations: ANS, as needed spray; EPOST, early-postemergence; glyphosate-IP, glyphosate (isopropylamine salt); glyphosate-DIA, (diammonium salt); fb, followed by; LAYBY, late-postemergence-directed; PDS, postemergence-directed; POST, postemergence; PRE, preemergence; PREBAN, preemergence-banded.

INTRODUCTION

Weed management in cotton (*Gossypium hirsutum* L.) often requires applications of soil, postemergence (POST), and postemergence-directed (LAYBY) herbicides for season-long weed control (Culpepper and York 1998; Wilcut et al. 1995). The use of early postemergence-directed (PDS) herbicide treatments and the requirement of special equipment for such applications to small cotton make this practice a tedious and slow process (Askew and Wilcut 1999; Culpepper and York 1998; Wilcut et al. 1997). Additionally, the need for a height differential between cotton and the weeds (Culpepper and York 1999) along with the possible need for multiple PDS treatments and/or cultivation based on weed populations increases the cost of production often without achieving the desired level of weed control (Snipes and Mueller 1992; Wilcut et al. 1995, 1997). These factors along with the ease of application, have led to many cotton growers opting to apply herbicides strictly POST (Wilcut et al. 1996). Two options for POST application in cotton are glyphosate and pyrithiobac.

Glyphosate is a non-selective, systemic herbicide that controls many grass and broadleaf weeds common to agronomic crops (Askew and Wilcut 1999; Culpepper and York 1999; Tharp and Kells 1999; VanGessel et al. 2000). Since the commercial introduction of glyphosate-resistant (GR) cotton in 1997 in the U.S., there has been a shift away from soil-applied herbicides (York personal communication). GR cotton offers many benefits to growers including broad-spectrum control of perennial and annual weeds (Bradley 1995), potential to eliminate soil-applied herbicides, ease of POST application (Culpepper and York 1999), and a favorable environmental profile (Culpepper and York 1999, Wachope et al. 1985). However, drawbacks include lack of residual weed control necessitating multiple applications (Askew et al. 2002), marginal control of Florida pusley (*Richardia scabra* L.) and yellow and purple nutsedge (*Cyperus esculentus* L. and *C. rotundus* L.), and the requirement of timely applications for control of annual morningglories (Faircloth et al. 2001). Glyphosate can only be applied POST up to the 4 leaf (L) stage[1]. After the 4L stage, glyphosate should be applied PDS at the base of the plant[1] to minimize glyphosate contact with the cotton foliage. Research has shown glyphosate uptake after the 4L growth stage can result in glyphosate accumulation in reproductive tissues (Pline et al. 2001, 2002a). Accumulation combined with lower expression of the altered enolpyruvylshikimate-3-phosphate synthase (EPSPS) in male reproductive structures can cause premature fruit abortion, poor seed set, abnormalities in male reproductive structures, and pollen sterility (Jones and Snipes 1999; Pline et al. 2002a, 2002b).

Cotton growers often must apply a residual LAYBY treatment for season-long weed control (Askew et al. 2002; Scott et al. 2001, 2002). Because of the lack of residual activity from glyphosate, weed emergence late in the season can be a problem if cotton has poor canopy closure from early-season weed interference (Wilcut et al. 2003). Cotton has tolerance to *S*-metolachlor EPOST and *S*-metolachlor provides residual control of many annual grass and small-seeded broadleaf weeds including *Amaranthus* spp., Florida pusley, and common lambsquarters (*Chenopodium album* L.) (Grichar et al. 2004). An additional benefit of *S*-metolachlor is that it offers a different site of action for resistance management, and application flexibility (Mallory-Smith and Retzinger 2003).

The recent increase in strip-tillage cotton production on the mid-Atlantic and Southeastern Coastal Plain (Anonymous 2002), and the lack of data concerning weed management in strip-tillage systems necessitates additional research. There are several advantages for utilizing strip-tillage production systems. These advantages include: (1) water conservation and reduction of sand blasting of cotton on sandy soils, (2) reduced tillage operations and the number of passes across the field, and (3) improvement in soil tilth and water-holding capacity over time (Bradley 1995). Strip-tillage production systems work well in soils that develop a hardpan or plow layer that impedes root growth (Sholar et al. 1995). The objectives of this research were to evaluate weed management, crop response, and yield from two glyphosate formulations[2, 3] alone and in mixture with *S*-metolachlor compared to similar systems without *S*-metolachlor, in both strip- and conventional-tillage cotton.

MATERIALS AND METHODS

Field studies were conducted at the Central Crops Research Station near Clayton, North Carolina in 2001 and 2002, the Upper Coastal Plain Research Station near Rocky Mount, North Carolina in 2001 and 2002, and the Peanut Belt Research Station near Lewiston-Woodville, North Carolina in 2002. Soils were a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudults) with 1.8% organic matter and a pH of 5.9 at Clayton, a Goldsboro fine sandy loam (fine-loamy, siliceous, thermic Aquic Paleudults) with 1.0% organic matter and a pH of 6.0 at Rocky Mount, and a Goldsboro sandy loam with 1.1% organic matter and a pH of 5.8 at Lewiston-Woodville. The experimental design was a randomized complete block design with each treatment replicated three times. Treatments were arranged as a split block with tillage as the main plot and herbicide treatments as the subplots to facilitate tilling and planting. The herbicide program consisted of a factorial arrangement of glyphosate formulation, EPOST, and LAYBY herbicide treatment options. Treatments consisted of a nontreated check, glyphosate-IP (glyphosate-isopropylamine salt) at 1.12 kg active ai/ha EPOST alone, glyphosate-IP EPOST followed by (fb) prometryn at 1.12 kg ai/ha plus MSMA at 2.24 kg ai/ha LAYBY, *S*-metolachlor at 1.12 kg ai/ha plus glyphosate-IP EPOST, and *S*-metolachlor plus glyphosate-IP EPOST fb prometryn plus MSMA LAYBY, glyphosate-DIA (glyphosate-diammonium salt) at 1.12 kg ai/ha EPOST alone, glyphosate-DIA EPOST fb prometryn plus MSMA LAYBY, *S*-metolachlor plus glyphosate-DIA EPOST alone, and *S*-metolachlor plus glyphosate-DIA EPOST fb prometryn plus MSMA LAYBY. Nonionic surfactant[4] at 0.25% (v/v) was included with prometryn plus MSMA LAYBY treatments. All weed management systems were used in both strip-and conventional-tillage cotton production systems and included pendimethalin at 1.12 kg ai/ha preemergence-banded (PREBAN) on a 46 cm wide band on the seed drill. Cotton size at the time of the EPOST application was 3 to 4L and 12L at the LAYBY application.

In the strip-till systems, glyphosate-IP at 1.12 kg/ha was applied 2 to 3 weeks before planting for wheat (*Triticum aestivum* L.) cover crop burndown. At planting, all strip-till systems received paraquat at 0.56 kg ai/ha plus a nonionic surfactant at 0.25% (v/v) for additional cover crop burndown. Herbicides were applied with a compressed-air sprayer calibrated to deliver 140 L/ha at 176 kPa. Land preparation included opening the soil with the subsoiler shank of a Ro-Till planter, with the planter units removed to open the soil and destroy the plowplans beneath the rows 2 wk before planting. Fluted coulters attached to the planter smoothed the soil and broke up large clods. Rolling crumblers mounted immediately behind the fluted coulters, served to further smoothen the seedbed. Approximately 60% of the surface residue remained in the tilled area, and 90 to 95% of the nontilled area was covered with residue after seedbed preparation (data not shown).

Cotton seeds were planted using a conventional planter in both tillage systems. Cotton varieties ‘Stoneville 4892 BG/RR’ (Clayton 2001), ‘Paymaster 1218 BG/RR’ (Rocky Mount 2001), ‘Deltapine 5415 RR’ (Clayton 2002), ‘Deltapine 451 BG/RR’ (Lewiston-Woodville 2002), and ‘FiberMAX 989 RR’ (Rocky Mount 2002) were planted. Cotton varieties were selected based on cotton yield performance in North Carolina Official Variety Trials (Bowman 2002). Planting dates ranged from April 25 to May 7. Cotton was seeded at 15 seeds/m of row with aldicarb applied at 1.0 kg ai/ha in-furrow for early-season insect control. Plots were 6.1 m long and consisted of four 91 cm wide rows at Lewiston-Woodville and Rocky Mount and four 97 cm wide rows at Clayton. Depending on location, application dates for all herbicide programs ranged between April 25 to May 7

(PREBAN), May 28 to May 31 (EPOST), and June 18 to July 16 (LAYBY). Weed species, densities, and growth stages at EPOST applications are listed in Table 1.

Early-, mid-, and late-season weed control based on biomass and population reductions, was estimated visually on a scale of 0 to 100, where 0 = no control and 100 = death of all plants (Frans et al. 1986). Three separate injury parameters (stunting, discoloration, and stand reduction) were visually estimated for cotton 1 to 2 weeks after EPOST treatment and late in the season. Overall injury was also estimated as a combination of the three injury parameters. Only late-season weed ratings are reported. The two center rows of each plot were harvested once with a spindle picker modified for small-plot research between October 20 and November 10, depending on the location. Lint and seed yield were adjusted based on the 2-yr statewide average percent lint composition of each cultivar from the North Carolina Official Variety Testing Trials (Bowman 2002).

An economic budget developed by the North Carolina Cooperative Extension Service (Brown 2003) that included operating inputs, fixed costs, and cotton yield value was modified to represent the various weed management programs. Adjustments in operating costs included crop seed and technology fees, herbicide application costs, and herbicide and adjuvant costs. Costs of seed, technology, herbicides, and adjuvants were based on averages of the quoted prices from three local agricultural suppliers in 2003. Planting cost including cost of seed and technology fees were \$54.30/ha for glyphosate-resistant programs. Estimated costs of PREBAN, EPOST, and LAYBY applications were \$2.90, \$5.50, and \$7.80/ha, respectively, based on the performance rates of machines and hourly operation costs (Anonymous 1998; Askew and Wilcut 1999). Chemical costs per ha were as follows: glyphosate, $25.83/ha; *S*-metolachlor, $34.44/ha; MSMA, $12.77/ha; nonionic surfactant, $1.65/ha; pendimethalin, $8.00/ha; and prometryn, $17.28/ha. Crop value was estimated at $1.36/ha based on seasonal averages of the New York Stock Cotton Exchange. The enterprise budget was adjusted by multiplying the lint yield from each herbicide program with the estimated market price. This budget did not consider discounts, such as micronair and extraneous matter, nor was it based on true lint percentages on a per-plot basis. However, the economic analysis did allow general comparisons between the various herbicides and tillage effects on profitability by including the overriding effects of yield and cost of herbicide programs (Askew et al. 2002).

Nontreated control plots could not be harvested because of weed biomass interference with machinery. Therefore the nontreated controls were removed before analysis. Homogeneity of variance was examined by plotting residuals, and visually estimated percentage data were converted to square roots of the arcsine to stabilize variance. Transformed percentage data and nontransformed yield and economics data were subjected to analysis of variance (ANOVA), and treatment sums of squares were partitioned to reflect the split-plot treatment design or the year-location effects (McIntosh 1983). Where year, location, and glyphosate treatments were not significant, data were pooled. Data were analyzed separately if significant year by location effects were detected. Appropriate transformed means were separated using Fisher's Protected least significant difference (LSD) at P=0.05; however, nontransformed means are presented for clarity.

RESULTS AND DISCUSSION

Crop Response. Cotton injury was pooled over locations and there was an EPOST main treatment effect. Early-season cotton injury (Table 2) was minimal (3%) with the addition of *S*-metolachlor to either glyphosate formulation and was consistent with injury observed previously with the *S*-metolachlor solvent system (Edmisten et al. 2003). This injury is characterized by transient necrotic speckling on exposed leaves. Cotton in the nontreated control was stunted due to early season weed interference compared to cotton in plots where herbicides were used. No differences were observed in cotton response to herbicide treatments for evaluations made later in the season (data not shown).

Weed Control. The lack of a significant treatment by location interaction allowed the pooling of data for late-season weed control for each species over all locations. The interaction of EPOST by LAYBY treatments was significant for all weed species. Weed control was similar for both glyphosate formulations, thus data were also averaged over glyphosate formulations. Hereafter, glyphosate will refer to both glyphosate-IP and glyphosate-DIA. Similar weed control with both glyphosate formulations has been reported in strip-tillage cotton (Price et al. 2002). Additionally, tillage did not affect weed control with herbicides evaluated and allowed pooling over tillage (Tables 2 and 3).

