PALMER AMARANTH AND IVYLEAF MORNINGGLORY MANAGEMENT IN ENHANCED GLYPHOSATE-RESISTANT COTTON

by

Max A. Batla, B.S.

A Thesis

In

CROP SCIENCE

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCE

Approved

Wayne Keeling

Peter Dotray

Randy Boman

Jeff Johnson

John Borrelli
Dean of the Graduate School

May, 2007

ACKNOWLEDGMENTS

I would first like to thank Dr. Wayne Keeling and Dr. Peter Dotray for giving me this opportunity to further my education and gain knowledge of weed science and research. The many hours spent and advice given in order to perfect this research is greatly appreciated.

I would also like to thank Dr. Jeff Johnson and Dr. Randy Boman for serving as committee members and for their thoughts and inputs towards this research.

My fellow graduate students Adam Ford and Matt Schwertner have been a great help not only in the field but also in the classroom. I would like to thank John Everitt for all his help in the field and in the office. His inputs and answers to countless questions about this research and weed science are also greatly appreciated. Undergraduate student worker Walt Keeling was a great help in doing a lot of the man labor and irrigation. All the memories and friendships made with this group of people throughout these two years will never be forgotten.

I would like to thank Cotton Incorporated Texas State Support Committee for their partial funding and support of this research and Texas Tech University and the Texas Agricultural Experiment Station for providing students with great facilities to gain knowledge and conduct high quality research.

Lastly, I would like to thank my family and friends for their continuous support throughout the past years. Especially my soon to be wife Carrie for all her love and support which gives me motivation to keep moving forward in my life.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is an important crop on the Texas Southern High Plains (TSHP). In 2005, over 4 million bales of cotton were produced on 1.07 million hectares (USDA 2006b). Compared to fast-growing crops such as corn (*Zea mays* L.) and sunflower (*Helianthus spp*. L.), cotton emerges and grows slowly for the first few weeks after planting. A slow growing crop, coupled with adverse early-season weather conditions typical of the TSHP, can slow plant growth even further and allow weeds to compete for light, water, and nutrients.

Of the weeds present on the TSHP, Palmer amaranth [*Amaranthus palmeri* (S.) Watts.] is estimated to be the most common and troublesome. Palmer amaranth is a competitive weed and was estimated to cause a 12% reduction of cotton yield in 2002 (Byrd 2003). Devil's-claw [*Proboscidea louisianica* (Mill.) Thuellung] is common to the TSHP and caused a 4% reduction in cotton yield in 2002 (Byrd 2003). Although ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] is not a widespread weed on the TSHP, there are an increasing number of fields infested each year. It was estimated in 2002 that ivyleaf morningglory caused a 12% reduction in cotton yield across Texas (Byrd 2003). Because these weeds germinate throughout the growing season, repeated herbicide applications and/or cultivations are required for season-long weed control. Although weeds emerging late in the season are less competitive than those emerging early in the season, reductions in lint yield, quality, harvest efficiency, and profitability can still occur (Buchanan and Burns 1971).

With the introduction of pyrithiobac and herbicide-resistant cotton in the 1990's, weed control in cotton has evolved from extremely labor intensive (hand-hoeing, frequent mechanical cultivations, and spot spraying) to increased reliance on chemical herbicides in reduced-till systems. Abernathy (1981) stated that cotton production in the United States without herbicides could result in a 32% yield reduction from weed competition.

Glyphosate is a non-selective herbicide used to control many annual and perennial broadleaf and grass weeds. The introduction of glyphosate-resistant (Roundup Ready) cotton allowed producers to more effectively control many annual and perennial weeds. However, glyphosate applications are restricted to postemergence-topical (POST) through the four-leaf cotton growth stage, and glyphosate applied after this stage must be made postemergence-directed (PDIR) to reduce the risk of yield loss (Welch et al. 1997; Light et al. 2003). Although producers have been successful at controlling early-season weed flushes, season-long control in Roundup Ready cotton has been limited due to the small POST application window, weed size, semi-arid conditions, and repeated weed flushes during the growing season.

The introduction of enhanced glyphosate-resistant (Roundup Ready Flex) cotton in 2006 offered cotton varieties with season-long tolerance to glyphosate POST over-the-top applications. Additional benefits of the Roundup Ready Flex cotton systems include less reliance on selective spray equipment, the ability to tailor herbicide applications to weed stage rather than cotton stage, and the opportunity to use an increased glyphosate rate for difficult-to-control weeds. Roundup Ready Flex systems also provide the ability to use other herbicide sites of action as needed for weed management or the management of resistant biotypes (Clewis et al. 2006a; Burgos et al. 2006). However, repeated use of glyphosate over the years has led to weed resistance in many states across the cotton belt. Keeling et al. (2006) reported that soil-applied herbicides are important as an economical means to maintain effective weed control while minimizing the potential for weed resistance development. It was estimated in 2006 that 61% of the region's cotton hectares were planted to Roundup Ready cotton varieties while 13% was planted to newly introduced Roundup Ready Flex cotton varieties. The wide use and acceptance of this new technology suggest that there will be an increase in Roundup Ready Flex cotton production as producers seek more flexible applications. Research in this area is needed to provide producers with information on the most effective use of glyphosate, residual herbicides, and in-season cultivations for managing weeds, and also reduce the risk of developing weed resistance across the TSHP. Therefore, field studies were conducted to evaluate the effects of weed competition as well as management strategies for Palmer amaranth, devil's-claw, and ivyleaf morningglory in Roundup Ready Flex cotton.

CHAPTER II

REVIEW OF LITERATURE

Cotton is a member of the genus *Gossypium*, which contains 49 species distributed throughout most tropical and subtropical regions of the world (Smith and Cothren 1999). It has played an important role in the United States economy for over 200 years as an important cash crop and as a source of foreign exchange. Although cotton is not native to the continental United States, the first English immigrants to grow cotton were from the Jamestown settlement in 1607 (Smith et al. 1999). Production regions gradually shifted from east to west and cotton production increased dramatically after the invention of the cotton gin in 1793.

Botanically, cotton is a perennial of tropical and semi-tropical origins (Supak et al. 1992). Through the domestication of cotton by selection and natural crossing, cotton is grown as a day-neutral annual in temperate regions with long, warm summers. Cotton is a multi-purpose crop which produces lint, oil, seed meal, and hulls. The spinnable lint (fibers) is produced on the seed coat and, according to Bajaj (1998), lint is the most important source of fiber currently being used in the textile industry.

Today, only four species of *Gossypium* are used in commercial cotton production; two (*Gossypium arboretum* and *Gossypium herbaceium*) are diploids (n=13) of Middle East or Old World origin and two (*Gossypium barbadense* and *Gossypium hirsutum*) are tetraploids (n=26) that evolved in the New World (Supak et al. 1992). Of these four, *Gossypium barbadense* contributes only a small portion to the annual cotton crop and its growth is restricted to a few areas across the United States (Pima cotton), the Nile River drainage area (Egyptian cotton), and in Peru (Tanguis cotton), while *Gossypium hirsutum* currently dominates world cotton cultivation and provides over 90% of the annual cotton crop (Brubaker et al. 1999).

In the United States, cotton is grown in 17 states across the southern portion. In 2005, the United States produced over 23.2 million bales of upland cotton on 5.48 million hectares and generated over $5.2 billion. Texas was the leading state producing about 8.44 million bales on 2.26 million hectares which valued $1.77 billion (NASS 2006a). In 2005 the Texas Southern High Plains, which consists of 16 counties, was the leading production area in the state producing over 4.1 million bales on 1.07 million hectares of irrigated and non-irrigated land (NASS 2006b).

Tremendous loss in cotton production and fiber quality is caused by various diseases and pests (Bajaj 1998). Some of the most troublesome pests found in cotton on the Texas Southern High Plains are weeds. A weed may be defined as an unwanted plant or a plant out of place. Although there are many ways to define a weed, Buchanan (1992) stated that weeds are those plants that interfere with other plants that humans grow for food, feed, and fiber or for asthetic reasons (lawns, flowers, etc.).

Weeds are commonly classified according to their life cycle. Weeds are grouped as annuals, biennials, and perennials. Annuals are species that complete their life cycle in 1 year or less (from seed germination to seed production) and have by far the largest number of weed species that compete with annual row crops (Aldrich and Kremer 1997). There are two kinds of annuals. Summer annuals germinate in the spring, produce seed, and die in the autumn. Winter annuals germinate in the fall of one year, overwinter, resume growth, produce seed, and die the next year. Biennials require two growing seasons to complete their life cycle. These weeds usually form rosettes (radial clusters of leaves prostrate to the ground) the first season and, during the second season, they send up flower stalks (referred to as bolting), set seed, and die (Anderson 1996). Perennials are those species that live for three or more years. A distinguishing feature is that perennial weeds propagate by both sexual (seeds) and/or asexual (vegetative) means (Anderson 1996).

Crop losses caused by weeds can be very large and are often a direct result of competition with weeds for light, water, and nutrients. Two plants are in competition with each other when the growth of either one or both of them is reduced or their form modified as compared with their growth or form in isolation (Bleasdale 1960). In the United States alone, the estimated average annual loss exceeds $6 billion (Aldrich and Kremer 1997). Ten species cause approximately 75% of cotton loss caused by weeds. Six of the 10 commonly found in the High Plains of Texas include morningglory (*Ipomoea* spp.), common cocklebur (*Xanthium strumarium* L.), pigweed (*Amaranthus* spp.), Russian thistle [*Salasola iberica* (Sennen) Pau], johnsongrass (*Sorghum halepense* L.), and silverleaf nightshade (*Solanum elaeagnifolium* Cav.) (Holm et al. 1977). This widely divergent population of weeds that affect cotton ensures continuous competition pressure to the cotton crop (Buchanan 1992).

Palmer amaranth (*Amaranthus palmeri* S. Wats.) is an erect, branched, summer annual broadleaf plant reaching 2 m in height (Elmore 1990). The rapid growth, deep root system, and high water use efficiency enable Palmer amaranth to compete effectively with crops. Pigweeds (*Amaranthus* spp.) are among the most common weeds in cotton throughout the southern United States (Rushing et al. 1985). In 2002, *Amaranthus* spp. infested over 2.02 million hectares of cotton in Texas and had an estimated 12% reduction in cotton yield (Byrd 2003). Morgan et al. (2001) stated that cotton lint yield was reduced linearly from 13.4 to 56.9% in rows containing 1 to 10 Palmer amaranth plants per 9.1 m, respectively. Buchanan and Burns (1971) found that eight pigweed plants per 7.31 m of row reduced yield 70% and at a higher density of 48 plants per row m, yield was reduced 90%. Palmer amaranth can also have an impact on the mechanical harvesting of cotton. Smith et al. (2000) reported that Palmer amaranth densities of 17 plants per ha nearly doubled the total harvest time and higher weed densities of 1,754 plants per ha increased the harvesting time 3.5-fold when compared to weed-free cotton.

Devil's-claw [*Proboscidea louisianica* (Mill.) Thellung], also known as unicorn plant, is a member of the Martyniaceae family and is native to the southwestern United States (Riffle et al. 1990). It is a coarse, viscidpubescent, spreading, annual herb with prostrate branches up to 1m long, and a well–developed taproot (Martin and Hutchins 1980). Devil's-claw is a troublesome weed in the Oklahoma and Texas cotton fields that are harvested by strippers. Mercer et al. (1990) found that devil's-claw densities of 6.6 weeds per 10 m of row caused a 42% reduction of cotton yield. In 2002, it was estimated that *Proboscidea* spp. reduced cotton yield 4% and infested over 0.6 million hectares across Texas (Byrd 2003).

Morningglory (*Ipomoea* spp.) is the third most troublesome weed in cotton grown in Texas (Dowler 1992). Ivyleaf Morningglory [*Ipomoea hederacea* (L.) Jacq] is a hairy, trailing annual from a taproot with stems up to 6 m long. In 2002, *Ipomoea* spp. infested over 0.28 million hectares of Texas cotton and caused a 12% reduction in yield (Byrd 2003). Keeley et al. (1986) reported that ivyleaf mornningglory at a density of one plant per 2 m of row resulted in complete crop loss. Rogers et al. (1996) found that cotton lint yield was reduced an estimated 6% for each weed/10 m of row up to 10 weeds and also stated that it is unlikely that a producer could tolerate even one ivyleaf morningglory/10 m of row in his fields. Competition from ivyleaf morningglories can also hinder the harvesting of cotton.

Weed control is the process of reducing weed growth and/or infestations to an acceptable level (Herbicide Handbook 1989). It is a matter of degree, ranging from poor to excellent, and the degree of weed control obtained is dependent on (1) the characteristics of the weed species involved and (2) the effectiveness of the control practice(s) used (Anderson 1996). Methods of controlling weeds in cotton can be grouped into five general categories: preventative, cultural, mechanical (physical), biological, and chemical.

Preventative weed control represents measures taken to prevent the introduction, establishment, and/or spread of specified weed species in areas not currently infested with these plants (Anderson 1996). Such measures include production of weed-free seed, and cleaning of weed-infested crop seed. Today, planting of contaminated crop seed continues to be a major source of spread of noxious weeds (Walker 1995). Other preventable means of dissemination include the transport of weed seeds and plant parts from farm to farm on planting, tilling, and harvesting equipment. The success of preventative weed management programs varies with the weed species, its means of dissemination, and the amount of effort applied (Walker 1995).