Broadleaf signalgrass. Glyphosate EPOST controlled broadleaf signalgrass (*Brachiaria platyphylla* (Griseb.) Nash.) 44% when evaluated late season while glyphosate plus *S*-metolachlor EPOST controlled 58% of the emerged weeds (Table 2). Other research has shown the benefits of adding a chloroacetamide herbicide, like *S*-metolachlor, for broadleaf signalgrass control in peanut (*Arachis hypogaea* L.) (Chamblee et al. 1982). However this level of control is not adequate for annual grass control. Annual grasses like broadleaf signalgrass not only compete with the cotton crop for nutrients (especially nitrogen); their presence at harvest can lead to quality reductions due to a reduction in harvest efficiency and contamination (Edmisten 2005). Research has shown that broadleaf signalgrass can emerge rapidly in high numbers under warm moist conditions throughout the growing season (Burke et al. 2003). Therefore, multiple herbicide applications are generally needed for season-long control. Glyphosate alone or in mixture with *S*-metolachlor fb the LAYBY of prometryn plus MSMA controlled broadleaf signalgrass $\geq$98%. Due to the lack of residual control of glyphosate, annual grass control is improved with a residual soil-applied herbicide or a residual LAYBY application (Askew et al. 2002; Culpepper and York 1999; Faircloth et al. 2001).

Common lambsquarters. Glyphosate EPOST controlled common lambsquarters (*Chenopodium album* L.) 64% while glyphosate plus *S*-metolachlor EPOST controlled 84% (Table 2). *S*-metolachlor provides some residual control of common lambsquarters (Paulsgrove and Wilcut 2001). Glyphosate EPOST alone or in mixture with *S*-metolachlor fb a LAYBY treatment controlled common lambsquarters 100%. Previous research with bromoxynil or glyphosate EPOST fb a LAYBY treatment of cyanazine plus MSMA provided similar levels of control (Askew et al. 2002; Paulsgrove and Wilcut 1999, 2001).

Common ragweed. Glyphosate EPOST alone controlled common ragweed (*Ambrosia artemisiifolia* L.) 54% and the addition of *S*-metolachlor in an EPOST tank mixture increased control 6 percentage points (Table 2). Due to its rapid growth rate and ability to emerge early in the season, common ragweed can be very competitive and detrimental to early season cotton growth (Clewis et al. 2001). The tall growth habit (as tall as 138 cm) and large biomass (1,150 g per plant) at harvest of common ragweed would likely interfere with harvesting efficiency (Clewis et al. 2001). Thus near 100% control is needed for this problematic annual broadleaf weed. Continuous use of glyphosate has lead to suspected glyphosate-resistant biotypes of common ragweed in Arkansas (Scott et al. 2005; Sellers et al. 2005). However, there has been no documented case of common ragweed resistance to with *S*-metolachlor or metolachlor (Heap 2005). Thus, the addition of *S*-metolachlor with glyphosate applications may provide a resistance management tool for common ragweed biotypes resistant to other modes of action. While *S*-metolachlor does not provide 100% control it does provide 2-four weeks of suppression on the coarse-textured soils of the mid-Atlantic and Southern Coastal Plain (authors' personal observations) as evidenced by these data. The addition of a LAYBY treatment following glyphosate EPOST alone or in mixture with *S*-metolachlor controlled common ragweed 100%.

Entireleaf and pitted morningglory. Glyphosate EPOST or tank mixed with *S*-metolachlor controlled entireleaf (*Ipomoea hederacea* var. *integriuscula* Gray.) and pitted morningglory (*Ipomoea lacunosa* L.) no more than 40%, respectively, when evaluated late season (Tables 2 and 3). This level of control is not adequate as the vining growth of *Ipomoea* spp. interferes with harvesting efficiency, thus leading to cotton yield and fiber quality reductions (Wood et al. 1999). *Ipomoea* spp. have been reported to grow laterally 0.91 m to nearby plants or structure to grow up for access to light above the canopy (Price and Wilcut 2002). Glyphosate alone or in mixture with *S*-metolachlor fb a LAYBY controlled entireleaf and pitted morningglory similarly ($\geq$97%).

Goosegrass. Glyphosate EPOST controlled goosegrass (*Eleusine indica* (L.) Gaertn.) 33% while glyphosate plus *S*-metolachlor EPOST controlled 76% of the population (Table 2). Lack of residual control by glyphosate allowed goosegrass germination throughout the growing season. Increased soil temperatures late in the season are conducive to increased goosegrass germination and emergence (Nishimoto and McCarty 1997). Culpepper and York (1999) also reported that the lack of residual activity in glyphosate-only systems resulted in late season emergence of goosegrass. Continuous use of glyphosate has lead to resistant biotypes of goosegrass in Malaysia (Baerson et al. 2002). However, there has been no documented case of resistance to goosegrass with *S*-metolachlor or metolachlor (Heap 2005). Thus, the addition of *S*-metolachlor would provide a resistance management tool as well as increased control of goosegrass (Mallory-Smith and Retzinger 2003). Glyphosate alone or in mixture with *S*-metolachlor fb a LAYBY controlled goosegrass similarly (>96%). Previous studies have reported that when residual soil-applied or LAYBY herbicides were used in conjunction with glyphosate-containing programs, control of goosegrass increased (Askew et al. 2002; Culpepper and York 1999).

Jimsonweed. Jimsonweed (*Datura stramonium* L.) was controlled 38% with glyphosate EPOST (Table 2). The inclusion of *S*-metolachlor to glyphosate EPOST was not beneficial for improving late-season control. Jimsonweed is a very problematic weed for North Carolina cotton growers due to climatic conditions, which are conducive to its growth and its competitiveness with cotton (Scott et al. 2000). Glyphosate EPOST alone or in mixture with *S*-metolachlor fb the LAYBY controlled jimsonweed 100%.

Large crabgrass. Glyphosate EPOST, as seen with goosegrass did not provide full-season control of large crabgrass (*Digitaria sanguinalis* (L.) Scop.) (38%). The addition of *S*-metolachlor in tank mixture improved late-season control 36 percentage points (Table 3). In other studies, grass control was increased when glyphosate programs included a residual herbicide (Askew et al. 2002; Culpepper and York 1999). Glyphosate alone or in mixture with *S*-metolachlor fb the LAYBY controlled large crabgrass similarly ($\geq$96%). Glyphosate, prometryn, and MSMA all control annual grasses such as large crabgrass (Burke and Wilcut 2004; Porterfield et al. 2003; York and Culpepper 2003).

Palmer amaranth. Glyphosate EPOST alone controlled Palmer amaranth (*Amaranthus palmeri* S. Wats.) 27% and control was improved 47 percentage points by the inclusion of *S*-metolachlor in tank mixture with glyphosate (Table 3). Palmer amaranth has extremely fast growth rates in North Carolina early in the season, with height increases frequently in excess of 15 cm per week (Schroeder et al. 2005). The rapid growth rate allows later germinating Palmer amaranth to quickly grow too tall for adequate spray coverage with PDS or LAYBY herbicides. Consequently a residual herbicide such as *S*-metolachlor in tank mixture with glyphosate EPOST may allow for smaller Palmer amaranth plants at the time of PDS or LAYBY application. Additionally, biotypes of Palmer amaranth resistant to glyphosate have been reported in 2005 in Georgia and in North Carolina (Stanley Culpepper and Alan York, personal communications, and authors' personal observations). These data show that *S*-metolachlor may be an effective management tool for glyphosate resistance in Palmer amaranth. Glyphosate alone or in mixture with *S*-metolachlor fb a residual LAYBY controlled Palmer amaranth similarly ($\geq$96%). Previous research has also shown less effective control of Palmer amaranth without a residual herbicide (Dotray et al. 1996; Scott et al. 2001).

Smooth pigweed. Glyphosate EPOST alone controlled smooth pigweed (*Amaranthus hybridus* L.) 45% and control improved to 70% with *S*-metolachlor as a tank mixture with glyphosate (Table 3). Glyphosate EPOST alone or in mixture with *S*-metolachlor fb the LAYBY controlled smooth pigweed 100%. Previous research has shown that season-long control of smooth pigweed requires a residual herbicide or multiple herbicide applications (Culpepper and York 1997; Scott et al. 2001).

Velvetleaf. Velvetleaf (*Abutilon theophrasti* Medicus) was controlled 30% late season with glyphosate EPOST alone and control improved 9 percentage points with a tank mixture of *S*-metolachlor (Table 3). Glyphosate alone or in mixture with *S*-metolachlor fb the LAYBY controlled velvetleaf similarly (100%). Other studies have shown that the addition of a residual herbicide and MSMA LAYBY significantly increased control of velvetleaf (Askew et al. 2002; Jordan et al. 1997). Velvetleaf control is important as 3.5 plants/m of row can cause 84% cotton yield losses and can cover cotton plants 3 to 5 weeks after planting (Bailey et al. 2003).

Yellow foxtail. Yellow foxtail (*Setaria glauca* (L.) Beauv.) was controlled 35% late season with glyphosate EPOST alone and control was improved to 67% with the addition of *S*-metolachlor (Table 3). Glyphosate alone or in mixture with *S*-metolachlor EPOST fb a residual LAYBY controlled yellow foxtail similarly ($\geq$96%).

Yellow nutsedge. Yellow nutsedge (*Cyperus esculentus* L.) was controlled 63% late season with glyphosate EPOST alone and control was not improved the addition of *S*-metolachlor in tank mixture (Table 3). Glyphosate alone or in mixture with *S*-metolachlor EPOST fb the LAYBY controlled yellow nutsedge similarly (95% and 96%, respectively). MSMA, a tank mixture component of the LAYBY, has been widely used for a number of years to control yellow nutsedge in cotton. Pendimethalin and prometryn do not control yellow nutsedge (Burke and Wilcut 2004; Clewis et al. 2005; Porterfield et al. 2003).

Cotton Lint Yield. A lack of a significant treatment by location interaction allowed the pooling of cotton lint yield data over locations. The interaction of EPOST by LAYBY treatments was significant for yield. Yield was similar for both glyphosate formulations and tillage systems, thus data were also averaged over glyphosate formulations and tillage (Table 4). Glyphosate EPOST alone systems yielded the least at 620 kg/ha (Table 4). Glyphosate EPOST alone does not provide residual control of weeds (Table 2 and 3), and later emerging weeds reduced yields. The inclusion of *S*-metolachlor to glyphosate EPOST in tank mixture increased cotton lint yield to 840 kg/ha. This yield increase reflects improved control of broadleaf signalgrass, common lambsquarters, common ragweed, goosegrass, large crabgrass, Palmer amaranth, smooth pigweed, velvetleaf, and yellow foxtail from the addition of *S*-metolachlor (Tables 2 and 3). Weed management systems that did not contain a LAYBY treatment yielded less than LAYBY-containing systems. Lower yields may be attributed to late season interference from weeds (Buchanan and Burns 1970). Similar yield reductions have been seen in other studies (Askew and Wilcut 1999; Culpepper and York 1999; Wilcut et al. 2003). Cotton treated with glyphosate EPOST fb a LAYBY or glyphosate plus *S*-metolachlor EPOST fb a LAYBY yielded 1000 and 1090 kg/ha, respectively. Similar research has also shown increases in cotton lint yield with systems including a LAYBY of MSMA plus prometryn or cyanazine (Corbett et al. 2002; Porterfield et al. 2003).

Economic Returns. A lack of a significant treatment by location interaction allowed pooling of data for net economic returns over locations. The interaction of EPOST by LAYBY treatments was significant for net economic returns. Economic returns were similar for both glyphosate formulations and tillage systems, thus data were also averaged over glyphosate formulations and tillage (Table 4). Trends in net economic returns were similar to yield trends, which reflected the level of weed control provided by each herbicide system. Systems with less weed control and yield resulted in lower net economic returns. Glyphosate EPOST alone systems returned $739/ha, whereas the inclusion of *S*-metolachlor in mixture with glyphosate EPOST increased net returns to $964/ha. Consistency in yield and economic returns are of critical importance to cotton growers. Glyphosate alone or tank-mixed with *S*-metolachlor EPOST fb a residual LAYBY resulted in equivalent net returns ($1255/ha and $1304/ha, respectively). This high net return reflected the high level of weed control seen in both systems.

Economically effective weed management can be obtained in both strip and conventional glyphosate-resistant cotton with glyphosate EPOST fb prometryn plus MSMA LAYBY. Cotton tolerance and weed control were similar with either glyphosate formulation as was cotton lint yield and economic returns for some weed species. *S*-metolachlor provided residual control between glyphosate EPOST application (4L cotton POST over-the-top) and the LAYBY (12-14L cotton). *S*-metolachlor allowed for a more effective LAYBY application on some small weed seedlings instead of possible larger and harder to control weeds (Jordan et al. 1992, 1993; Poston et al. 1993). The addition of *S*-metolachlor EPOST provides growers an additional site of action in GR cotton that can optimize yield potential and economic return, and reduce selection pressure for possible GR weed species and small-seeded broadleaf weeds, especially annual grasses that have developed resistance to other sites-of-action (Heap 2005). In particular, the inclusion of *S*-metolachlor would be particularly effective on common lambsquarters, goosegrass, large crabgrass, Palmer amaranth, smooth pigweed, and yellow foxtail.

SOURCES OF MATERIALS

[1]Roundup UltraMax® herbicide product label. Monsanto Co., 800 North Lindbergh Boulevard, St. Louis, MO 63167.