Cultural methods of weed management are simply the direction of all production practices towards the creation of a favorable environment for the cotton plant and, at the same time, an undesirable environment for weeds (Buchanan 1992). Some cultural control strategies include the selection of variety, time of planting, planting pattern, crop rotations, and irrigation. These factors may be manipulated so that crop growth is favored over the weed. In field studies conducted by Johnson, III et al. (2005), row spacing significantly affected total weed density and peanut yield. Rotation with other crops, particularly with crops that permit widely differing weed control procedures and practices, aid in long-term weed management (McWhorter and Hartwig 1965).

Mechanical or physical weed control tactics are the oldest methods of managing weeds. These control tactics include hand and machine tillage, mulching, cutting, pulling, and dragging. Prior to the introduction of herbicides, hand-hoeing accounted for well over half of the total labor requirement in the production of cotton (Buchanan 1992).

Tillage is a major mechanical control tactic which suppresses or reduces weed growth and infestations. Historically, cultivation has been used specifically for weed control and the frequency often depends on the individual situations found in the field (Snipes et al. 1992). Buchanan and Hitbold (1977) stated that there was little benefit of cultivation on cotton yield beyond that of weed control. Some disadvantages of cultivation include its lack of sustained control, the difficulty controlling weeds growing directly in the drill-row, and its promotion of soil erosion under some conditions (Buchanan 1992). Despite the disadvantages, tillage practices on the Texas Southern High Plains are effective at reducing wind erosion. Although mechanical control is still effective for controlling many weeds, Snipes and Mueller (1992) stated that acceptable weed control in cotton with cultivation alone cannot be achieved.

Biological control is a broad term for the exploitation of living organisms, or their products, to reduce or prevent the growth and reproduction of weeds (Cardina 1995). Some organisms used in biological control include herbivorous animals, insects, pathogens, and nematodes. Ideally, a successful biological control agent should cause a reduction in both weed density and health (Sheikh et al. 2001). Kennedy et al. (1991) found that bacteria located in the rhizosphere of roots have been shown to suppress the growth of downy brome (*Bromus tectorum* L.). Sheikh et al. (2001) conducted field studies with a biocontrol agent, *Pseudomonas syringae* pv. *tagetis*, and found that woollyleaf bursage [*Ambrosia grayi* (A. Nels.)], a perennial weed on the Texas Southern High Plains, was susceptible at all growth stages. Likewise, the puncturevine seed weevil [*Microlarinus lareynii* (Jac. Du Val)], which infests the seed bur of puncturvine (*Tribulus terrestris* L.), was introduced in the 1960's to biologically control puncturevine (Rummel and Arnold 1992). Boydston and Williams (2004) stated that combining *Aceria malherbea*, a gall-forming eriophyid mite, with low doses of 2,4-DB or glyphosate greatly reduced field bindweed (*Convolvulus arvensis* L.) shoot and root biomass.

Chemical weed control uses selective herbicides which kill or suppress plant growth. The use of herbicides for weed control began in 1944 with the introduction of 2,4-D and MCPA. Herbicides became popular in crop production due to the selectivity between the crops and weeds. Herbicides can be applied in cotton by different methods including applications made preplant, preemergence (PRE), and postemergence (POST). Preplant applications are made prior to planting and may be incorporated into the soil by tillage or water. However, preplant applications may also be made with foliar herbicides as a burndown option for weeds present in the field before planting. Preemergence herbicide applications are made after the crop is planted but before the crop emerges. Postemergence applications are made after crop emergence and may be made broadcast over the top or directed under the crop canopy.

In the 1960's, the introduction of trifluralin dramatically changed cotton production in the United States (Buchanan 1992). These preplant incorporated (PPI) herbicides effectively and economically controlled many grasses and small-seeded broadleaf weeds (Abernathy and Keeling 1979) by inhibiting the growth of roots and shoots in seedlings of susceptible species and by causing swelling of root tips (Appleby and Valverde 1988). Trifluralin and pendimethalin are dinitroaniline herbicides applied alone or as part of a sequential combination with PRE and POST herbicides to approximately 90% of the cotton seeded on the Texas Southern High Plains (Abernathy and Keeling 1979; Byrd and York 1987). In field studies conducted by Scott et al. (2002), trifluralin alone did not control tall or entireleaf morningglory but did control Palmer amaranth 28 to 30%. Although these herbicides have been reported to injure cotton, Keeling et al. (1996) reported that no negative effects on cotton yield or quality resulted from applications of normal or higher use rates of trifluralin or pendimethalin. Scott et al. (2002) also stated that trifluralin alone did not injure cotton.

Herbicides applied PRE are often used in conjunction with PPI herbicides to broaden the spectrum of weeds controlled. Preemergence herbicides are applied in a broadcast or band over the cotton row and rain or irrigation is needed to activate (move) these herbicides in the soil. Fluometuron, prometryn, and diuron are some of the more common PRE herbicides used on the Texas Southern High Plains. These herbicides are routinely used to control Palmer amaranth and larger seeded broadleaf weeds such as devil's-claw and morningglory (*Ipomoea* spp.). Porterfield et al. (2002) found that fluometuron PRE improved weed control by 17% and increased cotton yield compared to systems that did not use fluometuron PRE. However, PRE herbicides seldom provide sufficient season-long weed control (Buchanan 1992; Crowley et al. 1979). Therefore, effective weed management systems in cotton require both soil- and POST-applied herbicides (Buchanan 1992).

Postemergence herbicides applied on the Texas Southern High Plains that offer residual weed control without maturity delays or yield reductions include pyrithiobac and *S*-metolachlor. These herbicides add residual activity and can provide additional control of weeds emerging late in the season. Pyrithiobac was registered in 1996 for postemergence over-the-top applications in cotton (Culpepper and York 1998) and controls many broadleaf weeds with minimum or no injury to cotton (Henniger et al. 1992; Keeling et al. 1993). In field studies conducted by Paulsgrove and Wilcut (2001), pyrithiobac PRE increased control of pitted morningglory (*Ipomoea lacunose* L.), prickly sida (*Sida spinosa* L.), sicklepod (*Arabis canadensis* L.), and spurred anoda [*Anoda cristata* (L.) Schlecht] 24 to 38%. Cotton has tolerance to *S*-metolachlor early-postemergence (EPOST), and *S*-metolachlor provides residual control of many annual grass and small-seeded broadleaf weeds, including *Amaranthus* species, Florida pusley (*Richardia scabra* L.), and common lambsquarters (*Chenopodium album* L.) (Grichar et al. 2004). Clewis et al. (2006b) reported that *S*-metolachlor improved the control of Palmer amaranth, smooth pigweed (*Amaranthus hybridus* L.) and common lambsquarters 20 to 25% when applied with glyphosate EPOST.

Weed management systems in non-transgenic cotton typically include soil applied and postemergence herbicides. Various herbicides must be applied postemergence-directed because of crop injury potential, but growers prefer to apply herbicides POST (Culpepper and York 1999). Currently, fluometuron, pyrithiobac, and MSMA are some herbicides that are available for POST control of certain broadleaf weeds in non-transgenic cotton (Reddy 2001). Of these herbicides, fluometuron and MSMA must be applied PDIR. Postemergence herbicides have generally shifted from selective to nonselective herbicides with the introduction of herbicide resistant cotton varieties. Resistance has been developed to herbicides including bromoxynil, glufosinate, and glyphosate.

Bromoxynil-resistant cotton was the first of the transgenic cotton varieties introduced in 1995. Bromoxynil is a non-selective herbicide and a photosystem II inhibitor. Bromoxynil-resistant cotton was able to tolerate bromoxynil by the use of the

BXN gene, which codes for a specific nitrilase enzyme that degrades the herbicide. Bromoxynil-resistant cotton was the beginning of a new era in cotton weed control. Unfortunately, bromoxynil was not the most effective POST herbicide and was quickly replaced following the introduction of new and improved transgenic cotton varieties.

Glufosinate is a non-selective foliar-applied herbicide that has been used for vegetative management in noncrop environments for several years (Blackshaw 1989; Lanie et al. 1994; Wilson et al.1985). The recent introduction of glufosinate-resistant crops has created new opportunities for use of this herbicide for selective weed control in crop production (Tharp et al. 1999). Glufosinate inhibits the glutamine synthetase enzyme in susceptible plants (Bellinder et al. 1985; Logusch et al. 1991) and Blair-Kerth et al. (2001) indicated that the transformation events for glufosinate resistance in cotton were successful and the glufosinate-resistance gene was expressed throughout the growing season. Research by Dotray et al. (2004) and Steckel et al. (1997) suggested that glufosinate was most effective when applied to small weeds and herbicide coverage at the time of application was very important. Although glufosinate provides broad-spectrum control of annual grass and broadleaf weeds early in the season, continued emergence of weeds require multiple herbicide applications for season-long weed control and high yields (Barker et al. 2005). Improved control in glufosinate-resistant cotton has been reported with a tank-mixture of pyrithiobac and glufosinate when compared to glufosinate alone (Griffith et al. 2005).

Glyphosate-resistant (Roundup Ready) cotton was commercially available in 1997 and was initially used on nearly 324,000 ha (Heering et al. 1998). Glyphosate is recognized as an environmentally benign herbicide that is very effective on a broad spectrum of annual and perennial grass and broadleaf weeds, and sedges (Culpepper and York, 1998). The enzyme inhibited by glyphosate is 5-enol-pyruvyshikimate-3-phosphate synthase (EPSP synthase or EPSPS), thus limiting synthesis and regulation of aromatic amino acids (Devine at al. 1993; Franz 1985). Glyphosate-resistant cotton contains a gene coding for EPSPS, a glyphosate-resistant enzyme (Nida et al. 1996). Glyphosate can be applied postemergence over-the-top from emergence through the four-leaf stage of glyphosate-resistant cotton (Welch et al. 1997). After cotton reaches the five-leaf stage, applications of glyphosate must be made PDIR to prevent crop injury (Jones and Snipes 1999; Matthews et al. 1997). Culpepper and York (1998) stated that for effective weed control and adequate crop safety with PDIR herbicides, a height differential between the crop and the weed was required. Achieving a height differential can be difficult early in the growing season when the cotton plants are growing slow compared to the weeds due to cooler weather and other environmental factors.

With limitations in current Roundup Ready cotton, the introduction of an enhanced glyphosate-resistant (Roundup Ready Flex) cotton in 2006 allowed for improvements in overall weed control. Roundup Ready Flex cotton was created by transforming Coker 312 plant material using a disarmed *Agrobacterium tumefaciens* method and a CP4-EPSPS gene construct (Joy 2005). Both Roundup Ready Flex cotton and Roundup Ready cotton express the same CP4-EPSPS protein but utilize different promoters. However, Roundup Ready Flex cotton is resistant to glyphosate at both the vegetative stage (up to 4 leaf) and reproductive stage (beyond 5 leaf) allowing for an extended glyphosate application window. It also allows greater glyphosate use rates for more difficult to control weeds and gives producers the ability to make herbicide applications based on weed stage rather than cotton stage.

Weed management in glyphosate-resistant cotton has been successful. Culpepper and York (1999) found that 2 applications of glyphosate controlled smooth pigweed (*Amaranthus hybridus* L.) and common lambsquarters 94 to 96%. Although glyphosate controls many actively growing grass and broadleaf weeds, it does not provide residual weed control. Culpepper and York (1998) reported that glyphosate applied EPOST controlled weeds greater than 90%, but continued germination resulted in poor late-season control.

Extensive use of glyphosate has led to the development of glyphosate-resistant weed biotypes in many states across the cotton belt. This suggests the importance of residual herbicides to herbicide programs in Roundup Ready cotton. Culpepper and York (1998) found that glyphosate applied once did not adequately control most species and soil applied herbicides generally increased late-season weed control in systems with glyphosate applied once. Igsett et al. (1997) and Keeton and Murdock (1997) reported that glyphosate in conjunction with residual herbicides have been shown to provide excellent weed control. Joy et al. (2005) reported that the addition of a soil residual herbicide such as trifluralin PPI, and *S*-metolachlor or pyrithiobac POST reduced the number of in-season glyphosate applications (from three to two) for season-long Palmer amaranth and devil's-claw control and increased rates of glyphosate improved ivyleaf morningglory control. With the introduction of Roundup Ready Flex cotton, research is needed to obtain optimum timings and rates of glyphosate applications with the use of residual herbicides and mechanical cultivation to improve weed control across the Texas Southern High Plains.

CHAPTER III

MATERIALS AND METHODS

Field experiments were conducted in 2005 and 2006 at the Texas Agricultural Experiment Station near Lubbock to evaluate Palmer amaranth [*Amaranthus palmeri* (S) Wats], devil's-claw [*Proboscidea louisianica* (Mill.) Thellung], and ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] management in Roundup Ready Flex cotton. The soil type was an Acuff clay loam [Fine-loamy, mixed, thermic Aridic Paleustolls, (41% sand, 25% silt, 34% clay)] with <1% organic matter and pH of 7.6.

Three experiments were conducted each year, including: Palmer amaranth and devil's-claw management, Palmer amaranth competition, and ivyleaf morningglory management. For all experiments, Stoneville 4554 B2RF cotton was planted on 102 cm rows at a depth of 5 cm and a seeding rate of 17 kg/ha. Planting dates were May 18, 2005 and May 8, 2006. Rainfall totaled 358 mm in 2005 and 347 mm in 2006 (Table 3.1). The ivyleaf morningglory experiment received an additional 152 mm of water by furrow irrigation in 2005 and 228 mm in 2006. Both Palmer amaranth experiments received an additional 152 mm of water by furrow irrigation in 2005 and 381 mm in 2006.