[2]Roundup UltraMax® herbicide product label. Monsanto Co., 800 North Lindbergh Boulevard, St. Louis, MO 63167.

[3]Touchdown 3AE herbicide product label. Syngenta Corporation, 2200 Concord Pike, PO Box 8353, Wilmington, DE 19803-8353.

[4]Induce nonionic low foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylarylpolyoxyalkane ether and isopropanol), free fatty acids, and 10% water. Helena Chemical Company, Suite 500, 6075 Popular Avenue, Memphis, TN 38137.

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Table 1. Weed species, growth stages, and densities in the nontreated control at early-postemergence (EPOST) application[a].

	Locations				
Weed species	Clayton 2001	Clayton 2002	Lewiston 2002	Rocky Mt 2001	Rocky Mt 2002
	leaf number[b] (plants/m^2)				
Broadleaf signalgrass	—— ——	—— ——	—— ——	1-3 (12)	1-2 (5)
Common lambsquarters	1-7 (9)	—— ——	2-4 (15)	—— ——	2-10 (10)
Common ragweed	—— ——	—— ——	1-4 (10)	C-5 (15)	C-4 (10)
Entireleaf morningglory	C-2 (14)	C-4 (7)	C-4 (9)	C-2 (3)	C-3 (5)
Goosegrass	1-2 (6)	1-3 (10)	2-4 (50)	C-3 (3)	1-3 (7)
Jimsonweed	C-3 (12)	C-3 (6)	—— ——	C-2 (5)	2-6 (10)
Large crabgrass	2-4 (11)	2-4 (6)	1-3 (10)	—— ——	1-2 (5)
Palmer amaranth	—— ——	C-5 (19)	—— ——	—— ——	2-8 (10)
Pitted morningglory	—— ——	—— ——	C-3 (5)	C-2 (6)	C-2 (8)
Smooth pigweed	C-5 (12)	C-4 (5)	—— ——	C-3 (3)	—— ——
Velvetleaf	—— ——	C-2 (7)	—— ——	—— ——	C-3 (7)
Yellow foxtail	1-3 (8)	1-3 (4)	—— ——	—— ——	—— ——
Yellow nutsedge	—— ——	—— ——	8-13 cm (17)	5-8 cm (15)	5-8 cm (9)

[a]Weed counts were taken between June 8 and June 24 depending on location.

[b]Leaf numbers represented by ‘C’ stand for cotyledon growth stage.

Table 2. Interaction of early-postemergence (EPOST) and late postemergence-directed (LAYBY) herbicide treatments on early-season crop injury and late season broadleaf signalgrass, common lambsquarters, common ragweed, entireleaf morningglory, goosegrass, and jimsonweed control averaged over location, years, tillage options, and glyphosate formulations[a].

Herbicide system[b]		Early crop injury	Broadleaf signalgrass	Common lambsquarters	Common ragweed	Entireleaf morningglory	Goosegrass	Jimsonweed
EPOST[c]	LAYBY[d]	———	———	———	%	———	———	———
Glyphosate	No	1 b	44 c	64 c	54 c	37 b	33 c	38 b
Glyphosate + *S*-metolachlor	No	3 a	58 b	84 b	60 b	39 b	76 b	41 b
Glyphosate	Yes	1 b	98 a	100 a	100 a	98 a	96 a	100 a
Glyphosate + *S*-metolachlor	Yes	3 a	99 a	100 a	100 a	98 a	99 a	100 a

[a]Roundup UltraMax® herbicide product label. Monsanto Co., 800 North Lindbergh Boulevard, St. Louis, MO 63167. Touchdown 3AE herbicide product label. Syngenta Corporation, 2200 Concord Pike, PO Box 8353, Wilmington, DE 19803-8353. Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

Table 2. (cont'd)

[b]Cotton cultivars 'Stoneville 4892 BG/RR', 'Paymaster 1218 BG/RR', 'Deltapine 5415 RR', 'Deltapine 451 BG/RR' and 'Fibermax 989 RR' were planted conventionally and in strip-tillage cotton production systems. All treatments included pendimethalin at 1.12 kg ai/ha preemergence-banded (PREBAN) on a 46 cm wide band on the crop drill.

[c]The early postemergence (EPOST) herbicide rates were glyphosate at 1.12 kg ai/ha and *S*-metolachlor at 1.12 kg ai/ha.

[d]The late post-directed (LAYBY) herbicide rates were prometryn at 1.12 kg ai/ha, MSMA at 2.24 kg ai/ha and NIS at 0.25% v/v.

Table 3. Interaction of early-postemergence (EPOST) and late postemergence-directed (LAYBY) herbicide treatments on late-season large crabgrass, Palmer amaranth, pitted morningglory, smooth pigweed, velvetleaf, yellow foxtail, and yellow nutsedge control averaged over location, years, tillage options, and glyphosate formulations[a].

Herbicide system[b]		Large crabgrass	Palmer amaranth	Pitted morningglory	Smooth pigweed	Velvetleaf	Yellow foxtail	Yellow nutsedge
EPOST[c]	LAYBY[d]				%			
Glyphosate	No	38 c	27 c	39 b	45 c	30 c	35 c	63 b
Glyphosate + *S*-metolachlor	No	74 b	73 b	40 b	70 b	39 b	67 b	65 b
Glyphosate	Yes	96 a	96 a	98 a	100 a	100 a	96 a	95 a
Glyphosate + *S*-metolachlor	Yes	99 a	98 a	97 a	100 a	100 a	100 a	96 a

[a]Roundup UltraMax® herbicide product label. Monsanto Co., 800 North Lindbergh Boulevard, St. Louis, MO 63167. Touchdown 3AE herbicide product label. Syngenta Corporation, 2200 Concord Pike, PO Box 8353, Wilmington, DE 19803-8353. Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

Table 3. (cont'd)

[b]Cotton cultivars 'Stoneville 4892 BG/RR', 'Paymaster 1218 BG/RR', 'Deltapine 5415 RR', 'Deltapine 451 BG/RR' and 'Fibermax 989 RR' were planted conventionally and in strip-tillage cotton production systems. All treatments included pendimethalin at 1.12 kg ai/ha preemergence-banded (PREBAN) on a 46 cm wide band on the crop drill.

[c]The early postemergence (EPOST) herbicide rates were glyphosate at 1.12 kg ai/ha and *S*-metolachlor at 1.12 kg ai/ha.

[d]The late post-directed (LAYBY) herbicide rates were prometryn at 1.12 kg ai/ha, MSMA at 2.24 kg ai/ha and NIS at 0.25% v/v.

Table 4. Interaction of early-postemergence (EPOST) and late postemergence-directed (LAYBY) herbicide systems on cotton lint yield and net economic returns averaged over location and/or years, tillage options, and glyphosate formulations[a].

Herbicide system[b]		Lint yield	Economic return
EPOST[c]	LAYBY[d]	——kg/ha——	——$/ha——
Glyphosate	No	620 d	739 c
Glyphosate + *S*-metolachlor	No	840 c	964 b
Glyphosate	Yes	1000 b	1255 a
Glyphosate + *S*-metolachlor	Yes	1090 a	1304 a

[a]Roundup UltraMax® herbicide product label. Touchdown 3AE herbicide product label. Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b]Cotton cultivars 'Stoneville 4892 BG/RR', 'Paymaster 1218 BG/RR', 'Deltapine 5415 RR', 'Deltapine 451 BG/RR' and 'Fibermax 989 RR'. All treatments included pendimethalin at 1.12 kg ai/ha preemergence-banded (PREBAN) on a 46 cm wide band on the crop drill.

[c]The early postemergence (EPOST) herbicide rates were glyphosate at 1.12 kg ai/ha and *S*-metolachlor at 1.12 kg ai/ha.

[d]The late post-directed (LAYBY) herbicide rates were prometryn at 1.12 kg ai/ha, MSMA at 2.24 kg ai/ha and NIS at 0.25% v/v.

Chapter 4. Weed Management and Crop Response with Glyphosate, *S*-metolachlor, Trifloxysulfuron-Sodium, Prometryn, and MSMA in Glyphosate-Resistant Cotton

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ABSTRACT. Field studies were conducted in five states at six locations from 2002 through 2003 to evaluate weed control and cotton response to early-postemergence (EPOST), postemergence (POST)/POST-directed spray (PDS), and late postemergence-directed (LAYBY) systems utilizing glyphosate-DIA (diammonium salt), *S*-metolachlor, trifloxysulfuron-sodium, prometryn, and MSMA. Early POST applications were made from

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mid-May through mid-June; POST/PDS from early June through mid-July; and LAYBY from early July through mid-August. Early-season cotton injury and discoloration was minimal (<1%) with all treatments; mid- and late-season injury was minimal (<2%) except for trifloxysulfuron-sodium POST (11 and 9%, respectively). For the EPOST, POST/PDS, and LAYBY applications weeds were at cotyledon to 10 leaf (L), 1 to 25L, and 2 to 25L, respectively. Annual broadleaf and grass weed control was increased with the addition of *S*-metolachlor to glyphosate-DIA EPOST systems (85 to 98% control) compared with glyphosate-DIA EPOST alone (65 to 91% control), except for sicklepod control where equivalent control was observed. Annual grass control was greater with glyphosate-DIA plus trifloxysulfuron-sodium PDS than with trifloxysulfuron-sodium POST or PDS or trifloxysulfuron-sodium plus MSMA PDS (90 to 94% vs. 75 to 83% control). With few exceptions, broadleaf weed control was equivalent for trifloxysulfuron-sodium applied POST alone or PDS alone or in combination with glyphosate-DIA PDS or MSMA PDS herbicide treatments (81 to 99% control). The addition of a LAYBY herbicide treatment increased broadleaf weed control by 11 to 36 percentage points compared to systems without a LAYBY. Cotton lint yield increased 420 kg/ha with the addition of *S*-metolachlor to glyphosate-DIA EPOST treatments compared to systems without *S*-metolachlor EPOST. Cotton lint yield was increased 330 to 910 kg/ha with the addition of a POST herbicide treatment compared to systems without a POST/PDS treatment. The addition of a LAYBY herbicide treatment increased cotton lint yield by 440 kg/ha compared to systems without a LAYBY.

Nomenclature: Glyphosate-TM; MSMA; prometryn; *S*-metolachlor; trifloxysulfuron-sodium; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. ECHCG; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash. BRAPP; entireleaf morningglory, *Ipomoea hederacea* var. *integriuscula* Gray. IPOHG; goosegrass, *Eleusine indica* (L.) Gaertn. ELEIN; large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; pitted morningglory, *Ipomoea lacunosa* L. IPOLA; sicklepod, *Cassia obtusifolia* L. CASOB; smooth pigweed, *Amaranthus hybridus* L. AMACH; cotton, *Gossypium hirsutum* L. 'DP 458 RR/BG', 'DP 555 RR/BG', 'FM 989 RR/BG', 'PM 2344 RR/BG', 'ST 4793 RR'.

Key words: Trimethylsulfonium salt, weed management.

INTRODUCTION

Glyphosate-resistant (GR) cotton (*Gossypium hirsutum* L.) offers many benefits to growers including broad-spectrum control of annual and perennial grass, sedge and broadleaf weeds (Clewis et al. 2006; Franz et al. 1997; Tharp and Kells 1999; VanGessel et al. 2000), potential to eliminate soil-applied herbicides, ease of postemergence (POST) application (Culpepper and York 1999), low cost, and a favorable environmental profile (Culpepper and York 1999; Shaner 2000). The wider application window of glyphosate application timing in GR cotton (POST up to 4 leaf (L) and POST-directed spray (PDS) from 5 to 8L) increases the flexibility of POST weed management decisions. However, these advances in biotechnology have shifted weed management programs from traditional multiple herbicide application systems approach to relying on total POST herbicide systems (including PDS and late POST-directed (LAYBY) applications) (Askew and Wilcut 1999; Culpepper and York 1999; Culpepper et al. 2000; Thomas et al. 2006).

A recent survey conducted by six universities and Marketing Horizons, Inc. showed that a third of 1,195 growers of cotton, corn (*Zea mays* L.), and soybean [*Glycine max* (L.) Merr.] (representing six agricultural states) surveyed relied solely on glyphosate for weed management (Clewis et al. 2007). It is estimated that >95% of all cotton currently grown in Mississippi and North Carolina is glyphosate-resistant (York and Shaw, personal communication). Glyphosate drawbacks include lack of residual weed control necessitating multiple applications (Askew et al. 2002), marginal control of Florida pusley (*Richardia scabra* L.) and yellow and purple nutsedge (*Cyperus esculentus* L. and *C. rotundus* L.), and the requirement of timely applications for control of annual morningglories (Faircloth et al. 2001). Another more recent concern with glyphosate use in resistance development is in weeds such as common ragweed (*Ambrosia artemisiifolia* L.) (Brewer et al. 2006), common waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] (Patzoldt et al. 2004; Zelaya and Owen 2002), giant ragweed (*Ambrosia trifida* L.) (Heap 2007), horseweed (*Conyza canadensis* L. Cronq.) (Koger et al. 2004; Mueller et al. 2003; VanGessel 2001), Italian ryegrass (*Lolium multiflorum* Lam.) (Perez-Jones et al. 2005), and Palmer amaranth (*Amaranthus palmeri* S. Wats.) (Culpepper et al. 2006).

Fundamentals for successful weed management in all crop production systems incorporate timely application, proper herbicide selection, and use of multiple sites of action (Wilcut and Askew 1999). The registration of trifloxysulfuron-sodium provided growers with another

POST option for broadleaf weed control in cotton. Trifloxysulfuron-sodium is a sulfonylurea herbicide that inhibits the acetolactate synthase enzyme (ALS, EC 4.1.3.18) primarily and is used for broadleaf and perennial sedge control (Porterfield et al. 2002b; Richardson et al. 2007). Trifloxysulfuron-sodium has low toxicological properties, a favorable environmental profile, and low use rates (Anonymous 2007a). Previous research has shown that trifloxysulfuron-sodium POST controls common lambsquarters (*Chenopodium album* L.), common ragweed, entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray.), pitted morningglory (*Ipomoea lacunosa* L.), smooth pigweed (*Amaranthus hybridus* L.), Palmer amaranth, sicklepod (*Cassia obtusifolia* L.), tall morningglory (*Ipomoea purpurea* L. Roth.), and yellow nutsedge (Burke and Wilcut 2004; Porterfield et al. 2002b, 2003; Richardson et al. 2007). However, trifloxysulfuron-sodium will not control jimsonweed (*Datura stramonium* L.), prickly sida (*Sida spinosa* L.), spurred anoda (*Anoda cristata* L. Schlecht.), and several annual grasses and only suppresses purple nutsedge and johnsongrass (*Sorghum halepense* L. Pers.) (Corbett et al. 2004; Crooks et al. 2003; Porterfield et al. 2002b, 2003; Richardson et al. 2003). Cotton injury from trifloxysulfuron-sodium has been minimal, with symptoms of chlorosis and stunting; however, cotton at the 5L stage on warm, well-drained soils recovers rapidly (Burke and Wilcut 2004; Crooks et al. 2003; Richardson et al. 2004a; Thomas et al. 2006). Weed resistance to the ALS family of herbicides is widespread with ninety-three cases reported worldwide (Heap 2007).

Proactive weed resistance management should take priority when developing weed management systems in any crop. Weed resistance management in cotton can be particularly problematic due to the limited POST options (glyphosate, pyrithiobac, and trifloxysulfuron-sodium), widespread weed resistance to the ALS herbicide family and developing glyphosate resistance concerns (Culpepper and York 2005). Multiple herbicide sites of action will be a key for controlling potential resistant biotypes. However, with the decrease in use of soil-applied herbicides due to the overwhelming success of glyphosate-resistant cotton, the objective of this research was to evaluate a systems approach for POST control of several annual broadleaf and grass weeds across the Cotton Belt using herbicides with multiple sites of action.

MATERIALS AND METHODS

Field studies were conducted in five states at six locations from 2002 through 2003. Two studies were conducted in North Carolina in 2002 and 2003 at North Carolina Dept. of Ag. & CS's Caswell Research Farm near Kinston, NC. Other studies were conducted at the Northeast Research Station near St. Joseph, LA, at the USDA-ARS Research Station near Stoneville, MS, at the Lockett Experiment Station near Vernon, TX, and at the Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center near Headland, AL in 2003. Cotton planting (dates, row spacing, varieties, etc.) and soil information varied for all locations and are presented in Table 1.

The experiments were in a randomized complete block design with a factorial treatment arrangement of two early POST (EPOST) treatment options, five POST/PDS treatment options, and two LAYBY treatment options, resulting in a total of 20 treatments. A nontreated check was also included for comparison. The EPOST herbicide options consisted of 1) glyphosate-DIA (glyphosate-diammonium salt[1]) at 840 g ae/ha or 2) glyphosate-DIA plus *S*-metolachlor[2] at 1,120 g ai/ha. The POST and PDS herbicide options consisted of 1) no herbicide, 2) trifloxysulfuron-sodium[3] at 5.3 g ai/ha applied POST, 3) PDS, 4) in combination with MSMA at 2,240 g ai/ha PDS, or 5) in combination with glyphosate-DIA PDS. The LAYBY herbicide options consisted of 1) no herbicide or 2) prometryn at 1,120 g ai/ha plus MSMA LAYBY. All treatments were replicated three to four times. All trifloxysulfuron-sodium applications and the LAYBY herbicide applications included a nonionic surfactant[4] at 0.25% (v/v). Herbicide application dates varied for each location and are listed for each location in Table 1.

Barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), broadleaf signalgrass (*Brachiaria platyphylla* (Griseb.) Nash.), goosegrass (*Eleusine indica* (L.) Gaertn.), and large crabgrass (*Digitaria sanguinalis* (L.) Scop.) control was evaluated in each experiment. Broadleaf weeds evaluated for control included entireleaf morningglory, pitted morningglory, smooth pigweed, and sicklepod. Cotton growth stages and height along with weed species growth stages, densities, and height are listed in Table 2 by application timing. Weed control and cotton injury based on biomass and population reductions, were estimated visually on a scale of 0 to 100%, where 0 = no control and 100 = death of all plants (Frans et al. 1986). Three separate injury parameters (stunting, discoloration, and stand reduction) were visually estimated for cotton 7 to 10 d after POST treatments and after LAYBY treatments. Overall injury was also estimated as a combination of the three injury parameters. Mid- and late-season weed ratings are reported. The two center rows of each plot were harvested once with a spindle or stripper picker modified for small-plot research. Lint and seed yield were adjusted based on the 2-year statewide average percent lint composition of each cultivar by each state.

Nontreated control plots could not be harvested because of weed biomass interference with machinery. Therefore, the nontreated controls were removed before analysis. Homogeneity of variance was examined by plotting residuals, and visually estimated percentage data were converted to square roots of the arcsine to stabilize variance. Data for weed control and crop injury were converted to square roots of the arcsine to stabilize variance (Gomez and Gomez 1984). Data were subjected to an analysis of variance (ANOVA) using the general linear models (GLM) procedure of SAS (SAS 1998), and sums of squares were partitioned to evaluate location and herbicide treatments (McIntosh 1983). All data are presented non-transformed for reader clarity. If location effects were not significant, data were pooled; otherwise data are presented by location.

RESULTS AND DISSCUSSION

Crop response. Early-season cotton injury and discoloration was minimal (<1%) with all treatments (data not shown). The POST/PDS herbicide treatment main effect for mid- and late-season cotton injury was significant but interaction with EPOST and LAYBY herbicide treatments was not significant (Table 3). Data are presented averaged over EPOST and LAYBY herbicide treatments and experiment locations. Mid- and late-season cotton injury was $\leq$2% for all trifloxysulfuron-sodium PDS treatments. However, trifloxysulfuron-sodium POST injured cotton 11 and 9% at mid- and late-season evaluations, respectively. This level of injury to cotton in North Carolina and Virginia commonly occurs (Crooks et al. 2003; Porterfield et al. 2003; Richardson et al. 2004a, 2004b). Injury was visually apparent as a chlorosis, discoloration of treated cotton foliage, and stunting (data not shown). Cotton injury may occur when trifloxysulfuron-sodium POST applications are made to smaller cotton over-the-top in saturated soils (Anonymous 2007a). Since metabolism of trifloxysulfuron-sodium has been reported to be the main basis for tolerance (Askew and Wilcut 2002), it is possible that cool and wet conditions may influence the rate of metabolism, consequently reducing tolerance. Branson et al. (2002) reported significantly greater cotton injury from trifloxysulfuron-sodium under cool, saturated soil conditions in controlled environment studies.

Weed control. Only late-season evaluations of weed control are presented, as harvesting efficiency and, therefore, yield are influenced by weed presence late in the season (Wilcut et al. 1995). Significant main effects for EPOST, POST/PDS, and LAYBY treatments for barnyardgrass, broadleaf signalgrass, entireleaf morningglory, goosegrass, large crabgrass, pitted morningglory, sicklepod, and smooth pigweed control, with no significant location, years, or treatment interactions were observed (Tables 4 and 5).

Annual grasses. Annual grass control ranged from 65 to 81% with glyphosate-DIA EPOST alone when averaged over POST/PDS and LAYBY treatments (Table 4). For annual grasses evaluated inclusion of *S*-metolachlor to glyphosate-DIA EPOST increased control 11 to 20 percentage points. In other studies, grass control was increased when glyphosate systems included a residual herbicide (Askew et al. 2002; Clewis et al. 2006; Culpepper and York 1999). Continuous use of glyphosate has lead to resistant biotypes of goosegrass in Malaysia

(Baerson et al. 2002). However, there has been no documented case of resistance to goosegrass with *S*-metolachlor or metolachlor (Heap 2007). Thus, the addition of *S*-metolachlor EPOST or MSMA PDS or LAYBY to glyphosate systems would provide a resistance management tool as well as increased control of goosegrass and other annual grasses (Mallory-Smith and Retzinger 2003).

Trifloxysulfuron-sodium plus glyphosate-DIA PDS averaged over EPOST and LAYBY treatments was the most effective POST option for control of annual grasses (90 to 94%) (Table 4). However, trifloxysulfuron-sodium plus MSMA PDS averaged over EPOST and LAYBY treatments controlled goosegrass similarly at 93% equal to trifloxysulfuron-sodium plus glyphosate-DIA PDS. Treatments that included trifloxysulfuron-sodium POST or, PDS alone, or in combination with MSMA PDS controlled barnyardgrass, broadleaf signalgrass, and large crabgrass equally (74 to 82%). Compared with no POST herbicide treatment goosegrass control was not improved with trifloxysulfuron-sodium POST or PDS. Previous research has shown that trifloxysulfuron-sodium alone does not control annual grasses including broadleaf signalgrass, fall panicum (*Panicum dichotomiflorum* Michx.), goosegrass, and large crabgrass (Burke et al. 2002; Crooks et al. 2003); while glyphosate formulations controlled annual grass populations at the time of treatment and was not influenced by trifloxysulfuron-sodium in mixture (Thomas et al. 2006). However, trifloxysulfuron-sodium may provide some suppression of annual grasses until a LAYBY application can be applied (Thomas et al. 2006).

The inclusion of a LAYBY herbicide treatment regardless of the EPOST or POST treatments increased season-long annual grass control 18 to 36 percentage points compared to not applying a LAYBY treatment (Table 4). The improvement in annual grass control by the addition of prometryn plus MSMA at LAYBY illustrates the importance of a contact (MSMA) and a residual herbicide (prometryn) component for season-long control of annual grasses (Clewis et al. 2006; Porterfield 2002b; Thomas et al. 2006).

Broadleaf weeds. When averaged over POST/PDS and LAYBY treatment options, glyphosate-DIA EPOST alone controlled entireleaf morningglory, pitted morningglory, smooth pigweed, and sicklepod 77 to 91% (Table 5). The inclusion of *S*-metolachlor to glyphosate-DIA EPOST increased control of entireleaf morningglory, pitted morningglory, and smooth pigweed (5 to 9 percentage points), but sicklepod control was not improved. The rapid growth rate of some weed species allows later germinating broadleaf weeds, especially pigweed species, to quickly grow too tall for adequate spray coverage with PDS or LAYBY herbicides. Consequently, a residual herbicide such as *S*-metolachlor in the tank mixture with glyphosate-DIA EPOST may delay emergence of broadleaf weeds resulting in small weeds at the time of PDS or LAYBY applications and improve control (Clewis et al. 2006; Porterfield et al. 2003).

The main effect of POST/PDS treatments was significant (Table 5). The addition of POST or PDS herbicide treatments increased control of *Ipomoea* spp. 24 to 38 percentage points compared to no POST herbicide treatment. All trifloxysulfuron-sodium POST and PDS treatments controlled smooth pigweed and sicklepod equally (at least 90%). Compared to not applying a POST treatment control of smooth pigweed was increased 21 to 23 percentage points and control of sicklepod 26 to 30 percentage points. Previous research has shown that season-long control of broadleaf weeds requires a residual herbicide or multiple herbicide applications (Culpepper and York 1997; Scott et al. 2001). Trifloxysulfuron-sodium POST alone or with the addition of glyphosate-DIA PDS or MSMA PDS controlled *Ipomoea* spp. similarly (87 to 95%). Trifloxysulfuron-sodium PDS with or without the addition of MSMA PDS and trifloxysulfuron-sodium POST provided equal levels of control. Similar benefits with trifloxysulfuron-sodium have been reported for smooth pigweed, sicklepod, and *Ipomoea* spp. (Porterfield et al. 2002a; Thomas et al. 2006).