Postemergence-topical (POST), preplant incorporated (PPI), and preemergence (PRE) herbicide applications were made using a tractor-mounted compressed air sprayer or a CO_2 pressurized backpack sprayer both calibrated to deliver 93 L/ha. The tractor sprayer was operated at a speed of 5 km/hr at 241 kPa with TurboTeeJet 110015VS nozzles (Spraying Systems Co., North Avenue and Schmale Road, Wheaton, IL 60188). The backpack sprayer was operated at a speed of 5 km/hr at 179 kPa with TurboTeeJet 110015VS nozzles. Preplant herbicides were incorporated to a depth of 8 to 12 cm immediately after application using a spring-tooth harrow. Postemergence-directed (PDIR) applications were made using a Red Ball® 420 Lay-By hooded sprayer (Redball, LLC, 140 30th Avenue SE, Benson, MN 56215-0159) calibrated to deliver 93 L/ha at a speed of 8 km/hr. Spray tips used for the PDIR applications were TeeJet 80015VS and 8001VS flat-fan nozzles. Application data for all experiments are shown in Tables 3.7 thru 3.12.

Percent weed control was estimated 14 and 28 days after each glyphosate application followed by an end of season evaluation using a scale from 0 (no control) to 100% (complete control). Cotton was harvested on October 18, 2005 and October 20, 2006 and samples were removed from each plot for ginning to determine the percent turnout of cotton lint. Ginned lint samples were analyzed with a High Volume Instrument (HVI) and Commodity Credit Corporation (CCC) loan values were calculated using the 2006 loan chart. Economic analysis was done for Palmer amaranth and devil's-claw management and ivyleaf morningglory management. Weed control costs were calculated using average herbicide costs from three local dealers (Table 3.13). Weed control costs for each treatment or weed management system also included herbicide application costs, herbicide incorporation costs, and cultivation costs (Tables 3.14 and 3.15).

For all experiments, data was analyzed using SAS version 9.1. Data was subjected to analysis of variance and means were separated using Fisher's Protected LSD test at the 5% level of probability. Percent weed control data were arcsine transformed before analysis. However, non-transformed data are presented with the transformed mean separations used.

Palmer Amaranth and Devil's-claw Management

In 2005 and 2006, field studies were established to evaluate Palmer amaranth and devil's-claw management in Roundup Ready Flex cotton with different glyphosate POST application timings in combination with PPI and POST residual herbicides (Table 3.2). The study was arranged in a randomized complete block design. Plots were 4 rows by 9 m in length and a natural infestation of weeds were present.

Herbicides used for Palmer amaranth and devil's-claw management systems included trifluralin PPI at 0.84 kg ai/ha, *S*-metolachlor at 1.4 kg ai/ha applied EPOST, pyrithiobac at 0.04 kg ai/ha applied EPOST, and glyphosate at 0.84 kg ae/ha applied early-postemergence (EPOST), mid-postemergence (MPOST), postemergence-directed (PDIR), and as needed (ASN) (Table 3.3). Yield was determined by harvesting all four rows of each plot using a four row plot stripper in 2005 and the middle two rows using a two row plot stripper in 2006.

Palmer Amaranth Competition

Field studies were conducted to evaluate application timing of glyphosate POST on Palmer amaranth competition in Roundup Ready Flex cotton and its effects on cotton yield and quality (Table 3.4 and 3.5). Studies were arranged in a randomized complete block design and treatments were replicated three times. Plots were 4 rows by 9 m and a natural infestation of Palmer amaranth was present. All treatments for the competition studies were compared with or without trifluralin PPI at 0.84 kg ai/ha and glyphosate was applied at 0.84 kg ae/ha. Plots were maintained for the remainder of the growing season with glyphosate ASN applications and hand-hoeing. Palmer amaranth densities were recorded at the time of application using a square meter quadrant placed randomly in the plot. Yield was determined by harvesting all four rows of each plot using a four row plot stripper in 2005 and the middle two rows using a two row plot stripper in 2006.

Ivyleaf Morningglory Management

In 2005 and 2006, field studies were conducted to evaluate different rates of glyphosate POST in combination with PRE and POST residual herbicides and mechanical cultivation for improved control of ivyleaf morningglory in Roundup Ready Flex cotton. Studies were arranged as a randomized block design with a factorial arrangement of treatments. Weed management inputs included prometryn at 1.34 kg ai/ha applied PRE, glyphosate at 0.84 and 1.25 kg ae/ha applied POST and PDIR, pyrithiobac at 0.04 kg ai/ha applied EPOST, and mechanical cultivations made as needed using a row crop cultivator (Table 3.6). Management systems included both rates of glyphosate alone and with all possible combinations of the other inputs. Trifluralin PPI was applied at 0.84 kg ai/ha to the entire test area to eliminate interference with unwanted weed species. Glyphosate was applied PDIR once in 2005 and twice in 2006 due to late weed emergence in the crop row and the crop canopy not allowing for good herbicide coverage. Yield for both years was determined by harvesting the middle two rows of the four row plots using a two row plot stripper.

Table 3.1. Yearly rainfall distribution by month for 2005, 2006, and the 30-year average[a,b].

Month	Yearly Rainfall		
	2005	2006	30-year avg
	mm		
Jan	30	0	13
Feb	32	4	18
Mar	16	58	19
Apr	6	16	32
May	48	59	58
Jun	33	18	75
Jul	63	3	54
Aug	59	24	59
Sep	7	132	65
Oct	64	27	43
Nov	0	6	18
Dec	0	0	17
Total	358	347	474

[a] Abbreviations: avg, average; mm, millimeters.
[b] Thirty year average reported by NOAA 2007.

Table 3.2. Application timing, method, and dates for Palmer amaranth and devil's-claw management in 2005 and 2006[a].

			Date	
Application	timing	method	2005	2006
trifluralin	PPI	PPI	Mar 3	Mar 27
glyphosate	EPOST	POST	Jun 9	May 24
glyphosate	MPOST	POST	Jun 16	Jun 6
glyphosate	EPOST ASN	POST	Jul 11	Jun 28
glyphosate	MPOST ASN	POST	Jul 11	Jul 11
glyphosate	ASN	PDIR	Jul 11	Jun 12 and 17

[a] Abbreviations: ASN, as-needed; EPOST, early postemergence; MPOST, mid postemergence; PDIR, postemergence-directed; POST, postemergence; PPI, preplant incorporated.

Table 3.3. Cotton growth stage and weed size for Palmer amaranth and devil's-claw management in 2005 and 2006[a].

	2005			2006		
Glyphosate Application	Cotton stage[b]	Palmer amaranth	Devil's-claw	Cotton stage	Palmer amaranth	Devil's-claw
		cm			cm	
EPOST	2 to 3 lf	5 to 10	cot to 5	2 lf	cot to 5	cot to 5
MPOST	5 lf	10 to 20	8 to 15	4 to 5 lf	10 to 20	15 to 20
PDIR ASN	10 lf	10 to 25	8 to 15	5 to 6 lf	5 to 10	5 to 10
EPOST ASN	12 to 14 lf	10 to 20	5 to 15	10 lf	10 to 25	10 to 30
MPOST ASN	12 to 14 lf	10 to 20	5 to 15	13 lf	10 to 25	10 to 30
PDIR II ASN	NA	NA	NA	14 lf	5 to 40	5 to 30

[a] Abbreviations: ASN, as-needed; cot, cotyledon; EPOST, early postemergence-topical; lf, leaf; MPOST, mid-postemergence topical; NA, not applicable; PDIR, postemergence-directed.
[b] Cotton stage reported in number of true leaves.

Table 3.4. Palmer amaranth competition treatments, application timings, and dates for experiments in 2005 and 2006[a].

Treatment[b]	Application timing	Application Date 2005	2006
trifluralin	PPI	Mar 3	Mar 27
glyphosate	5 cm weeds	Jun 9	May 24
trifluralin	PPI	Mar 3	Mar 27
glyphosate	+ 7 days	Jun 16	Jun 1
trifluralin	PPI	Mar 3	Mar 27
glyphosate	+ 14 days	Jun 23	Jun 8
trifluralin	PPI	Mar 3	Mar 27
glyphosate	+ 21 days	Jun 30	Jun 15
trifluralin	PPI	Mar 3	Mar 27
glyphosate	+ 28 days	Jul 11	Jun 23
trifluralin	PPI	Mar 3	Mar 27
glyphosate	5 cm weeds	Jun 9	May 24
glyphosate	+ 7 days	Jun 16	Jun 1
glyphosate	+ 14 days	Jun 23	Jun 8
glyphosate	+ 21 days	Jun 30	Jun 15
glyphosate	+ 28 days	Jul 11	Jun 23
non-treated	NA	NA	NA

[a] Abbreviations: NA, not applicable; PPI, preplant incorporated.
[b] Rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate.

Table 3.5. Application date, cotton stage, and weed size for Palmer amaranth competition in 2005 and 2006[a].

Application timing	2005			2006		
	Date	cotton stage	weed size	Date	cotton stage	weed size
			-- cm --			-- cm --
POST 5 cm weeds	Jun 9	cot to 2 lf	cot to 5	May 24	cot to 2 lf	cot to 5
+ 7 days	Jun 16	4 lf	5 to 10	Jun 1	3 lf	5 to 20
+ 14 days	Jun 23	7 lf	15 to 20	Jun 8	5 lf	10 to 35
+ 21 days	Jun 30	10 lf	15 to 45	Jun 15	7 lf	15 to 50
+ 28 days	Jul 11	12 lf	15 to 61	Jun 23	10 lf	15 to 71

[a] Abbreviations: cot, cotyledon; lf, leaf; POST, postemergence-topical.

Table 3.6. Application date, method, crop stage, and weed size for ivyleaf morningglory management in 2005 and 2006[a].

	2005				2006			
Application[b]	Date	Application Method	Crop Stage	Weed Size	Date	Application Method	Crop Stage	Weed Size
				-- cm --				-- cm --
PRE	Mar 3	PRE	NA	NA	Mar 27	PRE	NA	NA
POST I	Jun 2	POST	2 lf	cot to 5	Jun 6	POST	4 to 5 lf	2 to 7
POST II	Jun 22	POST	6 to 8 lf	cot to 15	Jun 30	POST	10 lf	2 to 18
POST III	Jul 12	POST	12 to 14 lf	5 to 34	Jul 26	PDIR	15 lf	5 to 37
POST IV	Aug 8	PDIR	16 to 18 lf	5 to 38	Aug 24	PDIR	16 lf	5 to 45

[a] Abbreviations: cot, cotyledon; lf, leaf; PDIR, postemergence-directed; POST, postemergence topical; PRE, preemergence.

[b] Applications reflect prometryn applied PRE and glyphosate POST. Pyrithiobac tankmixed with glyphosate at POST I timing. Cultivations directly followed first three POST applications of glyphosate.

Table 3.7. Application descriptions for Palmer amaranth and devil's-claw management in 2005[a].

	PPI	EPOST	MPOST	ASN
Application Date	Mar 3	Jun 9	Jun 16	Jul 11
Air temperature (^{o}C)	19	33	37	30
Relative Humidity (%)	30	35	25	39
Wind Speed (kph)	16	11	11	3
Soil surface temp (^{o}C)	9	40	41	32
Cloud cover (%)	20	50	0	0

[a] Abbreviations: ASN, as needed; EPOST, early postemergence; kph, kilometers per hour; MPOST, mid postemergence; PPI, preplant incorporated.

Table 3.8. Application descriptions for Palmer amaranth and devil's-claw management in 2006[a].

	PPI	EPOST	MPOST	PDIR	EPOST ASN	MPOST ASN	PDIR ASN
Application Date	Mar 27	May 24	Jun 6	Jun 12	Jun 28	Jul 11	Jul 17
Air temperature (^{o}C)	17	37	25	34	26	36	32
Relative Humidity (%)	18	8	54	23	30	27	29
Wind Speed (kph)	11	11	6	9	13	14	13
Soil surface temp (^{o}C)	13	29	29	34	29	39	33
Cloud cover (%)	75	0	80	10	10	0	10

[a] Abbreviations: ASN, as needed; EPOST, early postemergence; kph, kilometers per hour; MPOST, mid postemergence; PDIR, postemergence-directed; PPI, preplant incorporated.

Table 3.9. Application descriptions for Palmer amaranth competition in 2005[a].

	PPI	POST I	POST II	POST III	POST IV	POST V
Application Date	Mar 3	Jun 9	Jun 16	Jul 23	Jun 30	Jul 11
Air temperature (^{o}C)	19	33		32	34	30
Relative Humidity (%)	30	35		33	25	39
Wind Speed (kph)	16	11		11	6	3
Soil surface temp (^{o}C)	9	40		35	38	32
Cloud cover (%)	20	50	0	0	20	0

[a] Abbreviations: kph, kilometer per hour; POST, postemergence-topical; PPI, preplant incorporated.

Table 3.10. Application descriptions for Palmer amaranth competition in 2006[a].

	PPI	POST I	POST II	POST III	POST IV	POST V
Application Date	Mar 27	May 24	Jun 1	Jul 8	Jun 15	Jul 23
Air temperature (^{o}C)	17	37	25	23	23	17
Relative Humidity (%)	18	8	63	48	47	77
Wind Speed (kph)	11	11	2	13	11	7
Soil surface temp (^{o}C)	13	29	23	28	28	25
Cloud cover (%)	75	0	85	0	40	60

[a] Abbreviations: kph, kilometer per hour; POST, postemergence-topical; PPI, preplant incorporated.

Table 3.11. Application descriptions for ivyleaf morningglory management in 2005[a].

	PRE	POST I	POST II	POST III	POST IV
Application Date	May 18	Jun 2	Jun 22	Jul 12	Aug 8
Air temperature (^{o}C)	34	32	32	29	26
Relative Humidity (%)	13	36	30	44	57
Wind Speed (kph)	11	6	9	8	11
Soil surface temp (^{o}C)	21	25	40	32	33
Cloud cover (%)	30	70	0	70	20

[a] Abbreviations: kph, kilometer per hour; POST, postemergence-topical; PRE, preemergence.

Table 3.12. Application descriptions for ivyleaf morningglory management in 2006[a].

	PRE	POST I	POST II	POST III	POST IV
Application Date	May 8	Jun 6	Jun 30	Jul 26	Aug 24
Air temperature (^{o}C)	34	25	28	27	29
Relative Humidity (%)	11	54	46	48	46
Wind Speed (kph)	9	6	6	14	13
Soil surface temp (^{o}C)	20	29	29	28	27
Cloud cover (%)	0	80	0	10	0

[a] Abbreviations: kph, kilometer per hour; POST, postemergence-topical; PRE, preemergence.

Table 3.13. Custom application and herbicide costs used for weed control[a].

Management tool	Rate[b]	Cost
		$/ha
Herbicides[c]		
trifluralin	0.84	6.50
glyphosate	0.84	13.44
glyphosate	1.25	19.54
pyrithiobac	0.04	22.77
S-metolachlor	1.12	33.15
prometryn	1.40	22.97
Custom applications[d]		
herbicides	NA	7.41
cultivation	NA	12.35

[a] Abbreviations: NA, not applicable.
[b] Rates = kg ai/ha, trifluralin, pyrithiobac, *S*-metolachlor, and prometryn; kg ae/ha, glyphosate.
[c] Herbicide prices averaged from three local dealers.
[d] Custom application prices based on most common rates from the 2004 Texas Custom Rates Statistics (NASS 2005).

Table 3.14. Weed control costs used for economic analysis on Palmer amaranth and devil's-claw management[a].

Weed management system[b]	Application timing	Herbicide Cost	Herbicide application cost	Herbicide incorporation cost	Total weed control costs
		$/ha			
Trifluralin					
glyphosate fb glyphosate	EPOST	33.37	22.23	12.35	67.95
glyphosate+pyrithiobac fb glyphosate	EPOST	56.14	22.23	12.35	90.72
glyphosate+*S*-metolachlor fb glyphosate	EPOST	66.52	22.23	12.35	101.10
glyphosate fb glyphosate	MPOST	33.37	22.23	12.35	67.95
glyphosate+pyrithiobac fb glyphosate	MPOST	56.14	22.23	12.35	90.72
glyphosate+*S*-metolachlor fb glyphosate	MPOST	66.52	22.23	12.35	101.10
RR standard: glyphosate fb glyphosate	PDIR	33.37	22.23	12.35	67.95
No PPI					
Glyphosate fb glyphosate	EPOST	26.87	14.82	0	41.69
glyphosate+pyrithiobac fb glyphosate	EPOST	49.65	14.82	0	64.47
glyphosate+*S*-metolachlor fb glyphosate	EPOST	60.02	14.82	0	74.84
glyphosate fb glyphosate	MPOST	26.87	14.82	0	41.69
glyphosate+pyrithiobac fb glyphosate	MPOST	49.65	14.82	0	64.47
glyphosate+*S*-metolachlor fb glyphosate	MPOST	60.02	14.82	0	74.84
RR standard: glyphosate fb glyphosate	PDIR	26.87	14.82	0	41.69
trifluralin alone	PPI	6.50	7.41	12.35	26.26
non-treated	NA	0	0	0	0

[a] Abbreviations: EPOST, early-postemergence; fb, followed-by; LSD, least significant difference; MPOST, mid-postemergence; NA, not applicable; NS, not significant; PDIR, postemergence-directed; PPI, preplant incorporated; RR, Roundup Ready.

[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.

Table 3.15. Weed control costs used for economic analysis on ivyleaf morningglory management[a].

Weed management System	Herb cost Rate[b]		Herb app cost Rate		Cultivation cost Rate		Total WCC Rate	
	0.84	1.25	0.84	1.25	0.84	1.25	0.84	1.25
	$/ha							
glyphosate	53.75	78.15	29.64	29.64	0.00	0.00	83.39	107.79
glyphosate+pyr	76.52	100.92	29.64	29.64	0.00	0.00	106.16	130.56
pro fb glyphosate	76.72	101.12	37.05	37.05	0.00	0.00	113.77	138.17
glyphosate fb cult	53.75	78.15	29.64	29.64	37.05	37.05	120.44	144.84
pro fb glyphosate+pyr	99.49	123.90	37.05	37.05	0.00	0.00	136.54	160.95
glyphosate+pyr fb cult	76.52	100.92	29.64	29.64	37.05	37.05	143.21	167.61
pro fb glyphosate fb cult	76.72	101.12	37.05	37.05	37.05	37.05	150.82	175.22
pro fb glyphosate+pyr fb cult	99.49	123.90	37.05	37.05	37.05	37.05	173.59	198.00

[a] Abbreviations: cult, cultivation; fb, followed-by; Herb, herbicide; pro, prometryn; pyr, pyrithiobac; WCC, weed control cost.
[b] Rates of glyphosate.

CHAPTER IV

RESULTS AND DISCUSSION

A year by treatment interaction was observed for Palmer amaranth, devil's-claw, and ivyleaf morningglory management; therefore, data was analyzed by year in 2005 and 2006. However, data was pooled over years for Palmer amaranth competition because no year by treatment interaction was observed for cotton lint yield.

Palmer Amaranth and Devil's-claw Management

Palmer Amaranth Control

In 2005, early-season (14 DAT) Palmer amaranth control ranged from 95 to 100%, with trifluralin preplant incorporated (PPI) alone controlling Palmer amaranth 96% (Table 4.1). Glyphosate applied early postemergence-topical (EPOST) achieved 100% control of Palmer amaranth 14 DAT. Glyphosate systems applied MPOST controlled Palmer amaranth 95 to 99%, with similar control achieved with glyphosate alone or glyphosate plus *S*-metolachlor or pyrithiobac. At 28 DAT, Palmer amaranth was controlled 83% with trifluralin PPI alone. Palmer amaranth control was similar between glyphosate applied either EPOST or MPOST and control ranged from 85 to 98%; however, there was a trend towards increased control with the use of *S*-metolachlor or pyrithiobac tank-mixed with glyphosate. At the end of the season (120 DAT), trifluralin PPI alone did not provide adequate Palmer amaranth control (66%).

After all systems received a sequential ASN glyphosate application, complete Palmer amaranth control was achieved across all glyphosate POST systems. However, less effective Palmer amaranth control (98 and 94%) was observed with commercial Roundup Ready glyphosate systems either with or without trifluralin PPI, respectively. In 2005, frequent rainfall throughout the growing season allowed optimum crop growth, reducing the amount of in-season irrigations needed and subsequently, less weed germination throughout the growing season. A glyphosate POST-only system controlled Palmer amaranth 100%; therefore, no benefit from a PPI or tank-mixed residual herbicides was observed.

In 2006, early-season Palmer amaranth control ranged from 92 to 100%, with trifluralin PPI controlling Palmer amaranth 82% (Table 4.1). Glyphosate following trifluralin PPI controlled Palmer amaranth 98 to 100%, with similar control between EPOST and MPOST timings. When no PPI was used, Palmer amaranth control ranged from 92 to 98%, with a trend towards improved control when glyphosate applications were delayed from EPOST to MPOST. Delaying glyphosate applications to MPOST allowed for more weed seeds to germinate before the application, and germination of seeds after the application was minimal due to dryer soil conditions.

When evaluated 28 DAT, trifluralin PPI controlled Palmer amaranth 47%. Trifluralin followed by (fb) glyphosate EPOST controlled Palmer amaranth 94%. Pyrithiobac or *S*-metolachlor tank-mixed with glyphosate EPOST improved Palmer amaranth control to 98 and 99%. Glyphosate EPOST without a PPI controlled Palmer amaranth 75%, and the addition of pyrithiobac or *S*-metolachlor to glyphosate EPOST improved control to 89 and 91%, respectively. Glyphosate MPOST controlled Palmer amaranth 98 to 100%, and no benefit was observed from trifluralin PPI or tank-mixes of *S*-metolachlor or pyrithiobac with glyphosate MPOST. At the end of the season, trifluralin PPI controlled Palmer amaranth 30%. Similar Palmer amaranth control (95 to 99%) was observed across all glyphosate-based Roundup Ready Flex systems following trifluralin PPI, with no benefit from pyrithiobac or *S*-metolachlor tank-mixed with glyphosate. When no PPI was used, pyrithiobac or *S*-metolachlor tank-mixed with glyphosate EPOST fb glyphosate controlled Palmer amaranth 95 and 92%. Less effective Palmer amaranth control was observed from glyphosate EPOST fb glyphosate (85%).

The commercial Roundup Ready systems comprised of glyphosate EPOST fb two PDIR glyphosate applications either with or without trifluralin PPI controlled Palmer amaranth 86 and 87%. Similar Roundup Ready Flex systems required fewer glyphosate applications throughout the growing season to achieve similar or greater Palmer amaranth control (85 and 97%). In 2006, four in-season furrow irrigations were needed, which resulted in continuous weed seed germination throughout the growing season. Therefore, overall Palmer amaranth control was less effective in 2006 compared to the 2005 growing season.

<u>Devil’s-claw Control</u>

In 2005, devil’s-claw control 14 days after glyphosate applications ranged from 85 to 100%, and no devil’s-claw control was observed with the use of trifluralin PPI alone (Table 4.2). Glyphosate EPOST controlled devil’s-claw 98 to 100%, and control declined (85 to 93%) when glyphosate applications were delayed to MPOST (7 days). When applications were delayed from EPOST to MPOST, weed size increased from cotyledon to 5 cm (EPOST) to 8 to 15 cm (MPOST) (Table 3.3). Pyrithiobac or *S*-metolachlor tank-mixed with glyphosate did not improve early-season devil's-claw control. At 28 DAT, devil's-claw control ranged from 87 to 95%, with no benefit from the addition of pyrithiobac or *S*-metolachlor. At the end of the season, after all systems received a sequential ASN glyphosate application, devil's-claw was controlled 99 to 100% across all Roundup Ready Flex systems and residual herbicides did not improve control. However, less effective devil's-claw control (97 and 95%) was observed with commercial Roundup Ready cotton glyphosate systems either with or without trifluralin PPI.

In 2006, early-season devil's-claw was controlled 92 to 100%, and no control was observed from trifluralin PPI. Delayed glyphosate applications to the MPOST timing provided greater devil's-claw control (98 to 100%). This delay allowed more weeds to emerge before glyphosate was applied, and emergence of weeds after the application was minimal due to dryer soil conditions in 2006. Pyrithiobac or *S*-metolachlor tank-mixed with glyphosate did not always improve early-season devil's-claw control. However, when evaluated 28 DAT, pyrithiobac tank-mixed with glyphosate EPOST controlled devil's-claw 93 to 95%, which was more effective than glyphosate EPOST alone (81 and 82%). Glyphosate MPOST controlled devil's-claw 94 to 100%, and the addition of pyrithiobac or *S*-metolachlor to glyphosate MPOST controlled devil's-claw similar to glyphosate MPOST alone.

End of season devil's-claw control ranged from 97 to 100%. No benefit was observed from trifluralin PPI or when glyphosate was tank-mixed with residual herbicides. The commercial Roundup Ready systems, which were comprised of glyphosate EPOST fb two PDIR glyphosate applications, controlled devil's-claw 97 or 99% at the end of the season. However, similar Roundup Ready Flex glyphosate systems required fewer glyphosate applications throughout the growing season to achieve similar or greater devil's-claw control (97 to 100%).

In both years, this data indicates that timely early-season applications of glyphosate can be beneficial when Palmer amaranth and devil's-claw are present in the field. Similarly, Joy et al. (2004) found timely applications of glyphosate to be more beneficial than increased glyphosate rates. In addition, McCloskey (2006) stated that superior weed control resulted from preplant incorporated herbicide applications and earlier topical glyphosate applications. Although residual herbicides did not always improve Palmer amaranth and devil's-claw control, previous research found that the addition of a soil residual herbicide reduced the number of in-season glyphosate applications needed for season-long Palmer amaranth and devil's-claw control (Joy et al. 2005).

Yield, Net Returns, and Quality

Although end of season weed control ranged from 94 to 100% in 2005, cotton lint yield varied from 1,000 to 1,330 kg/ha and did not always correlate to end of season weed control achieved (Table 4.3). Delaying early-season glyphosate applications from

EPOST to MPOST (7 days) did not reduce cotton lint yield. However, when no herbicides were used, cotton yields were reduced 71% compared to a glyphosate only system. Net returns above weed control costs were strongly associated with cotton lint yield achieved and ranged from $1,210 to $1,605 per hectare (Table 4.3). Although weed management systems using residual herbicides had increased weed control costs, net returns were similar if not greater than glyphosate only systems.