A LAYBY treatment of prometryn plus MSMA averaged over locations, EPOST, and POST/PDS treatments controlled entireleaf morningglory, pitted morningglory, smooth pigweed, and sicklepod at least 95% compared to 68 to 88% control when no LAYBY was applied (Table 5). This level of increased control demonstrates the importance of LAYBY herbicides for weed control to avoid late-season weed competition and potential reduced harvesting efficiency (Thomas et al. 2006).

Cotton lint yield. Cotton lint yields as affected by the EPOST herbicide treatment main effects, pooled over locations, POST/PDS, and LAYBY herbicide treatments, were increased by 420 kg/ha where glyphosate-DIA was applied in combination with *S*-metolachlor compared with glyphosate-DIA EPOST alone (Table 6). This increase in cotton lint yield reflects the increased weed control seen with the tank mixtures of *S*-metolachlor plus glyphosate-DIA EPOST compared to glyphosate-DIA EPOST alone (Tables 4 and 5).

Residual herbicides may be particularly important in cotton weed control systems because cotton is very sensitive to early season weed interference (Askew and Wilcut 1999; Buchanan and Burns 1970).

Cotton lint yields were increased 330 to 910 kg/ha by POST/PDS herbicide applications compared to no POST herbicide treatment when pooled over locations, EPOST, and LAYBY herbicide treatments (Table 6). Yields were similar for cotton treated with trifloxysulfuron-sodium POST alone, PDS alone, or in combination with MSMA PDS. Cotton treated with trifloxysulfuron-sodium in combination with glyphosate-DIA PDS produced lint yield of 2,150 kg/ha which was greater than trifloxysulfuron-sodium POST but equal to cotton treated with trifloxysulfuron-sodium PDS alone or in mixture with MSMA PDS. Cotton treated with trifloxysulfuron-sodium POST alone yielded 290 to 580 kg/ha less than cotton treated with PDS herbicide treatments. Although these yield differences are not statistically different, these yield differentials may reflect the mid- and late-season cotton injury seen when trifloxysulfuron-sodium was applied POST on smaller cotton (Table 3). The significance of timely POST herbicide applications is critical to avoid a cotton lint yield loss of at least 330 or more kg/ha as seen when no POST herbicide treatment is utilized.

Cotton lint yields as affected by LAYBY herbicide applications, pooled over locations, EPOST, and POST/PDS herbicide treatments, were increased 440 kg/ha with the inclusion of a LAYBY herbicide treatment compared to not applying a LAYBY (Table 6). These results reflect improved weed control seen with the inclusion of a LAYBY herbicide as well as the importance of full-season weed control to insure efficient cotton harvesting (Table 5).

Similar responses have been reported in other studies showing that inclusion of a LAYBY application increased cotton yields compared to systems without a LAYBY herbicide treatment (Clewis et al. 2006; Porterfield et al. 2002b, 2003; Thomas et al. 2006).

The addition of *S*-metolachlor to glyphosate-DIA EPOST improved control of barnyardgrass, broadleaf signalgrass, goosegrass, large crabgrass, entireleaf morningglory, pitted morningglory, and smooth pigweed and increased yields compared to systems without *S*-metolachlor. The inclusion of *S*-metolachlor in a total POST weed control system is important to provide flexibility in subsequent application timings by controlling problematic grasses and smooth pigweed. The addition of *S*-metolachlor also provides an alternate mode of action in a proactive resistance management program, reducing the reliance on a single mode of action (Mallory-Smith and Retzinger 2003). The addition of trifloxysulfuron-sodium in combination with glyphosate-DIA PDS provided additional control of annual grasses compared to trifloxysulfuron-sodium POST alone, trifloxysulfuron-sodium PDS alone, or in combination with MSMA PDS. The inclusion of a LAYBY herbicide treatment increased control of both annual grasses and broadleaves evaluated and increased cotton lint yields. To maintain a total POST herbicide system in glyphosate-resistant cotton, timely applications must be made to small weeds throughout the growing season. Glyphosate in combination with herbicides such as *S*-metolachlor or trifloxysulfuron-sodium may broaden the application window while providing additional control of problematic weeds and also providing multiple sites of action for resistance management across the Cotton Belt.

SOURCES OF MATERIALS

[1]Touchdown®, Supplied by Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27419.

[2]Dual II Magnum®, Supplied by Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27409.

[3]Envoke®, formulated product with 75% active ingredient. Supplied by Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27409.

[4]Induce®, blend of alkylarypolyoxylane ether, free fatty acids, and isopropyl (90%), and water and formulation acids (10%). Supplied by Helena Chemical Corporation, 5100 Popular Avenue, Memphis, TN 38137.

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Table 1. Cotton planting and herbicide application information for the six locations across five states[a].

	Kinston, NC	Kinston, NC	St. Joseph, LA	Vernon, TX	Stoneville, MS	Headland, AL
Year	2002	2003	2003	2003	2003	2003
Cotton variety	FM 989 RR/BG	FM 989 RR/BG	DP 458 RR/BG	PM 2344 RR/BG	ST 4793 RR	DP 555 RR/BG
Row spacing	96.5 cm	96.5 cm	101. 6 cm	101. 6 cm	101. 6 cm	91.4 cm
Plot size	3.9 x 9.1 m	3.9 x 9.1 m	4.1 x 12.2 m	4.1 x 6.1 m	4.1 x 6.7 m	3.9 x 9.1 m
Seedling rate	13.1 seed/m	13.1 seed/m	13.1 seed/m	13.1 seed/m	13.1 seed/m	13.1 seed/m
Soil type	Norfolk loamy	Norfolk loamy	Mhoon silt loam	Acuff clay loam	Dundee sandy loam	Dothan fine sandy loam
pH	5.9	5.9	6.8	7.1	6.7	6.5
OM (%)	2.2	1.2	0.5	0.3	1.1	0.4
Planting date	May 6	May 6	April 28	April 27	May 9	May 6
EPOST application date	May 29	June 12	May 12	June 17	May 20	June 6
POST application date	June 10	June 23	June 2	July 9	June 10	June 24
PDS application date	June 10	June 23	June 2	July 9	June 17	July 15
LAYBY application date	June 19	July 10	July 1	August 14	June 24	August 5
Spray volume	140 L/ha	140 L/ha	140 L/ha	140 L/ha	187 L/ha	140 L/ha
Spray tip	11002VS	11002VS	11003AI	11002XR	8004VS	11002VS
Spray pressure	207 kPa	207 kPa	221 kPa	214 kPa	193 kPa	207 kPa

Table 1. Cont'd.

[a]Abbreviations used in table: EPOST = early POST, PDS = POST-directed spray, LAYBY = late postemergence-directed.

Table 2. Cotton and weed species, densities (Dens.), height (Ht.), and growth stages at application timings[a].

		EPOST			POST			PDS			LAYBY		
Location	Weed and cotton	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)
Headland, AL (2003)	Smooth pigweed	6	1	--	4	1	--	4	1	--	4	1	--
	Goosegrass	10	1	--	15	1	--	15	1	--	10	1	--
	Cotton	3	--	13	8	--	25	12	--	35	24	--	46
St. Joseph, LA (2003)	Smooth pigweed	C-2	10	--	3-4	8	--	3-4	8	--	4-5	4	--
	Sicklepod	C-2	8	--	3-4	6	--	3-4	6	--	4-5	4	--
	Large crabgrass	C-2	10	--	3-4	8	--	3-4	8	--	4-5	3	--
	Barnyardgrass	C-2	10	--	3-4	6	--	3-4	6	--	4-5	3	--
	Goosegrass	C-2	8	--	3-4	4	--	3-4	4	--	4-5	2	--

Table 2. Cont'd.

		EPOST			POST			PDS			LAYBY		
Location	Weed and cotton	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)
	Entireleaf Morningglory	C-2	10	--	3-4	8	--	3-4	8	--	4-5	4	--
	Pitted morningglory	C-2	12	--	3-4	10	--	3-4	10	--	4-5	5	--
	Cotton	2	--	5	5-6	--	15	5-6	--	15	10-12	--	36
Stoneville, MS (2003)	Smooth pigweed	1-4	--	3-8	1-4	--	3-8	1-4	--	3-8	2-5	--	5-13
	Broadleaf signalgrass	1-2	--	3	1-2	--	3	2-4	--	5-13	3-4	--	8-18
	Barnyardgrass	1-2	--	3	1-2	--	3	2-4	--	5-13	3-4	--	8-18
	Entireleaf morningglory	1-2	--	3-8	1-2	--	3-8	1-3	--	3-13	2-4	--	5-18

Table 2. Cont'd.

Location	Weed and cotton	EPOST Growth stage (LF #)	EPOST Dens. (m^2)	EPOST Ht. (cm)	POST Growth stage (LF #)	POST Dens. (m^2)	POST Ht. (cm)	PDS Growth stage (LF #)	PDS Dens. (m^2)	PDS Ht. (cm)	LAYBY Growth stage (LF #)	LAYBY Dens. (m^2)	LAYBY Ht. (cm)
	Pitted morningglory	1-2	--	3-8	1-2	--	3-8	1-3	--	3-13	2-4	--	5-18
	Cotton	C-4	--	8	5-12	--	10-30	5-12	--	10-30	14-20	--	10-35
Kinston, NC (2002)	Smooth pigweed	2-3	25	--	3-4	12	--	3-4	12	--	C-3	3	--
	Broadleaf signalgrass	1-3	8	--	2-4	9	--	2-4	9	--	1-2T	3	--
	Sicklepod	C-3	10	--	C-2	5	--	C-2	5	--	C-3	6	--
	Goosegrass	1-3	15	--	1-3	12	--	1-3	12	--	3-3T	4	--
	Entireleaf morningglory	C-2	8	--	C-2	5	--	C-2	5	--	C-3	3	--
	Pitted morningglory	C-2	6	--	C-4	7	--	C-4	7	--	C-3	5	--

Table 2. Cont'd.

		EPOST			POST			PDS			LAYBY		
Location	Weed and cotton	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)
	Cotton	2-3	--	8	4-6	--	20	4-6	--	20	8-10	--	46
Kinston, NC (2003)	Smooth pigweed	2-8	25	--	8	8	--	8	8	--	C-8	3	--
	Sicklepod	1-4	12	--	C-2	5	--	C-2	5	--	C-3	6	--
	Large crabgrass	1-6	20	--	1-3	8	--	1-3	8	--	1-3T	7	--
	Entireleaf morningglory	C-4	10	--	C-3	5	--	C-3	5	--	C-3	8	--
	Pitted morningglory	C-5	15	--	C-2	8	--	C-2	8	--	C-5	10	--
	Cotton	3-4	--	13	7-8	--	25	7-8	--	25	14	--	46
Vernon, TX (2003)	Smooth pigweed	C-10	--	1-5	2-25	--	3-41	2-25	--	3-41	5-25	--	8-61

Table 2. Cont'd.

		EPOST			POST			PDS			LAYBY		
Location	Weed and cotton	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)	Growth stage (LF #)	Dens. (m^2)	Ht. (cm)
	Cotton	C-4	--	3-10	5-12	--	10-30	5-12	--	10-30	14-20	--	10-36

[a]Abbreviations used in table: C = cotyledon, LF = number of leaves, T = tiller, EPOST = early POST, PDS = POST-directed spray, LAYBY = late postemergence-directed, AMACH = smooth pigweed, BRAPP = broadleaf signalgrass, CASOB = sicklepod, DIGSA = large crabgrass, ECHCG = barnyardgrass, ELEIN = goosegrass, GOSHI = cotton, IPOHG = entireleaf morningglory, and IPOLA = pitted morningglory.

Table 3. Postemergence (POST)/POST-directed spray (PDS) treatment main effects on mid- and late-season cotton injury averaged over early POST (EPOST) and late POST-directed (LAYBY) applications and experiment locations[a].

POST treatments[b]	Mid-season injury	Late-season injury
g ai/ha	———%———	
No POST	0 b	1 b
Trifloxysulfuron-sodium POST (5.3)	11 a	9 a
Trifloxysulfuron-sodium PDS (5.3)	1 b	2 b
Trifloxysulfuron-sodium (5.3) plus MSMA (2,240) PDS	1 b	2 b
Trifloxysulfuron-sodium (5.3) plus glyphosate-DIA (840) PDS	1 b	2 b
Locations[c]	6	6

[a]Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b]Abbreviations: glyphosate-DIA, glyphosate-diammonium salt. Means represent average injury from five POST or POST-directed spray (PDS) herbicide treatments. A nonionic surfactant at 0.25% (v/v) was included with all trifloxysulfuron-sodium treatments.

[c]Indicates the number of experiment locations where data were collected for each variable. See Table 1.

Table 4. Early postemergence (EPOST), postemergence (POST)/POST-directed spray (PDS), and late POST-directed (LAYBY) treatment main effects on late-season annual grass control averaged over experiment locations[a].