When trifluralin was used alone or when no herbicides were used, cotton lint yield was reduced by 82 and 94%, respectively in 2006 (Table 4.4). When glyphosate was used, cotton lint yield ranged from 980 to 1360 kg/ha and were not always related to end of season weed control achieved. Similar to 2005, no reductions in cotton lint yield was observed when early-season glyphosate applications were delayed from EPOST to MPOST (13 days). Lint quality measures including micronaire, length, and strength were similar for all weed management systems in both years (Tables 4.5 and 4.6) Net returns above weed control costs did not always parallel cotton lint yield. Therefore, net returns above weed control costs were similar, ranging from $1,110 to $1570 per hectare (Table 4.4). The use of residual herbicides with glyphosate-based weed management systems produced similar or increased net returns compared to glyphosate POST-only systems. In both years, the use of these herbicides was not only an economical option to improve weed control, but also a tool to reduce the risk of the development of glyphosate-resistant weeds.

Palmer Amaranth Competition

In 2006, Palmer amaranth densities present in the field at the time of application averaged 19 plants per m^2 when no PPI was used, and densities were reduced to an average of 4 plants per m^2 with the use of trifluralin PPI (Table 4.7). In 2005, frequent early-season rainfall was sufficient for crop germination. Palmer amaranth germination was less compared to 2006 when irrigation was needed for crop germination. This irrigation in 2006 produced higher numbers of Palmer amaranth which germinated with the crop.

When trifluralin PPI was used, cotton lint yield ranged from 1,070 to 1,190 kg/ha and was not affected when glyphosate applications were delayed up to 28 days (Table 4.7). Although yields were similar, reductions in early-season cotton growth were observed for glyphosate applications delayed 14, 21, and 28 days. However, adequate time, heat units, and moisture allowed for recovery of the crop. When no PPI was used, 14 and 24% cotton yield reductions were observed when glyphosate applications were delayed 21 and 28 days, respectively. Season-long Palmer amaranth competition reduced cotton lint yield 72% with trifluralin PPI alone and 82% when no herbicides were used. Although yield reductions were observed when glyphosate applications were delayed, the lint quality (micronaire, length, and strength) and loan value was not affected by the Palmer amaranth competition (Tables 4.8 and 4.9).

Although delaying early-season glyphosate applications is not recommended, this research indicates that trifluralin PPI can reduce early-season Palmer amaranth competition, and if needed, delaying glyphosate applications would not reduce cotton lint yield. However, when no PPI herbicides are used, early glyphosate applications should be made to minimize yield reductions caused by early-season Palmer amaranth competition. This data is consistent with similar research by Willis et al. (2004), who found that when Palmer amaranth removal was delayed beyond five weeks after emergence, significant decreases in lint yield and increases in Palmer amaranth biomass occurred.

Ivyleaf Morningglory Management

A weed management system by rate interaction was not observed for any evaluation timing for ivyleaf morningglory control in 2005 and 2006; therefore, data was averaged over weed management systems by rate and over glyphosate rates by weed management systems.

Weed Control

In 2005, ivyleaf morningglory control 14 days after the first glyphosate application ranged from 58 to 94% (Table 4.10). When averaged over glyphosate rates, glyphosate alone controlled ivyleaf morningglory 60%, and greater control was observed with systems including cultivation (86 to 93%), prometryn PRE (71 to 93%), or pyrithiobac POST (78 to 93%). Glyphosate at 1.25 kg ae/ha controlled ivyleaf morningglory 83%, which was similar to glyphosate at 0.84 kg/ha (79%).

At 14 days after the second glyphosate application, ivyleaf morningglory control was greater with glyphosate at 1.25 kg/ha (83%) compared to glyphosate at 0.84 kg/ha

(76%). Similar control (74 to 84%) was observed for all weed management systems when averaged over glyphosate rates.

Ivyleaf morningglory was controlled 72 to 97% after the third glyphosate application. Control was more effective when glyphosate was applied at 1.25 kg/ha (92%) compared to glyphosate at 0.84 kg/ha (84%). Glyphosate alone controlled ivyleaf morningglory 80% when averaged over rates, and control improved when cultivation was included in the weed management systems (93 to 94%). The use of prometryn PRE or pyrithiobac POST in glyphosate systems did not improve ivyleaf morningglory control compared to glyphosate alone.

End of season ivyleaf morningglory control ranged from 73 to 98%, and glyphosate alone controlled ivyleaf morningglory 83% when averaged over rates. Control improved with three in-season cultivations (92 to 94%) or when glyphosate was applied at 1.25 kg/ha (92 to 98%). There was a trend towards improved ivyleaf morningglory control with the use of PRE or POST residual herbicides with glyphosate systems. Although ivyleaf morningglory control improved with higher glyphosate rates, in-season cultivations, prometryn PRE, and pyrithiobac POST, complete control was not obtained across any weed management system. Due to frequent rainfall, multiple flushes of ivyleaf morningglory emerged throughout the growing season, which made weed management difficult.

In 2006, early-season ivyleaf morningglory control was greater with glyphosate at 1.25 kg/ha (98%) compared to glyphosate at 0.84 kg/ha (94%) (Table 4.11). Cultivation improved ivyleaf morningglory control (97 to 99%) compared to glyphosate alone (93%).

Preemergence or POST residual herbicides did not improve control when used with glyphosate alone (94 to 95%); however, ivyleaf morningglory was controlled 96% when both prometryn PRE and pyrithiobac POST were used with glyphosate.

Ivyleaf morningglory control after the second glyphosate application ranged from 91 to 99%. Glyphosate alone controlled ivyleaf morningglory 93% when averaged over rates, and control improved with in-season cultivations (96 to 99%). Similar ivyleaf morningglory control was observed with the use of prometryn PRE or pyrithiobac POST compared to glyphosate alone.

Weed management systems including cultivations provided complete control of ivyleaf morningglory after the third glyphosate application. Due to late emergence of ivyleaf morningglory, control declined towards the end of the season. Ivyleaf morningglory control 14 days after the fourth glyphosate application ranged from 87 to 98%. Glyphosate at 1.25 kg/ha controlled ivyleaf morningglory 97%, which was more effective than glyphosate at 0.84 kg/ha (90%). Control was similar for all weed management systems averaged over glyphosate rates; however, a trend towards improved end-of-season ivyleaf morningglory control with the use of PRE or POST residual herbicides or in-season cultivations was observed.

Although complete ivyleaf morningglory control was not achieved for any weed management system, control was more consistent in 2006 than in 2005. This may be attributed to environmental conditions including above average temperatures and little rainfall in 2006, which limited ivyleaf morningglory emergence and growth throughout the season. Ivyleaf morningglory control was improved in both years when glyphosate was used at 1.25 kg/ha compared to glyphosate at 0.84 kg/ha. This is similar to previous research by Joy et al. (2005) who concluded that increased glyphosate rates improved ivyleaf morningglory control. In-season cultivations improved ivyleaf morningglory control over both years; however, continuous ivyleaf morningglory emergence was a direct result of cultivations and may have had an affect on the end of season weed control achieved. No improvements in ivyleaf morningglory control were observed with prometryn PRE or pyrithiobac POST. However, no activation rainfall was received shortly after applications were made, and pyrithiobac was applied at the labeled glyphosate tank-mixed rate of 0.04 kg ai/ha for these experiments. In contrast, Porterfield et al. (2002) found that prometryn PRE gave 80% or greater control of pitted morningglory (*Ipomoea lacunose* L.) and Dotray et al. (2004) reported that ivyleaf morningglory control was improved when pyrithiobac was incorporated into weed management systems.

<u>Yield, Net Returns, and Quality</u>

In 2005, cotton lint yield ranged from 810 to 1,100 kg/ha (Table 4.12). When averaged over weed management systems, cotton lint yield was greater when glyphosate was applied at 1.25 kg/ha (1,010 kg/ha) compared to 0.84 kg/ha (900 kg/ha). Yield was similar for all weed management systems when averaged over glyphosate rates (850 to 1,020 kg/ha), and yield did not parallel end of season ivyleaf morningglory control achieved.

Net returns above weed control costs were reflective of cotton lint yield and ranged from \$940 to \$1,340 per hectare (Table 4.12). Due to increasing cost of fuel needed for cultivations and also higher prices of residual herbicides, four applications of glyphosate provided the greatest net return above weed control costs (\$1,135/ha). Although weed control costs were greater for systems with glyphosate at 1.25 kg ae/ha, increased ivyleaf morningglory control and improved yield produced greater net returns above weed control costs with glyphosate at 1.25 kg/ha (\$1082/ha) compared to glyphosate at 0.84 kg/ha (\$974/ha).

In 2006, cotton lint yield ranged from 1,010 to 1,490 kg/ha, and did not parallel end of season ivyleaf morningglory control achieved (Table 4.13). Similar lint quality and loan values were observed for all weed management systems in both years (Tables 4.14 and 4.15). Net returns above weed control costs ranged from \$1,130 to \$1,740 per hectare and were reflective of cotton lint yield. When averaged over weed management systems, similar net returns were observed between glyphosate rates. Differences among weed management systems were reflective of the cotton lint yield produced. In 2005 and 2006, the use of increased glyphosate rates, in-season cultivations, or residual herbicides did not always decrease net returns.

Table 4.1 Palmer amaranth management in Roundup Ready Flex cotton systems for 2005 and 2006[a].

Weed management system[b]	Application timing[c]	2005 14 DAT[d]	2005 28 DAT	2005 120 DAT	2006 14 DAT	2006 28 DAT	2006 120DAT
		% control					
trifluralin alone	PPI	96 bc	83 d	66 d	82 g	47 h	30 d
trifluralin fb							
gly fb gly	EPOST	100 a	91 bcd	100 a	98 bc	94 def	97 ab
gly+pyr fb gly	EPOST	100 a	95 abc	100 a	100 a	98 abc	99 a
gly+*S*-met fb gly	EPOST	100 a	98 a	100 a	100 a	99 ab	99 a
gly fb gly	MPOST	100 a	92 abcd	100 a	99 ab	99 ab	96 ab
gly+pyr fb gly	MPOST	96 bc	95 abc	100 a	100 a	99 ab	96 ab
gly+*S*-met fb gly	MPOST	99 abc	97 ab	100 a	100 a	98 abc	95 ab
RR standard: gly fb gly	PDIR	99 abc	94 abcd	98 b	100 a	99 ab	86 c
no PPI							
gly fb gly	EPOST	100 a	85 cd	100 a	92 f	75 g	85 c
gly+pyr fb gly	EPOST	100 a	95 abcd	100 a	98 bc	89 f	95 ab
gly+*S*-met fb gly	EPOST	100 a	95 abcd	100 a	95 e	91 ef	92 b
gly fb gly	MPOST	97 abc	88 bcd	100 a	97 cd	100 a	96 ab
gly+pyr fb gly	MPOST	98 abc	94 abcd	100 a	97 cd	99 ab	94 ab
gly+*S*-met fb gly	MPOST	95 c	93 abcd	100 a	97 cd	100 a	93 b
RR standard: gly fb gly	PDIR	98 abc	88 bcd	94 c	100 a	96 cde	87 c

[a] Abbreviations: DAT, days after treatment; EPOST, early-postemergence; fb, followed-by; gly, glyphosate; RR, Roundup Ready; *S*-met, *S*-metolachlor; MPOST, mid-postemergence; PDIR, postemergence-directed; PPI, preplant incorporated; pyr, pyrithiobac.
[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.
[c] Application timings reflect the first glyphosate application. However, RR standard systems had an initial glyphosate application made EPOST followed by glyphosate PDIR. In 2006, two PDIR applications of glyphosate were needed.
[d] Evaluation timings reflect days after the first glyphosate application.

Table 4.2. Devil's-claw management in Roundup Ready Flex cotton systems for 2005 and 2006[a].

Weed management system[b]	Application timing[c]	2005			2006		
		14 DAT[d]	28 DAT	120 DAT	14 DAT	28 DAT	120DAT
		% control					
trifluralin alone	PPI	0 d	0 d	0 d	0 h	0 f	0 d
trifluralin fb							
gly fb gly	EPOST	99 a	88 abc	100 a	92 g	82 e	100 a
gly+pyr fb gly	EPOST	100 a	95 a	100 a	97 cde	93 cd	99 ab
gly+*S*-met fb gly	EPOST	98 a	88 abc	100 a	95 ef	87 e	100 a
gly fb gly	MPOST	87 bc	87 bc	100 a	98 bcd	95 c	100 a
gly+pyr fb gly	MPOST	85 c	88 abc	99 ab	99 abc	94 c	99 ab
gly+*S*-met fb gly	MPOST	93 b	90 abc	100 a	99 abc	97 bc	99 ab
RR standard: gly fb gly	PDIR	92 bc	83 c	97 bc	100 a	100 a	97 bc
no PPI							
gly fb gly	EPOST	99 a	88 abc	100 a	94 fg	81 e	97 bc
gly+pyr fb gly	EPOST	100 a	92 ab	100 a	97 cde	95 cd	100 a
gly+*S*-met fb gly	EPOST	100 a	90 abc	100 a	96 def	88 de	99 ab
gly fb gly	MPOST	92 b	90 abc	100 a	98 bcd	100 a	99 ab
gly+pyr fb gly	MPOST	92 b	90 abc	100 a	100 a	100 a	99 ab
gly+*S*-met fb gly	MPOST	88 bc	89 abc	100 a	99 abc	100 a	99 ab
RR standard: gly fb gly	PDIR	88 bc	87 bc	95 c	100 a	99 ab	99 ab

[a] Abbreviations: DAT, days after treatment; EPOST, early-postemergence; fb, followed-by; gly, glyphosate; RR, Roundup Ready; *S*-met, *S*-metolachlor; MPOST, mid-postemergence; PDIR, postemergence-directed; PPI, preplant incorporated; pyr, pyrithiobac.