Herbicide treatments[b]	Barnyardgrass	Broadleaf signalgrass	Goosegrass	Large crabgrass
g ai/ha	%			
EPOST Main Effects:				
Glyphosate-TM (840)	66 b	65 b	81 b	72 b
Glyphosate-TM (840) plus *S*-metolachlor (1,120)	86 a	85 a	92 a	88 a
POST/PDS Main Effects:				
No POST	60 c	55 c	82 b	68 c
Trifloxysulfuron-sodium POST (5.3)	80 b	77 b	83 b	82 b
Trifloxysulfuron-sodium PDS (5.3)	76 b	75 b	82 b	79 b
Trifloxysulfuron-sodium (5.3) plus MSMA (2,240) PDS	74 b	82 b	93 a	80 b
Trifloxysulfuron-sodium (5.3) plus glyphosate-DIA (840) PDS	90 a	93 a	94 a	90 a
LAYBY Main Effects:				
No LAYBY	65 b	57 b	78 b	67 b
Prometryn (1,120) plus MSMA (2,240)	87 a	93 a	96 a	92 a
Locations[c]	2	2	3	3

Table 4. Cont'd.

[a]Values of control within a column and main treatment effects followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b]Abbreviations: glyphosate-DIA, glyphosate-diammonium salt. A nonionic surfactant at 0.25% (v/v) was included with prometryn plus MSMA and all trifloxysulfuron-sodium treatments. Herbicide rates expressed in g ai/ha are in parentheses.

[c]Indicates the number of experiment locations where data were collected for each variable. See Table 1.

Table 5. Early postemergence (EPOST), postemergence (POST)/POST-directed spray (PDS), and late POST-directed (LAYBY) treatment main effects on late-season broadleaf control averaged over experiment locations[a].

Herbicide treatments[b]	Entireleaf morningglory	Pitted morningglory	Sicklepod	Smooth pigweed
g ai/ha		%		
EPOST Main Effects:				
Glyphosate-TM (840)	77 b	82 b	87 a	91 b
Glyphosate-TM (840) plus *S*-metolachlor (1,120)	86 a	87 a	86 a	98 a
POST/PDS Main Effects:				
No POST	57 c	65 c	64 b	76 b
Trifloxysulfuron-sodium POST (5.3)	87 ab	89 ab	90 a	97 a
Trifloxysulfuron-sodium PDS (5.3)	81 b	84 b	91 a	98 a
Trifloxysulfuron-sodium (5.3) plus MSMA (2,240) PDS	88 ab	90 ab	94 a	99 a
Trifloxysulfuron-sodium (5.3) plus glyphosate-DIA (840) PDS	95 a	94 a	94 a	99 a
LAYBY Main Effects:				
No LAYBY	68 b	74 b	77 b	88 b
Prometryn (1,120) plus MSMA (2,240)	96 a	95 a	96 a	99 a
Locations[c]	3	4	3	4

Table 5. Cont'd.

[a]Values of control within a column and main treatment effects followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b]Abbreviations: glyphosate-DIA, glyphosate-diammonium salt. A nonionic surfactant at 0.25% (v/v) was included with prometryn plus MSMA and all trifloxysulfuron-sodium treatments. Herbicide rates expressed in g ai/ha are in parentheses.

[c]Indicates the number of experiment locations where data were collected for each variable. See Table 1.

Table 6. Early postemergence (EPOST), postemergence (POST)/POST-directed spray (PDS), and late POST-directed (LAYBY) treatment main effects on cotton lint yield averaged over experiment locations[a].

Herbicide treatment[b]	Cotton lint yield
g ai/ha	———kg/ha———
EPOST Main Effects:	
Glyphosate-TM (840)	1,530 b
Glyphosate-TM (840) plus *S*-metolachlor (1,120)	1,950 a
POST/PDS Main Effects:	
No POST	1,240 c
Trifloxysulfuron-sodium POST (5.3)	1,570 b
Trifloxysulfuron-sodium PDS (5.3)	1,880 ab
Trifloxysulfuron-sodium (5.3) plus MSMA (2,240) PDS	1,860 ab
Trifloxysulfuron-sodium (5.3) plus glyphosate-DIA (840) PDS	2,150 a
LAYBY Main Effects:	
No LAYBY	1,520 b
Prometryn (1,120) plus MSMA (2,240)	1,960 a
Locations[c]	6

[a]Values of control within a column and main treatment effects followed by the same letter are not significantly different at the 5% level as determined by Fisher’s Protected LSD test.

[b]Abbreviations: glyphosate-DIA, glyphosate-diammonium salt. A nonionic surfactant at 0.25% (v/v) was included with prometryn plus MSMA and all trifloxysulfuron-sodium treatments. Herbicide rates expressed in g ai/ha are in parentheses.

Table 6. Cont'd.

[c]Indicates the number of experiment locations where data were collected for each variable.See Table 1.

Chapter 5. Interference of Glufosinate-Resistant Corn in Glufosinate-Resistant Cotton.

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ABSTRACT. Studies were conducted at three locations in North Carolina in 2004 to evaluate density-dependent effects of glufosinate-resistant (GUR) corn (*Zea mays* L.) on GUR cotton (*Gossypium hirsutum* L.) growth and lint yield. GUR corn was taller than GUR cotton as early as 11 days (d) after planting, depending on location. A GUR corn density of 5.25 plant/m of crop row reduced late season cotton height by 38 to 43% at Clayton, Lewiston-Woodville, and Rocky Mount, respectively, compared to weed-free cotton height. GUR corn dry biomass per m crop row and GUR corn seed biomass per m of crop row decreased linearly with increasing GUR corn density at all locations. The relationship between GUR corn density and GUR cotton yield loss was described by the rectangular hyperbola model with the asymptote (*a*) constrained to 100% maximum yield loss. The estimated coefficient *i* (yield loss per unit density as density approaches zero) was 7, 5, and 6

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at Clayton, Lewiston-Woodville, and Rocky Mount, respectively. Percent GUR cotton lint yield loss increased 4, 5, and 8 percentage points at Clayton, Lewiston- Woodville, and Rocky Mount, respectively, with each 500 g increase in weed biomass/m of crop row. The examined GUR corn densities had a significant effect on cotton yield, but not as significant as many other problematic grass and broadleaf weeds.

Nomenclature: Glufosinate; corn, *Zea mays* L. ZEAMX, 'Pioneer 34A55LL', cotton, *Gossypium hirsutum* L., 'FM 958LL'.

Key words: Competition, economic threshold, models, weed biomass, weed density, plant height.

INTRODUCTION

Field corn (*Zea mays* L.) is grown on more hectares (ha) than any other crop in the United States. In 2000 and 2001, there were over 31 million ha of corn planted, respectively. North Carolina corn growers have averaged 6,515 kg/ha on 318,892 ha planted per year from 1996 to 2006 (USDA-NASS 2006). In the mid-1990's, it was reported that U.S. growers applied herbicides to 98% of the nation's field corn hectarage: 39% of the hectarage received a preemergence (PRE) herbicide only, 21% of the hectarage received a postemergence (POST) herbicide only, while 38% of the hectarage received both PRE and POST herbicides (USDA-NASS 1994). Herbicide-resistant corn hectarage has steadily increased from 7% in 2000 to 26% in 2005 (USDA-NASS 2000, 2005).

The use of herbicide-resistant cotton (*Gossypium hirsutum* L.) has been more widespread with 46 and 61% of the total hectarage planted in 2000 and 2005, respectively (USDA-NASS 2000, 2005). The increased use of herbicide-resistant varieties has resulted in less than 50% of the North Carolina cotton hectarage receiving a PRE herbicide (A. C. York, personal communication). Therefore, there is a potential for presence of herbicide-resistant corn volunteers in rotational crops the following year. The presence of volunteers may lead to many problems including harvesting inefficiency, competition of resources, and ovipositing sites for insects (York et al. 2004).

If an economic threshold is to be realized, data on weed interference must be collected for yield-loss prediction models (Coble and Byrd 1992). Since interference between GUR corn and GUR cotton has not been investigated, studies were conducted to determine effects of a range of GUR corn densities on GUR cotton growth and yield and to evaluate growth of GUR corn as affected by plant density.

MATERIALS AND METHODS

Field experiments were conducted at the Central Crops Research Station near Clayton, NC, the Upper Coastal Plain Research Station near Rocky Mount, NC, and the Peanut Belt Research Station near Lewiston-Woodville, NC in 2004. Soils included a Goldsboro sandy loam (fine-loamy, siliceous, thermic Aquic Paleudults) with 2.3% organic matter and pH 5.9 at Lewiston-Woodville; Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudults) with 2.1% organic matter and pH 5.4 at Rocky Mount; and Doathan loamy sand (fine-loamy, siliceous, thermic Plinthic Paleudults) with 2.6% organic matter and pH 6.1 at Clayton. Test sites were chisel plowed in the fall and then disked with a tandem-disk harrow, smoothed with a field cultivator, bedded with in-row subsoiling 1 d prior to planting. Pendimethalin at 0.84 kg ai/ha was applied PRE. Pendimethalin is registered for PRE application in corn and cotton (Anonymous 2003a). Cotton cultivars were 'FM 958LL' and corn cultivars were 'Pioneer 34A55LL' at all three locations. Seed were planted on conventional seedbeds at 15 seed per m of cotton row on May 6, May 11, and May 13 at Clayton, Rocky Mount, and Lewiston-Woodville, respectively. Plots were 6.1 m long and four 91-cm rows at Lewiston-Woodville and Rocky Mount with four 97-cm rows at Clayton. Fertilization and pest management practices were standard for cotton production in North Carolina (Bacheler 2007; Crozier 2007). Glufosinate at 408 g ai/ha was applied as recommended by the herbicide registration up to the V-7 stage of corn growth (Anonymous 2003b) and up to the early bloom stage of cotton growth (Anonymous 2004) to control emerged weeds. Plots were subsequently maintained weed-free by hand removal of weeds. The experimental design was a randomized complete block design (RCBD) with treatments replicated three times.

On the day of cotton planting at each location, GUR corn was planted at desired densities 15 cm from the crop row and at even spacings. Corn densities were 0, 1, 2, 4, 8, 16, and 32 plants per 6.1 m of row in the center two rows of each plot, which is equivalent to 0, 0.16, 0.33, 0.65, 1.31, 2.62, and 5.25 plants per m of row. The outer two rows of each plot were maintained as weed-free borders.

Corn and cotton heights were measured at 11, 20, 34, 49, 66, 81, and 104 days after planting (DAP) at Clayton, 12, 26, 33, 48, 59, 75, and 98 DAP at Lewiston-Woodville, and 10, 23, 36, 44, 61, 77, and 99 DAP at Rocky Mount. Up to four randomly selected GUR corn plants from each plot were measured from soil surface to top of the plant. Four randomly selected cotton plants from the center two rows of each plot were measured for height from the soil surface to the apical meristem. At the end of the growing season, up to four GUR corn plants were randomly selected from each plot and harvested to measure above-ground dry biomass and kernel set. The remaining GUR corn plants were cut at ground level and removed from plots to facilitate cotton harvest. The center two rows of each plot were harvested once with a spindle picker modified for small-plot research. Cotton lint yields were obtained using percentages of seed cotton yield data from 2004 North Carolina Official Variety Testing.

Statistical Analyses. Data were tested for homogeneity of variance prior to statistical analysis by plotting residuals. Analysis of variance (ANOVA) was performed on GUR corn dry biomass, kernel set, and cotton yield loss as a percentage of weed-free yields. Linear, quadratic, and higher-order polynomial effects of GUR corn density were tested by partitioning sums of squares (Draper and Smith 1981). Weed-density main effects were tested by error associated with appropriate location by weed-density interactions (McIntosh 1983). If significant GUR corn density effects were observed, regression analysis was performed. Nonlinear models were used if ANOVA indicated higher-order polynomial effects of GUR corn density were more significant than linear effects. Iterations were performed to determine parameter estimates with least sums of squares for all nonlinear models using the Gauss-Newton method via PROC NLIN in SAS (SAS 1998).

The Gompertz equation was fit to plant heights of each species in each plot (Knezevic et al. 2002). Variables in the Gompertz equation are *H*, *a*, *e*, and *T*, which are based on plant height in cm, the upper asymptote for late-season plant height, the base of natural logarithm, and the time in DAP, respectively, while *b* and *k* are constants. Multivariate analysis of variance (PROC MANOVA; SAS 1998) was conducted on the three estimated parameters for each fitted curve to test for location, weed-density, and location by weed-density effects.

The rectangular hyperbola (Askew and Wilcut 2001; Cousens 1988) was used to describe density-dependent effects of GUR corn on cotton yield loss. Variables in the rectangular hyperbola are *Y*, *a*, *D*, and *i*, which are based on a percent reduction of weed-free yield, the asymptote for percentage yield loss, the weed density per m crop row, and the yield loss per weed as weed density approaches zero, respectively. Coefficients of determination (R^2) were calculated for nonlinear regressions as in other studies (Askew and Wilcut 2001; Jasieniuk et al. 1999). The approximated R^2 and residual mean squares were used to determine goodness of fit to nonlinear models.