[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.

[c] Application timings reflect the first glyphosate application. However, RR standard systems had an initial glyphosate application made EPOST followed by glyphosate PDIR. In 2006, two PDIR applications of glyphosate were needed.

[d] Evaluation timings reflect days after the first glyphosate application.

Table 4.3. Effects of Palmer amaranth and devil's-claw control on Roundup Ready Flex cotton lint yield and net returns above weed control costs in 2005[a].

Weed management system[b]	Application timing	Yield	Gross revenue	Weed control costs	Net returns[c]
		kg/ha	$/ha		
Trifluralin					
glyphosate fb glyphosate	EPOST	1,030 cdef[d]	1,320	67.95	1,250 def[e]
glyphosate+pyrithiobac fb glyphosate	EPOST	1,120 bcdef	1,430	90.72	1,340 bcdef
glyphosate+*S*-metolachlor fb glyphosate	EPOST	1,100 bcdef	1,400	101.10	1,300 cdef
glyphosate fb glyphosate	MPOST	1,000 f	1,280	67.95	1,210 f
glyphosate+pyrithiobac fb glyphosate	MPOST	1,330 a	1,690	90.72	1,605 a
glyphosate+*S*-metolachlor fb glyphosate	MPOST	1,150 bc	1,470	101.10	1,370 bcde
RR standard: glyphosate fb glyphosate	PDIR	1,020 def	1,300	67.95	1,230 ef
No PPI					
glyphosate fb glyphosate	EPOST	1,090 bcdef	1,390	41.69	1,350 bcdef
glyphosate+pyrithiobac fb glyphosate	EPOST	1,140 bcd	1,460	64.47	1,390 bcd
glyphosate+*S*-metolachlor fb glyphosate	EPOST	1,130 bcde	1,440	74.84	1,365 bcdef
glyphosate fb glyphosate	MPOST	1,160 b	1,490	41.69	1,450 bc
glyphosate+pyrithiobac fb glyphosate	MPOST	1,120 bcdef	1,430	64.47	1,365 bcdef
glyphosate+*S*-metolachlor fb glyphosate	MPOST	1,200 b	1,540	74.84	1,460 ab
RR standard: glyphosate fb glyphosate	PDIR	1,010 ef	1,290	41.69	1,250 def
trifluralin alone	PPI	560 g	720	26.26	690 g
non-treated	NA	400 h	520	0	520 h

[a] Abbreviations: EPOST, early-postemergence; fb, followed-by; MPOST, mid-postemergence; NA, not applicable; PDIR, postemergence-directed; PPI, preplant incorporated; RR, Roundup Ready.

[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.

[c] Net returns only account for returns above weed control costs.

[d] Yield means followed by the same lower case letter (a,b,c) are not significantly different (P = 0.05)using Fisher's protected LSD.

[e] Net return means followed by the same lower case letter (a,b,c) are not significantly different (P = 0.05) using Fisher's protected LSD.

Table 4.4. Effects of Palmer amaranth and devil's-claw control on Roundup Ready Flex cotton lint yield and net returns above weed control costs in 2006[a].

Weed management system[b]	Application timing[c]	Yield	Gross revenue	Weed control costs	Net returns[d]
		kg/ha		$/ha	
Trifluralin					
glyphosate fb glyphosate	EPOST	1,020 b[e]	1,260	67.95	1,190 ab[f]
glyphosate+pyrithiobac fb glyphosate	EPOST	1,010 b	1,240	90.72	1,150 b
glyphosate+*S*-metolachlor fb glyphosate	EPOST	1,360 a	1,670	101.10	1,570 a
glyphosate fb glyphosate	MPOST	1,190 ab	1,470	67.95	1,400 ab
glyphosate+pyrithiobac fb glyphosate	MPOST	1,020 b	1,250	90.72	1,160 b
glyphosate+*S*-metolachlor fb glyphosate	MPOST	980 b	1,210	101.10	1,110 b
RR standard: glyphosate fb glyphosate fb glyphosate	PDIR	1,180 ab	1,450	67.95	1,380 ab
No PPI					
glyphosate fb glyphosate	EPOST	1,030 b	1,270	41.69	1,220 ab
glyphosate+pyrithiobac fb glyphosate	EPOST	1,200 ab	1,470	64.47	1,410 ab
glyphosate+*S*-metolachlor fb glyphosate	EPOST	1,210 ab	1,490	74.84	1,420 ab
glyphosate fb glyphosate	MPOST	1,120 ab	1,370	41.69	1,330 ab
glyphosate+pyrithiobac fb glyphosate	MPOST	1,250 ab	1,540	64.47	1,480 ab
glyphosate+*S*-metolachlor fb glyphosate	MPOST	1,180 ab	1,450	74.84	1,380 ab
RR standard: glyphosate fb glyphosate fb glyphosate	PDIR	1,220 ab	1,490	41.69	1,450 ab
trifluralin alone	PPI	250 c	310	26.26	280 c
non-treated	NA	90 c	110	0	110 c

[a] Abbreviations: EPOST, early-postemergence; fb, followed-by; MPOST, mid-postemergence; NA, not applicable; PDIR, postemergence-directed; PPI, preplant incorporated; RR, Roundup Ready.

[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.

[c] Application timing reflects the first glyphosate application. However, RR standard systems had an initial glyphosate application made EPOST followed by two PDIR applications of glyphosate.

[d] Net returns only account for returns above weed control costs.

[e] Yield means followed by the same lower case letter (a,b,c) are not significantly different (P = 0.05)using Fisher's protected LSD.

[f] Net return means followed by the same lower case letter (a,b,c) are not significantly different (P = 0.05) using Fisher's protected LSD.

Table 4.5. Cotton lint quality and CCC loan values for Palmer amaranth and devil's-claw management in 2005[a].

Weed management system[b]	Application timing	Micronaire	Length[c]	Strength	Loan value
			32/in	g/tec	$/kg
Trifluralin					
glyphosate fb glyphosate	EPOST	3.2	1.07	26.5	1.27
glyphosate+pyrithiobac fb glyphosate	EPOST	3.1	1.09	28.4	1.31
glyphosate+*S*-metolachlor fb glyphosate	EPOST	3.1	1.12	26.7	1.27
glyphosate fb glyphosate	MPOST	3.0	1.12	26.6	1.24
glyphosate+pyrithiobac fb glyphosate	MPOST	3.2	1.10	27.2	1.29
glyphosate+*S*-metolachlor fb glyphosate	MPOST	3.2	1.13	26.8	1.28
RR standard: glyphosate fb glyphosate	PDIR	3.2	1.10	27.2	1.23
No PPI					
glyphosate fb glyphosate	EPOST	3.2	1.09	26.7	1.29
glyphosate+pyrithiobac fb glyphosate	EPOST	3.1	1.12	26.6	1.25
glyphosate+*S*-metolachlor fb glyphosate	EPOST	3.0	1.11	27.1	1.27
glyphosate fb glyphosate	MPOST	3.2	1.11	26.5	1.32
glyphosate+pyrithiobac fb glyphosate	MPOST	3.1	1.11	26.7	1.27
glyphosate+*S*-metolachlor fb glyphosate	MPOST	3.1	1.11	26.6	1.24
RR standard: glyphosate fb glyphosate	PDIR	3.3	1.01	27.2	1.28
trifluralin alone	PPI	3.3	1.12	27.6	1.34
non-treated	NA	3.5	1.11	27.1	1.39
LSD		NS	NS	NS	NS

[a] Abbreviations: EPOST, early-postemergence; fb, followed-by; LSD, least significant difference; MPOST, mid-postemergence; NA, not applicable; NS, not significant; PDIR, postemergence-directed; PPI, preplant incorporated; RR, Roundup Ready.

[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.

[c] Length is a standard United States measurement given in 32/inch.

Table 4.6. Cotton lint quality and CCC loan values for Palmer amaranth and devil's-claw management in 2006[a].

Weed management system[b]	Application timing	Micronaire	Length[c]	Strength	Loan value
			32/in	g/tec	$/kg
Trifluralin					
glyphosate fb glyphosate	EPOST	5.2	1.04	29.9	1.18
glyphosate+pyrithiobac fb glyphosate	EPOST	5.2	1.04	28.8	1.16
glyphosate+*S*-metolachlor fb glyphosate	EPOST	5.0	1.05	30.1	1.23
glyphosate fb glyphosate	MPOST	5.2	1.04	30.3	1.23
glyphosate+pyrithiobac fb glyphosate	MPOST	5.2	1.03	29.5	1.15
glyphosate+*S*-metolachlor fb glyphosate	MPOST	5.2	1.05	30.7	1.22
RR standard: glyphosate fb glyphosate	PDIR	5.0	1.04	27.6	1.26
No PPI					
glyphosate fb glyphosate	EPOST	5.2	1.05	30.6	1.18
glyphosate+pyrithiobac fb glyphosate	EPOST	5.1	1.06	30.0	1.20
glyphosate+*S*-metolachlor fb glyphosate	EPOST	5.0	1.08	28.1	1.25
glyphosate fb glyphosate	MPOST	4.6	1.07	28.8	1.26
glyphosate+pyrithiobac fb glyphosate	MPOST	4.7	1.08	28.9	1.31
glyphosate+*S*-metolachlor fb glyphosate	MPOST	4.5	1.10	29.2	1.30
RR standard: glyphosate fb glyphosate	PDIR	4.9	1.09	29.0	1.31
trifluralin alone	PPI	5.1	1.06	29.0	1.21
non-treated	NA	4.5	1.09	27.8	1.31
LSD		NS	NS	NS	NS

[a] Abbreviations: EPOST, early-postemergence; fb, followed-by; LSD, least significant difference; MPOST, mid-postemergence; NA, not applicable; NS, not significant; PDIR, postemergence-directed; PPI, preplant incorporated; RR, Roundup Ready.
[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.
[c] Length is a standard United States measurement given in 32/inch.

Table 4.7. Weed density and cotton yield for Palmer amaranth competition combined for 2005 and 2006.

Days of competition	Palmer amaranth density[a] with trifluralin	Palmer amaranth density[a] without trifluralin	Cotton lint yield with trifluralin	Cotton lint yield without trifluralin
	plants/m^2		kg/ha	
0	2 x[b]	18 y	1,190 a[c]	1,050 ab
7	4 x	17 y	1,120 ab	1,170 a
14	5 x	16 y	1,170 a	1,110 ab
21	3 x	16 y	1,070 ab	1,010 bc
28	5 x	24 y	1,180 a	890 c
150	4 x	22 y	330 d	210 d

[a] Palmer amaranth density was only recorded in 2006 and cotton lint yield was combined for 2005 and 2006.
[b] Density means followed by the same lower case letter (x,y,z) are not significantly different (P=0.05) using Fisher's protected LSD.
[c] Yield means followed by the same lower case letter (a,d,c,) are not significantly different (P=0.05) using Fisher's protected LSD.

Table 4.8. Cotton lint quality and CCC loan values for Palmer amaranth competition in 2005[a].

Days of competition[b]	With trifluralin				Without trifluralin			
	Micronaire	Length[c]	Strength	Loan value	Micronaire	Length[c]	Strength	Loan value
		32/in	g/tec	$/kg		32/in	g/tec	$/kg
0	3.3	1.10	26.4	1.28	3.2	1.08	27.5	1.30
7	3.2	1.11	26.2	1.31	3.3	1.09	26.0	1.30
14	3.2	1.11	26.7	1.29	3.3	1.12	26.9	1.35
21	3.3	1.09	26.1	1.28	3.2	1.08	26.1	1.33
28	3.3	1.11	26.2	1.34	3.3	1.09	26.4	1.35
150	3.2	1.09	26.7	1.33	3.1	1.11	26.2	1.32
LSD	NS	NS	NS	NS	NS	NS	NS	NS

[a] Abbreviations: EPOST, early-postemergence; fb, followed-by; LSD, least significant difference; MPOST, mid-postemergence; NA, not applicable; NS, not significant; PDIR, postemergence-directed; PPI, preplant incorporated; RR, Roundup Ready.

[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.

[c] Length is a standard United States measurement given in 32/inch.

Table 4.9. Cotton lint quality and CCC loan values for Palmer amaranth competition in 2006[a].

Days of competition[b]	With trifluralin				Without trifluralin			
	Micronaire	Length[c]	Strength	Loan value	Micronaire	Length[c]	Strength	Loan value
		32/in	g/tec	$/kg		32/in	g/tec	$/kg
0	5.1	1.05	30.1	1.23	5.2	1.04	28.9	1.19
7	5.2	1.03	29.6	1.16	5.1	1.05	29.4	1.17
14	5.2	1.05	28.7	1.19	5.0	1.08	30.3	1.28
21	5.2	1.05	29.2	1.21	4.6	1.11	28.8	1.36
28	4.9	1.10	29.4	1.29	4.0	1.11	28.2	1.28
150	4.9	1.06	28.3	1.27	5.0	1.09	29.9	1.25
LSD	NS	NS	NS	NS	NS	NS	NS	NS

[a] Abbreviations: EPOST, early-postemergence; fb, followed-by; LSD, least significant difference; MPOST, mid-postemergence; NA, not applicable; NS, not significant; PDIR, postemergence-directed; PPI, preplant incorporated; RR, Roundup Ready.
[b] Herbicide rate=0.84 kg ai/ha, trifluralin; 0.84 kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.12 kg ai/ha, *S*-metolachlor.
[c] Length is a standard United States measurement given in 32/inch.