RESULTS AND DISCUSSION

GUR Corn and Cotton Height. GUR corn and GUR cotton heights were significantly different at each location, thus data are presented by location (Figure 1). Heights of GUR corn and GUR cotton plotted against time fit the Gompertz growth model. Average GUR corn height at the last measurement was 243, 213, and 216 cm at Clayton, Lewiston-Woodville, and Rocky Mount, respectively. GUR corn began to grow taller than GUR cotton as early as 11 DAP, depending on location. In addition, GUR cotton height was negatively influenced with increasing GUR corn density (Figures 1 and 2). When grown in competition with 5.25 GUR corn plants per m of row, GUR cotton height at harvest was reduced by 38, 43, and 43% at Clayton, Lewiston-Woodville, and Rocky Mount, respectively, compared to weed-free GUR cotton (Table 1). Thomas et al. (2007) reported similar reductions in cotton heights with glyphosate-resistant (GR) corn interference. Weeds that grow above crop canopies often intercept light and reduce yields. Tall growing weeds that canopy over cotton may interfere with agrichemical deposition, plant growth regulators, and insecticides onto cotton foliage due to the weed-crop architecture. Consequently, yield reduction could be magnified due to indirect influences of weeds that grow taller than cotton like GUR corn.

GUR Corn Above-Ground Dry Biomass. The effects of GUR corn density on GUR corn dry biomass was significantly affected by location, thus data are shown by location (Figure 3). GUR corn above-ground dry biomass decreased linearly with increasing weed density at all locations. GUR corn dry biomass decreased from 438 g per plant at 0.16 plants/m of cotton row to 321 g per plant at 5.25 plants/m of cotton row at Clayton. At Lewiston-Woodville, GUR corn dry biomass decreased from 232 g per plant at 0.16 plants/m of cotton row to 165 g per plant at 5.25 plants/m of cotton row. At Rocky Mount, GUR corn dry biomass decreased from 204 g per plant at 0.16 plants/m of cotton row to 122 g per plant at

5.25 plants/m of cotton row. This density-dependent decline in weed dry biomass per plant is indicative of intraspecific competition (Bridges and Chandler 1987; Rushing et al. 1985a, 1985b; Snipes et al. 1982). GR corn (Thomas et al. 2007) was reported to produce 515, 320, and 158 g dry biomass per plant at a 0.16 plants/m density at three locations in North Carolina.

GUR Corn Seed Production. The effect of GUR corn density on GUR corn kernel production was significantly affected by location, thus data are shown by locations (Figure 4). There was an inverse relationship between GUR corn kernel biomass and weed density at all locations. GUR corn kernel biomass decreased 48.2% from 280 g per plant at 0.16 plants/m of cotton row to 145 g per plant at 5.25 plants/m of cotton row at Clayton. At Lewiston-Woodville, GUR corn kernel biomass decreased 48.2% from 197 g per plant at 0.16 plants/m of cotton row to 102 g per plant at 5.25 plants/m of cotton row. At Rocky Mount, GUR corn kernel biomass decreased 46% from 187 g per plant at 0.16 plants/m of cotton row to 101 g per plant at 5.25 plants/m of cotton row.

GUR Cotton Lint Yield Loss. The effect of GUR corn dry biomass and percent GUR cotton lint yield loss was significantly affected by location, thus data are shown by locations (Figure 5). As GUR corn dry biomass/m of GUR cotton row increased, percent GUR cotton lint yield loss increased. Percent GUR cotton lint yield loss increased 4, 5, and 8 percentage points at Clayton, Lewiston-Woodville, and Rocky Mount, respectively, with each 500 g increase in weed biomass/m of crop row. Previous research has shown GR corn (Thomas et al. 2007), jimsonweed (*Datura stramonium* L.) (Scott et al. 2000), ladysthumb (*Polygonum* *persicaria* var. *persicaria* L.) (Askew and Wilcut 2002a), Palmer amaranth (*Amaranthus palmeri* L.) (Rowland et al. 1999), Pennsylvania smartweed (*Polygonum pensylvanicum* var. *laevigatum* Fern.) (Askew and Wilcut 2002b), tropic croton (Croton glandulosus var. septentrionalis Muell.-Arg.) (Askew and Wilcut 2001), unicorn-plant [*Proboscidea louisianica* (Mill.) Thellung] (Riffle et al. 1989), and velvetleaf (*Abutilon theophrasti* Medicus) (Smith et al. 1990) also exhibited an inverse relationship of plant biomass to cotton lint yield.

With maximum percent GUR cotton lint yield loss (*a*) set to 100, *i* values varied from 5 to 7 among locations (Figure 6). Based on these values, one GUR corn plant/m of GUR cotton row decreased cotton lint yield 7, 5, and 6% in Clayton, Lewiston-Woodville, and Rocky Mount, respectively. White and Coble (1997) reported that prediction accuracy at the lower end of weed density ranges is more important since economic thresholds often occur at weed densities below one weed/m of crop row. Thomas et al. (2007) reported that GR corn in GR cotton had *i* values ranging from 5 to 9, depending on location. Cotton lint yield losses were as high as 69, 67, 65, 59, 54, 44, 34, 30, 26, and 22% when grown with velvetleaf (Bailey et al. 2003), jimsonweed (Scott et al. 2000), Palmer amaranth (Rowland et al. 1999), ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] (Rogers et al. 1996), Palmer amaranth (Morgan et al. 2001), ivyleaf morningglory (Wood et al. 1999), Pennsylvania smartweed (Askew and Wilcut 2002b), tropic croton (Askew and Wilcut 2001), ladysthumb (Askew and Wilcut 2002a), and pale smartweed (*Polygonum lapathifolium* L.) (Askew and Wilcut 2002c), respectively, at one plant/m crop row. Yield losses associated with GUR corn were less than with many grass and broadleaf weeds common in cotton but still significant due to value of the cotton crop. Furthermore, these yield loss estimates may be overestimated due to the use of hybrid corn. Jugenheimer (1976) discussed several characteristics of hybrid vigor. When hybrids are open pollinated, hybrid vigor is reduced (Jugenheimer 1976). In normal field situations with volunteer GUR corn, these volunteers would display reduced vigor compared to commercial hybrids.

Numerous graminicides including clethodim, fluazifop, quizalofop, and sethoxydim are registered for POST treatment of GUR corn control in GUR cotton (York et al. 2005). Herbicide costs as listed in HADSS[1] plus a $10/ha application fee are shown (Table 2). Economic threshold was based on a support price of $1.32/kg for cotton lint (Askew et al. 2002) and weed free yield potential of 1955, 1708, and 1444 kg/ha at Clayton, Lewiston-Woodville, and Rocky Mount, respectively. The economic threshold for the various graminicides ranged from one GR corn plant per 14 to 44 m of crop row (Table 2), depending on herbicide selection and location. However, these calculations assume: that other cotton cultivars will respond similarly to GUR corn interference, that graminicides are equally efficacious, that similar weed-free yields are attainable, and a selling price of $1.32/kg for cotton lint. GUR corn is less competitive than many grass and broadleaf weeds of cotton. In addition to direct yield losses, GUR corn may limit light interception, agrichemical spray, and harvest efficiency. However, these data may overestimate the potential to cause yield losses due to the use of hybrid corn as seen in research by Jugenheimer (1976). Since there are known differences in hybrid vigor between commercial hybrids and open-pollinated hybrids, density-dependent studies using open pollinated hybrids also should be evaluated. Even though these data may not be directly relevant to open-pollinated hybrid volunteers, data could be used in the case of crop failure. Since many of the GUR systems usually use a total POST program, these data could be used to estimate in season cotton yield loss planted following a corn crop failure.

SOURCES OF MATERIALS

[1]HADSS, Herbicide Application Decision Support System-North Carolina version, AgRenaissance Software LLC, PO Box 91235, Raleigh, NC 27695.

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Table 1. Regression parameters ($y = ae^{-be^{-Kt}}$) for glufosinate-resistant (GUR) cotton height shown by location and GUR corn density. Values in parenthesis are standard errors (SE).

Location	Interference level (density per 6.1-m row)	*a*		*b*		*K*		R^2
		Cotton height						
		———cm (SE)———						
Clayton	0	115	(2.5)	5.14	(1.4)	0.731	(0.004)	0.98
	0.16	109	(5.6)	5.14	(1.9)	0.665	(0.007)	0.96
	0.33	107	(3.2)	6.03	(0.6)	0.807	(0.005)	0.99
	0.66	105	(5.5)	5.67	(1.3)	0.718	(0.008)	0.95
	1.31	103	(4.4)	6.84	(2.1)	0.862	(0.010)	0.94
	2.26	91	(5.3)	5.43	(2.0)	0.711	(0.007)	0.94
	5.25	71	(4.5)	5.93	(1.4)	0.754	(0.005)	0.96
Lewiston-Woodville	0	104	(0.8)	4.24	(2.8)	0.681	(0.006)	0.96
	0.16	97	(2.6)	3.75	(3.1)	0.541	(0.006)	0.97
	0.33	96	(3.5)	3.79	(3.5)	0.612	(0.005)	0.91
	0.66	94	(1.5)	3.76	(1.2)	0.591	(0.011)	0.91
	1.31	89	(2.5)	3.41	(2.5)	0.552	(0.014)	0.91
	2.26	85	(2.3)	3.68	(3.3)	0.677	(0.011)	0.93
	5.25	59	(4.5)	4.09	(4.1)	0.818	(0.007)	0.94
Rocky Mount	0	94	(5.5)	3.47	(2.6)	0.677	(0.003)	0.95
	0.16	84	(4.2)	3.05	(1.9)	0.585	(0.013)	0.97
	0.33	84	(5.9)	3.31	(3.2)	0.627	(0.014)	0.94
	0.66	78	(3.4)	3.12	(3.4)	0.592	(0.004)	0.89
	1.31	76	(4.0)	3.57	(4.0)	0.714	(0.006)	0.91
	2.26	70	(4.6)	2.34	(0.5)	0.650	(0.009)	0.89
	5.25	53	(5.3)	1.91	(3.5)	0.407	(0.024)	0.74
		Corn height						
		———cm (SE)———						
Clayton		243	(2.6)	14.6	(2.1)	0.074	(0.003)	0.97
Lewiston-Woodville		213	(4.7)	19.8	(3.5)	0.084	(0.006)	0.92
Rocky Mount		216	(3.1)	12.5	(1.9)	0.056	(0.007)	0.96

Table 2. Economic thresholds for glufosinate-resistant (GUR) corn in GUR cotton.

Herbicide[a]	Cost	Clayton	Lewiston-Woodville	Rocky Mount	Clayton	Lewiston-Woodville	Rocky Mount
	$/ha	——one plant/m crop row——			————plants/ha————		
Clethodim	35.3	35.2	20.3	23.1	311	511	448
Fluazifop	28.4	44.3	25.6	29.2	246	405	355
Quizalofop	50.0	24.3	14.2	16.2	442	727	638
Sethoxydim	28.1	43.8	25.2	28.8	249	410	360

[a]Herbicide costs included the herbicide (HADSS price) and application costs ($10/ha).

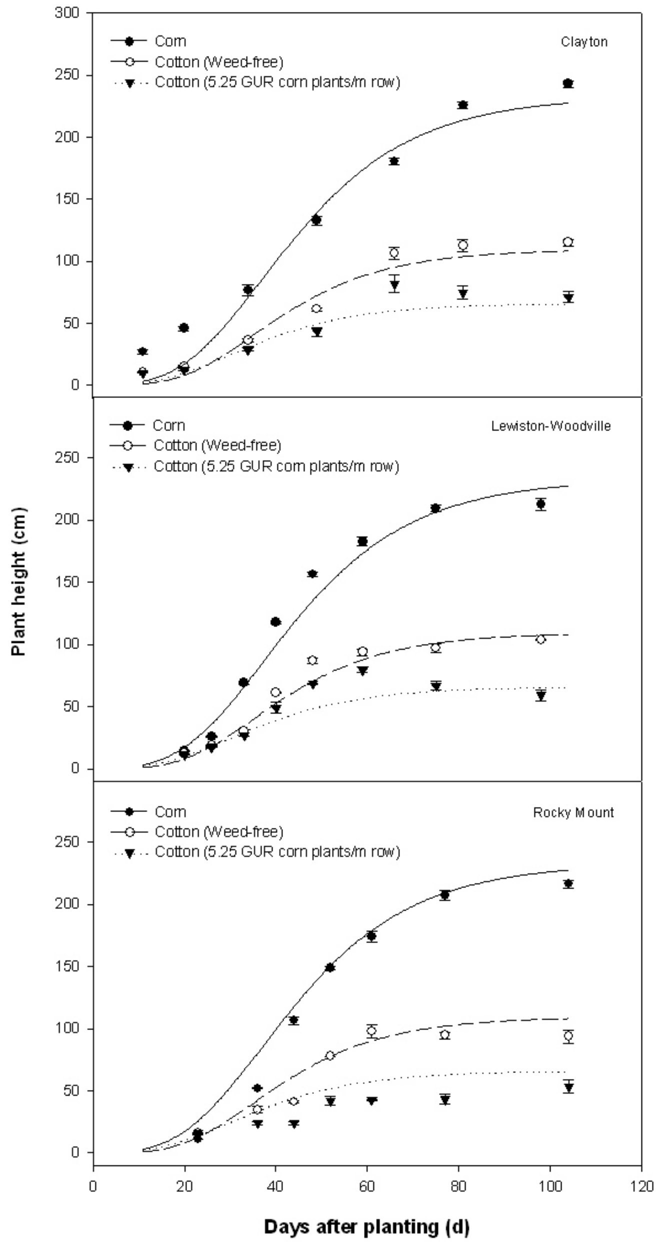

Figure 1. Glufosinate-resistant (GUR) corn height, GUR cotton height with no weed interference, and GUR cotton height with 5.25 corn plant m^{-1} of cotton row are shown. A significant weed density interaction was observed for cotton height. Regression parameters and corresponding R^2 values are shown in Table 1.

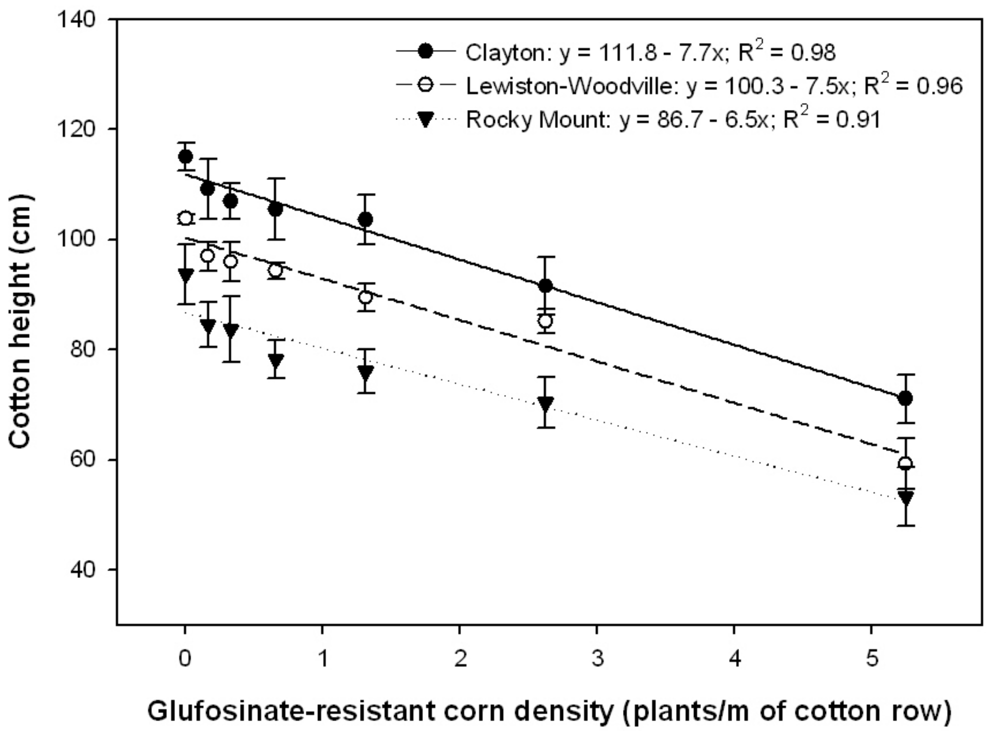

Figure 2. Effect of glufosinate-resistant (GUR) corn density on GUR cotton height at the last measuring timing at each location (104, 98, and 99 days after planting (DAP) at Clayton, Lewiston-Woodville, and Rocky Mount, respectively).

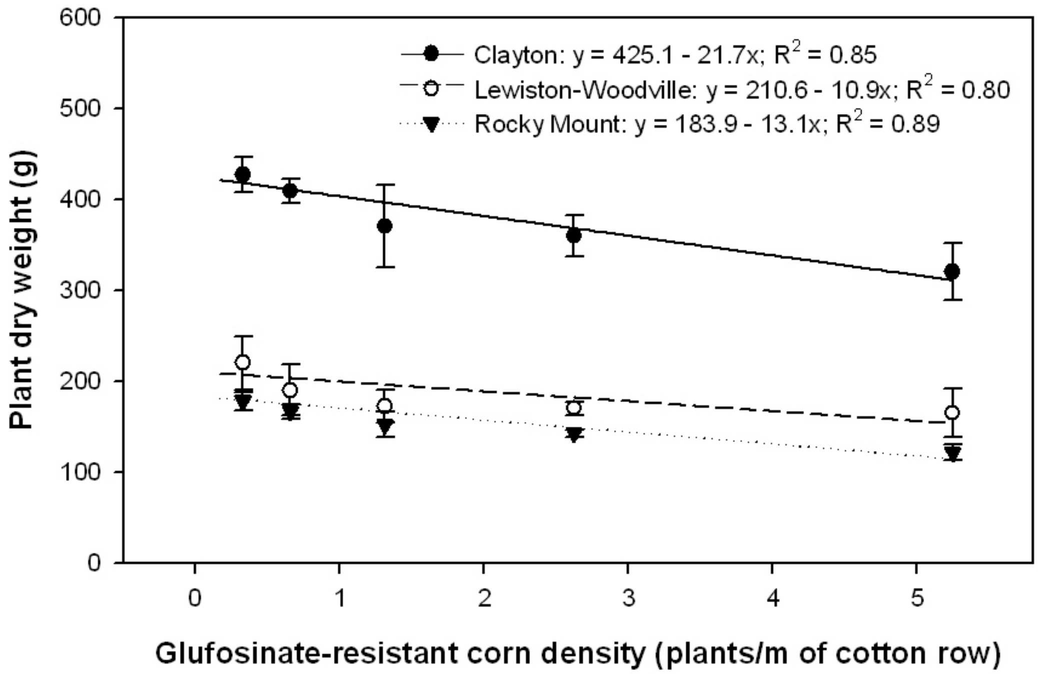

Figure 3. Effect of glufosinate-resistant (GUR) corn density on late-season GUR corn biomass per plant shown by location.

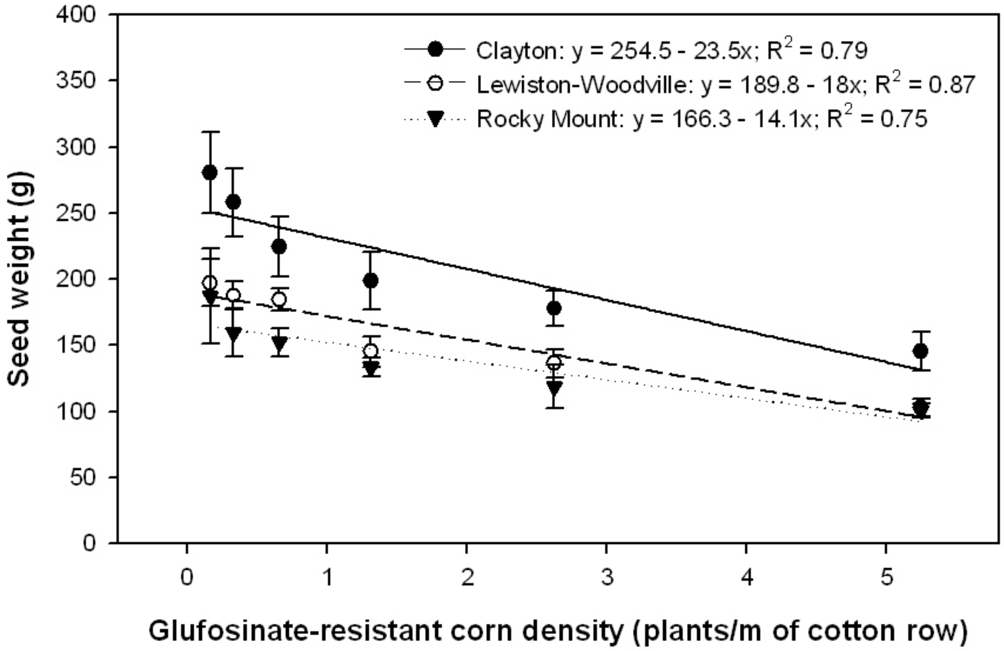

Figure 4. Effect of glufosinate-resistant (GUR) corn density on late-season GUR corn seed weight per plant shown by location.

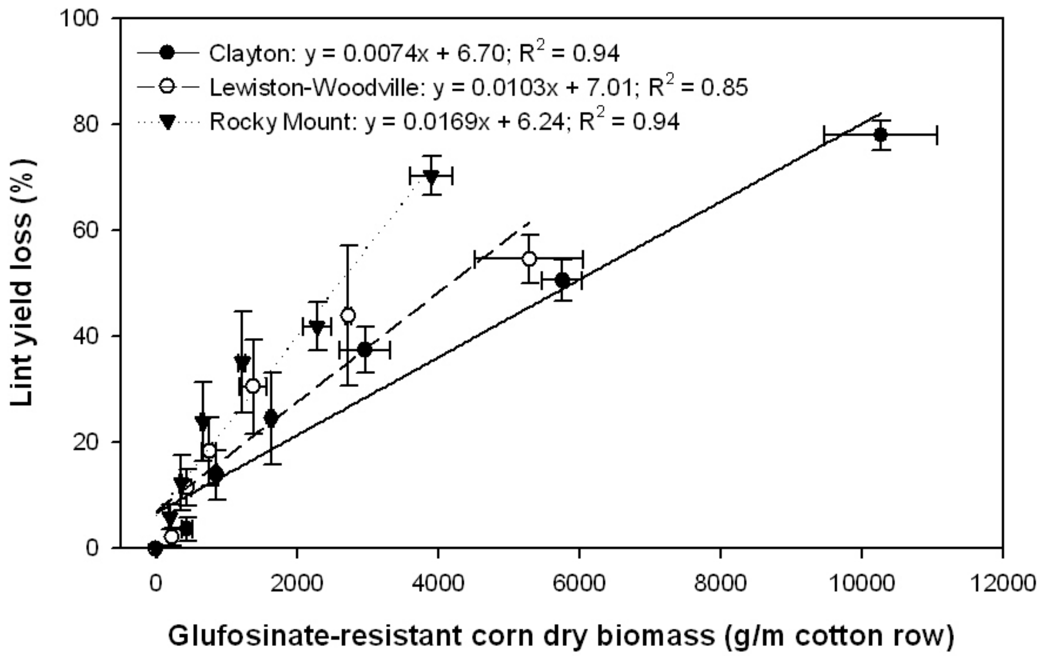

Figure 5. Effect of glufosinate-resistant (GUR) corn biomass m^{-1} crop row on GUR cotton lint yield shown by location.

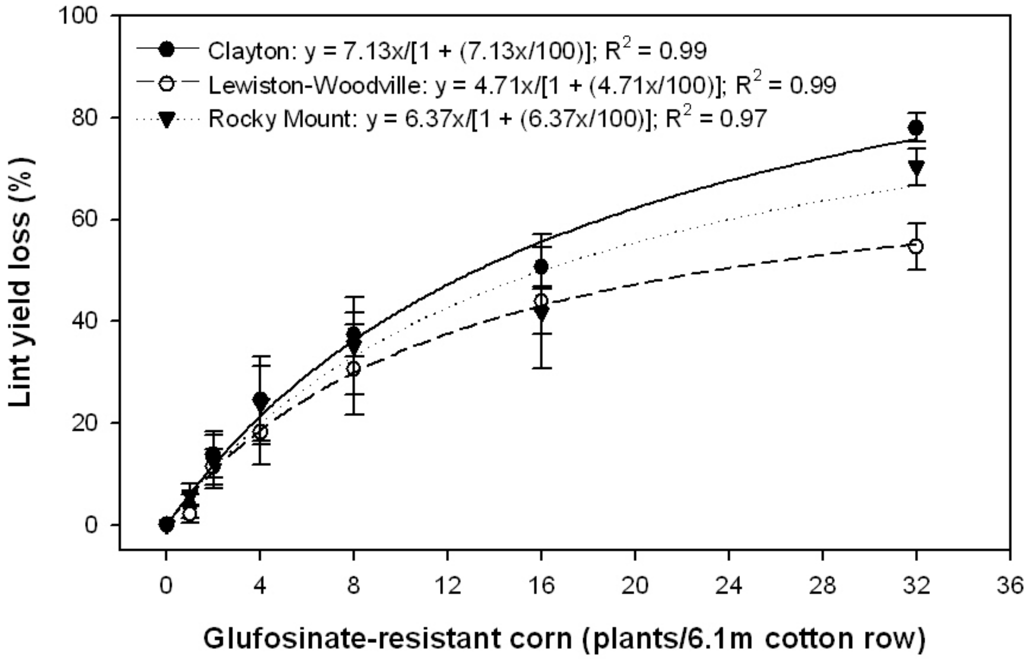

Figure 6. Glufosinate-resistant (GUR) cotton lint yield loss associated with season-long GUR corn interference.