Table 4.10. Ivyleaf morningglory management in Roundup Ready Flex cotton systems for 2005[a].

Weed management System[b,c]	14 DAT-1 Rate[d] 0.84	14 DAT-1 Rate[d] 1.25	14 DAT-1 avg	14 DAT – 2 Rate 0.84	14 DAT – 2 Rate 1.25	14 DAT – 2 avg	14 DAT – 3 Rate 0.84	14 DAT – 3 Rate 1.25	14 DAT – 3 avg	14 DAT – 4 Rate 0.84	14 DAT – 4 Rate 1.25	14 DAT – 4 avg
	% control											
glyphosate	63	57	60 e[e]	72	77	74 a	72	88	80 b	73	94	83 c
glyphosate+pyr	79	77	78 d	78	82	80 a	82	90	86 b	83	92	88 bc
pro fb glyphosate	58	83	71 d	67	82	74 a	77	89	83 b	78	92	85 c
glyphosate fb cult	86	87	86 bc	80	85	83 a	88	97	93 a	87	96	92 ab
pro fb glyphosate+pyr	80	81	81 cd	72	85	78 a	82	89	85 b	82	94	88 bc
glyphosate+pyr fb cult	91	92	92 ab	83	84	84 a	91	96	93 a	90	95	92 ab
pro fb glyphosate fb cult	90	94	92 ab	75	87	81 a	91	97	94 a	90	98	94 a
pro fb glyphosate+pyr fb cult	91	94	93 a	83	86	84 a	92	97	94 a	91	95	93 ab
avg	79 x[f]	83 x		76 y	83 x		84 y	92 x		84 y	94 x	

[a] Abbreviations: avg, average; cult, cultivation; DAT, days after glyphosate treatment; fb, followed-by; pro, prometryn; pyr, pyrithiobac.
[b] Rate=kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.44 kg ai/ha, prometryn.
[c] All systems recieved 3 sequential ASN glyphosate applications and systems with cultivation received three ASN cultivations.
[d] Rates of glyphosate.
[e] Weed management systems means followed by the same lower case letter (a,b,c,) are not significantly different (P=0.05) using Fisher's protected LSD.
[f] Rate means followed by the same lower case letter (x,y,z) are not significantly different (P=0.05) using Fisher's protected LSD.

Table 4.11. Ivyleaf morningglory management in Roundup Ready Flex cotton systems for 2006[a].

Weed management System[b,c]	14 DAT-1 Rate[d] 0.84	14 DAT-1 Rate 1.25	14 DAT-1 avg	14 DAT – 2 Rate 0.84	14 DAT – 2 Rate 1.25	14 DAT – 2 avg	14 DAT – 3 Rate 0.84	14 DAT – 3 Rate 1.25	14 DAT – 3 avg	14 DAT – 4 Rate 0.84	14 DAT – 4 Rate 1.25	14 DAT – 4 avg
	% control											
glyphosate	90	95	93 d[e]	91	95	93 b	87	96	92 b	87	94	91 a
glyphosate+pyr	93	96	95 cd	92	96	94 b	92	97	95 b	93	96	95 a
pro fb glyphosate	91	97	94 cd	91	96	94 b	90	97	94 b	91	98	95 a
glyphosate fb cult	95	99	97 b	96	98	97 a	99	100	100 a	88	95	92 a
pro fb glyphosate+pyr	94	98	96 bc	93	96	95 b	92	98	95 b	90	98	94 a
glyphosate+pyr fb cult	96	98	97 b	97	99	98 a	99	100	100 a	91	96	93 a
pro fb glyphosate fb cult	96	99	98 ab	93	99	96 a	99	100	100 a	91	98	94 a
pro fb glyphosate+pyr fb cult	98	99	99 a	98	99	99 a	99	100	100 a	90	97	94 a
avg	94 y[f]	98 x		94 y	97 x		94 y	98 x		90 y	97 x	

[a] Abbreviations: avg, average; cult, cultivation; DAT, days after glyphosate treatment; fb, followed-by; pro, prometryn; pyr, pyrithiobac.
[b] Rate=kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.44 kg ai/ha, prometryn.
[c] All systems recieved 3 sequential ASN glyphosate applications and systems with cultivation received three ASN cultivations.
[d] Rates of glyphosate.
[e] Weed management systems means followed by the same lower case letter (a,b,c,) are not significantly different (P=0.05) using Fisher's protected LSD.
[f] Rate means followed by the same lower case letter (x,y,z) are not significantly different (P=0.05) using Fisher's protected LSD.

Table 4.12. Cotton lint yield and net returns above weed control costs for ivyleaf morningglory management in Roundup Ready Flex cotton for 2005[a].

Weed management System[b, c]	Yield Rate[d] 0.84	Yield Rate[d] 1.25	Yield avg	Weed control costs Rate 0.84	Weed control costs Rate 1.25	Net returns[e] Rate 0.84	Net returns[e] Rate 1.25	Net returns[e] avg
	kg/ha			$/ha				
glyphosate	980	1,040	1,010 a[f]	83.39	107.79	1,270	1,320	1,300 a
glyphosate+pyr	940	1,020	980 a	106.16	130.56	1,180	1,280	1,230 ab
pro fb glyphosate	920	990	950 a	113.77	138.17	1,150	1,220	1,190 abc
glyphosate fb cult	820	820	850 a	120.44	144.84	1,010	1,070	1,040 c
pro fb glyphosate+pyr	920	1,050	980 a	136.54	160.95	1,130	1,290	1,210 ab
glyphosate+pyr fb cult	920	980	950 a	143.21	167.61	1,120	1,180	1,150 abc
pro fb glyphosate fb cult	940	1,100	1,020 a	150.82	175.22	1,140	1,340	1,240 ab
pro fb glyphosate+pyr fb cult	810	1,050	930 a	173.59	198.00	940	1,240	1,090 bc
avg	900 y[g]	1,010 x				1,120 y	1,240 x	

[a] Abbreviations: avg, average; cult, cultivation; fb, followed-by; pro, prometryn; pyr, pyrithiobac.
[b] Rate=kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.44 kg ai/ha, prometryn.
[c] All systems received 3 sequential ASN glyphosate applications and systems with cultivation received three ASN cultivations.
[d] Rates of glyphosate.
[e] Net returns only reflect returns above weed control costs.
[f] Weed management systems means followed by the same lower case letter (a,b,c,) are not significantly different (P = 0.05) using Fisher's protected LSD.
[g] Rate means followed by the same lower case letter (x,y,z) are not significantly different (P = 0.05) using Fisher's protected LSD.

Table 4.13. Cotton lint yield and net returns above weed control costs for ivyleaf morningglory management in Roundup Ready Flex cotton for 2006[a].

Weed management System[b, c]	Yield Rate[d] 0.84	Yield Rate[d] 1.25	Yield avg	Weed control costs Rate 0.84	Weed control costs Rate 1.25	Net returns[e] Rate 0.84	Net returns[e] Rate 1.25	Net returns[e] avg
	kg/ha			$/ha				
glyphosate	1,190	1,150	1,170 bc[f]	83.39	107.79	1,410	1,340	1,370 bc
glyphosate+pyr	1,400	1,400	1,400 a	106.16	130.56	1,650	1,630	1,640 a
pro fb glyphosate	1,380	1,420	1,400 a	113.77	138.17	1,620	1,650	1,630 a
glyphosate fb cult	1,150	1,010	1,080 c	120.44	144.84	1,330	1,130	1,230 c
pro fb glyphosate+pyr	1,390	1,360	1,380 a	136.54	160.95	1,620	1,550	1,590 ab
glyphosate+pyr fb cult	1,490	1,170	1,330 ab	143.21	167.61	1,740	1,310	1,520 ab
pro fb glyphosate fb cult	1,200	1,100	1,150 bc	150.82	175.22	1,350	1,210	1,280 c
pro fb glyphosate+pyr fb cult	1,310	1,290	1,300 ab	173.59	198.00	1,480	1,430	1,460 abc
avg	1,310 x[g]	1,240 x				1,530 x	1,410 x	

[a] Abbreviations: avg, average; cult, cultivation; fb, followed-by; pro, prometryn; pyr, pyrithiobac.
[b] Rate=kg ae/ha, glyphosate; 0.04 kg ai/ha, pyrithiobac; 1.44 kg ai/ha, prometryn.
[c] All systems received 3 sequential ASN glyphosate applications and systems with cultivation received three ASN cultivations.
[d] Rates of glyphosate.
[e] Net returns only reflect returns above weed control costs.
[f] Weed management systems means followed by the same lower case letter (a,b,c,d) are not significantly different (P = 0.05) using Fisher's protected LSD.
[g] Rate means followed by the same lower case letter (x,y) are not significantly different (P = 0.05) using Fisher's protected LSD.

Table 4.14. Cotton lint quality and CCC loan values for ivyleaf morningglory management in 2005[a].

Weed management System	Micronaire Rate[b] 0.84	Micronaire Rate[b] 1.25	Length[c] Rate 0.84	Length[c] Rate 1.25	Strength Rate 0.84	Strength Rate 1.25	Loan value Rate 0.84	Loan value Rate 1.25
			— 32/in —		— g/tec —		— $/ha —	
glyphosate	3.7	3.8	1.07	1.09	27.0	26.0	1.37	1.40
glyphosate+pyr	3.8	3.7	1.11	1.09	26.8	26.9	1.39	1.41
pro fb glyphosate	3.6	3.7	1.07	1.08	26.6	27.5	1.38	1.37
glyphosate fb cult	3.6	3.6	1.09	1.09	26.8	27.1	1.39	1.40
pro fb glyphosate+pyr	3.6	3.6	1.08	1.09	26.9	27.0	1.40	1.37
glyphosate+pyr fb cult	3.5	3.6	1.08	1.07	27.0	26.8	1.37	1.37
pro fb glyphosate fb cult	3.7	3.6	1.10	1.08	27.8	27.5	1.41	1.37
pro fb glyphosate+pyr fb cult	3.6	3.7	1.08	1.09	26.7	26.7	1.37	1.40
LSD	NS		NS		NS		NS	

[a] Abbreviations: cult, cultivation; fb, followed-by; NS, not significant; pro, prometryn; pyr, pyrithiobac.

[b] Rates of glyphosate.

[c] Length is a standard United States measurement given in 32/inch.

Table 4.15. Cotton lint quality and CCC loan values for ivyleaf morningglory management in 2006[a].

Weed management System	Micronaire Rate[b] 0.84	Micronaire Rate[b] 1.25	Length[c] Rate 0.84	Length[c] Rate 1.25	Strength Rate 0.84	Strength Rate 1.25	Loan value Rate 0.84	Loan value Rate 1.25
			32/in		g/tec		$/ha	
glyphosate	5.2	5.1	1.08	1.09	29.1	29.7	1.24	1.25
glyphosate+pyr	4.9	5.1	1.10	1.07	29.7	28.1	1.35	1.27
pro fb glyphosate	5.1	4.9	1.08	1.09	28.3	29.3	1.27	1.32
glyphosate fb cult	5.2	4.9	1.08	1.09	28.4	28.4	1.27	1.31
pro fb glyphosate+pyr	5.3	5.2	1.06	1.07	28.3	29.0	1.21	1.21
glyphosate+pyr fb cult	5.1	4.8	1.06	1.07	28.7	28.4	1.24	1.26
pro fb glyphosate fb cult	4.8	4.9	1.10	1.09	28.3	28.4	1.37	1.23
pro fb glyphosate+pyr fb cult	5.2	5.1	1.07	1.08	29.0	28.9	1.18	1.25
LSD	NS		NS		NS		NS	

[a] Abbreviations: cult, cultivation; fb, followed-by; NS, not significant; pro, prometryn; pyr, pyrithiobac.
[b] Rates of glyphosate.
[c] Length is a standard United States measurement given in 32/inch.

CHAPTER V

SUMMARY AND CONCLUSIONS

Roundup Ready Flex weed management systems provided similar season-long Palmer amaranth [*Amaranthus palmeri* (S.) Watts.] and devil's-claw [*Proboscidea louisianica* (Mill.) Thuellung] control in 2005. The use of residual herbicides did not improve control. However, when weed pressure increased in 2006, systems with residual herbicides provided more effective control compared to two applications of glyphosate alone. Although it is never recommended to delay early-season herbicide applications, the timing of glyphosate applications did not affect overall control of Palmer amaranth or devil's-claw in 2005 or 2006. The competitive affects of Palmer amaranth reduced cotton yield if glyphosate applications are delayed 30 to 35 days after crop emergence and the use of trifluralin PPI allowed for longer application delays with less yield loss.

Glyphosate-based Roundup Ready Flex weed management systems achieved greater control of Palmer amaranth compared to similar Roundup Ready systems in both 2005 and 2006. In 2006, the commercial Roundup Ready systems required an additional glyphosate application in order to achieve similar Palmer amaranth and devil's-claw control as Roundup Ready Flex systems.

Ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] was more difficult to control when compared to annual weeds such as Palmer amaranth and devil's-claw. Glyphosate was essential to effectively control ivyleaf moringglory season-long. Glyphosate applied at 1.25 kg/ha consistently improved ivyleaf morningglory control compared to glyphosate at 0.84 kg/ha in both years. However, the most effective ivyleaf morningglory control did not exceed 95%. The use of soil applied residual herbicides did not always improve season-long ivyleaf morningglory control. However, in-season cultivations following glyphosate provided additional early- and mid-season control of ivyleaf morningglory.

Cotton lint yield varied greatly across weed management systems and in most instances did not reflect the end of season weed control achieved. Net returns above weed control costs were highly reflective of the yield produced and were similar between weed management systems with or without residual herbicides. Although the use of residual herbicides were not essential for season-long weed control, the incorporation of these herbicides into Roundup Ready Flex weed management systems are economically feasible and add more modes of action to maintain effective weed control while at the same time minimizing the potential for the development of resistant weed species.

LITERATURE CITED

Abernathy, J.R. 1981. Estimated crop losses due to weeds with non-chemical management. p. 159-167 i*n* D. Pimental, ed. Handbook of pest management in agriculture. Vol. I. CRC Press, Boca Raton, FL.

Abernathy, J.R. and J.W. Keeling. 1979. Efficacy and rotational crop response to levels and dates of dinitroaniline herbicide applications. Weed Sci. 27:312-317.

Aldrich, R.J. and R.J. Kremer. 1997. Principles in weed management, 2nd Edition. Iowa State University Press. Ames, Iowa. p.12, 9.

Anderson, W.P. 1996. Weed Science: Principles and Applications. Third Ed. West Publishing Co., Minneapolis, MN.

Appleby, A.P. and B.E. Valverde. 1988. Behavior of dinitroanaline herbicides in plants. Weed Technol. 3:198-206.

Bajaj, Y.P.S. 1998. Biotechnology for the Improvement of Cotton. *In* Y.P.S. Bajaj. Biotechnology in Agriculture and Forestry, Vol 42 Cotton. Springer- Verlag Berlin Heidelberg. Germany. p. 3-36.

Barker, W.L., W.J. Everman, J.D. Wilcut, J.W. Wilcut, and J. Collins. 2005. Weed management in Liberty Link cotton. Proc. South. Weed Sci. Soc. 58:80.

Bellinder, R.R., K.K. Hatzios, and H.P. Wilson. 1985. Mode of action investigations with the herbicides HOE-39866 and SC-0224. Weed Sci. 33:779-785.

Blackshaw, R.E. 1989. HOE-39866 use in chemical fallow systems. Weed Technol. 3:420-428.

Blair-Kerth, L.K., P.A. Dotray, J.W. Keeling, J.R. Gannaway, M.J. Oliver, and J.E. Quisenberry. 2001. Tolerance of transformed cotton to glufosinate. Weed Sci. 49:375-380.

Bleasdale, J.K.A. 1960. Studies on plant competition. *In* J.L. Harper (ed.) The biology of weeds. Blackwell Sci. Publ. Oxford, UK. p. 133-142

Boydston, R.A. and M.M. Williams, II. 2004. Combined effects of *Aceria malherbae* and herbicides on field bindweed (*Convolvulus arvensis*) growth. Weed Sci. 52:297-301.

Brubaker, C.L., F.M. Bourland, and J.F. Wendel. 1999. The Origin and Domestication of Cotton. *In* C.W. Smith and J.T. Cothren (eds.). Cotton: Origin, History, Technology, and Production. John Wiley and Sons, Inc. New York, NY. p. 99-171.

Buchanan, G.A. 1992. Trends in Weed Control Methods. *In* C.G. McWhorter and J.R. Abernathy eds. Weeds of Cotton: Characterization and Control. The Cotton Foundation. Memphis, TN. p. 47-72.

Buchanan, G.A. and E.R. Burns. 1971. Weed competition in cotton. II. Cocklebur and redroot pigweed. Weed Sci. 19:580-582.

Buchanan, G.A. and A.E. Hitbold. 1977. Response of cotton to cultivation. Weed Sci. 25:132-134.

Burgos, N., S. Culpepper, P. Dotray, J.A. Kendig, J. Wilcut, R. Nichols. 2006. Managing herbicide resistance in cotton cropping systems. December Bulletin.

Byrd, J.D., Jr. 2003. Report of the 2002 cotton weed loss committee. Proc. Beltwide Cotton Conf. CD-ROM.

Byrd, J.D. and A.C. York. 1987. Annual grass control in cotton with fluazifop, sethoxydim, and selected dinitroaniline herbicides. Weed Sci. 35:388-394.

Cardina, J. 1995. Biological weed management. *In* A.E. Smith (ed.) Handbook of weed management systems. Marcel Dekker, Inc. New York, NY. p. 279-341.

Clewis, S.B., W.E. Thomas, and J.W. Wilcut. 2006a. Weed management in Roundup Ready Flex cotton. Proc Beltwide Cotton Conf. p. 2248.

Clewis, S.B., J.W. Wilcut, and D. Porterfield. 2006b. Weed management with *S*-metolachlor and glyphosate mixtures in glyphosate-resistant strip- and conventional- tillage cotton (*Gossypium hirsutum*). Weed Technol. 20:232-241.

Crowley, R.H., D.H. Teem, G.A. Buchanan, and C.S. Hoveland. 1979. Responses of *Ipomoea* spp. and *Cassia* spp. to preemergence herbicides. Weed Sci. 27:531-535.

Culpepper, A.S. and A.C. York. 1998. Weed management: Weed management in glyphosate-tolerant cotton. J. of Cotton Sci. 2:174-185.

Culpepper, A.S. and A.C. York. 1999. Weed management and net returns with transgenic, herbicide-resistant, and nontransgenic cotton (*Gossypium hirsutum*). Weed Technol. 13:411-420.

Devine, M.D., S.O. Duke, and C. Fedtke. 1993. Inhibition of amino acid biosynthesis. P. 252-263. *In* Physiology of herbicide action. Prentice Hall, Englewood Cliffs, NJ.

Dotray, P.A., T.A. Baughman, K.M. McCormick, and J.W. Keeling. 2004. Cotton weed management systems with Ignite. Proc. South. Weed Sci. Soc. 57:29.

Dowler, C.C. 1992. Weed survey-Southern states: Broadleaf crops subsection. Proc. South. Weed Sci. Soc. 45:392-407.

Elmore, C.D. 1990. Weed identification guide. South. Weed Sci. Soc. 3 AMAPA.

Franz, J.E. 1985. Discovery, development and chemistry of glyphosate. P. 3-14. *In* E. Grossbard and D. Atkinson (eds.) The herbicide glyphosate. Butterworth and Co., Ltd., London.

Grichar, W.J., B.A. Besler, K.D. Brewer, and B.W. Minton. 2004. Using soil-applied herbicides in combination with glyphosate in a glyphosate resistant cotton herbicide program. Crop Prot. 23:1007-1010.

Griffith, G., J. Barrentine, M. McClelland, K. Smith, and M. Kelley. 2005. Weed management with Ignite in LibertyLink cotton. Proc. South. Weed Sci. Soc. 58:26.

Heering, D.C., R.D. Voth, K. Ferreira, and J.A. Mills. 1998. Commercial experience with Roundup Ready cotton in 1997. Proc. Beltwide Cotton Conf. p. 851.

Henniger, C.G., J.W. Keeling, and J.R. Abernathy. 1992. Efficacy of DPX PE350 in cotton on the Texas Southern High Plains. Abstr. Weed Sci. Soc. Am. 32:4.

Herbicide Handbook. 1989. Sixth Ed. Weed Science Society of America. Champaign, IL. p. 267.

Holm, L.G., D.L. Plucknett, J.V. Pancho, and J.P. Herberger. 1977. The World's worst weeds: Distribution and biology. University Press of Hawaii, Honolulu. *In* D.E. Ethridge, R.T. Ervin, C.M. Hamilton, J.W. Keeling, and J.R. Abernathy. 1990. Economic Weed Control in High Plains Cotton. J. Prod. Agric., Vol. 3, no. 2, p. 246.

Igsett, T.D., E.C. Murdock, and A. Keeton. 1997. Weed control in Roundup Ready cotton. Proc. Beltwide Cotton Conf. p. 787.

Johnson III, W.C., E.P. Prostko, and B.G. Mullinix, Jr. 2005. Improving the management of dicot weeds in peanut with narrow row spacings and residual herbicides. Agron. J. 97:85-88.

Jones, M.A. and C.E. Snipes. 1999. Tolerance of transgenic cotton to topical applications of glyphosate. J. Cotton Sci. 3:19-26.

Joy, B.L. 2005. Weed management in Roundup Ready Flex cotton. M.S. Thesis. Lubbock, TX. Texas Tech University. 57 p.

Joy, B.L., J.W. Keeling, P.A. Dotray, and J.D. Everitt. 2004. Application timings and rates in Roundup Ready Flex cotton. Proc. South. Weed Sci. Soc. 57:254.

Joy, B.L., J.W. Keeling, P.A. Dotray, and J.D. Everitt. 2005. Palmer amaranth, devil'-claw, and ivyleaf morningglory control in Roundup Ready Flex cotton. Proc. South. Weed Sci. Soc. 58:64.

Keeley, P.E., R.J. Thullen, and C.H. Carter. 1986. Influence of planting date on growth of ivyleaf morningglory (*Ipomoea hederacea*) in cotton (*Gossypium hirsutum*). Weed Sci. 34:906-910.

Keeling, J.W., C.G. Henniger, and J.R. Abernathy. 1993. Effects of DPX PE350 on cotton (*Gossypium hirsutum*) growth, yield, and fiber quality. Weed Technol. 7:930-933.

Keeling, J.W., P.A. Dotray, and J.R. Abernathy. 1996. Effects of repeated applications of trifluralin and pendimethalin on cotton (*Gossypium hirsutum*). Weed Technol. 10:295-298.

Keeling, J.W., P.A. Dotray, and J.D. Everitt. 2006. Importance of residual herbicides in Roundup Ready and LibertyLink systems. Proc. South. Weed Sci. Soc. 59:222.

Keeton, A. and E.C. Murdock. 1997. Weed control in Roundup Ready conservation tillage cotton. Proc. Beltwide Cotton Conf. p. 781.

Kennedy, A.C., L.F. Elliott, F.L. Young, and C.L. Douglas. 1991. Rhizobacteria suppressive to the weed downy brome. Soil Sci. Soc. Am. J. 55:722-727.

Lanie, A.J., J.L. Griffin, P.R. Vidrine, and D.B. Reynolds. 1994. Weed control with non-selective herbicides in soybean (*Glycine max*). Weed Technol. 8:159-164.

Light, G.G., T.A. Baughman, P.A. Dotray, J.W. Keeling, and D.B. Wester. 2003. Yield of glyphosate-tolerant cotton as affected by topical glyphosate applications on the Texas Southern High Plains and Rolling Plains. J. Cotton Sci. 7:231-235.

Logusch, E. W., D.M. Walker, J.F. McDonald, and J.E. Franz. 1991. Inhibition of plant glutamine synthetase by substituted phosphinothricins. Plant Physiol. 95:1057-1062.

Martin, W.C. and C.R. Hutchins. 1980. A flora of New Mexico. J. Cramer. Vaduz, Germany. Vol. 2. p. 1856-1859.

Mathews, S.G., P. Brawley, T.C. Mueller, and R.M. Hayes. 1997. What happens when Roundup Ready cotton is sprayed with Roundup Ultra after the four leaf stage? Proc. Beltwide Cotton Conf. p. 779.

McCloskey, W.B. 2006. Weed competition and management in Arizona RR Flex cotton. Proc. Beltwide Cotton Conf. p. 2240.

McWhorter, C.G. and E.E. Hartwig. 1965. Effectiveness of pre-planting tillage in relation to herbicides in controlling johnsongrass for soybean production. Agron. J. 57:385-389.

Mercer, K.L., J.A. Pawlak, D.S. Murray, L.M. Verhalen, M.S. Riffle, and R.W. McNew. 1990. Distance-of-influence of devil's-claw (*Proboscidea louisianica*) on cotton (*Gossypium hirsutum*). Weed Technol. 4:87-91.

Morgan, G.D., P.A. Baumann, and J.M. Chandler. 2001. Competitive impact of Palmer amaranth (*Amaranthus palmeri*) on cotton (*Gossypium hirsutum*) development and yield. Weed Technol. 15:408-412.

[NASS] National Agricultural Statistics Service. 2005. 2004 Texas custom rates statistics. Bulletin 263(2).

[NASS] National Agricultural Statistics Service. 2006a. Web page: http//www.nass.usda.gov:8080/QuickStats/PullData_US.jsp. Accessed 21 August 2006.

[NASS] National Agricultural Statistics Service. 2006a. Web page: http//www.nass.usda.gov:8080/QuickStats/PullData_US_CNTY.jsp. Accessed 21 August 2006.

Nida, D.L., K.H. Kolacz, R.E. Guehler, W.R. Deaton, W.R. Schuler, T.A. Armstrong, M.L. Taylor, C.C. Ebert, G.J. Rogan, S.R. Padgette, and R.L. Fuchs. 1996. Glyphosate tolerant cotton: Genetic characterization and protein expression. J. Agric. Food Chem. 44:1960-1966.

[NOAA] National Oceanic and Atmospheric Administration. 2007. Monthly precipitation normals 1971-2000. Web page: http://www.srh.noaa.gov/lub/climate/CoopNormals/PrecipCoOp.htm. Accessed 17 January 2007.

Paulsgrove, M.D. and J.W. Wilcut. 2001. Weed management with pyrithiobac preemergence in bromoxynil-resistant cotton. Weed Sci. 49:567-570.

Porterfield, D., J.W. Wilcut, and S.D. Askew. 2002. Weed management with CGA-362622, fluometuron, and prometryn in cotton. Weed Sci. 50:642-647.

Reddy, K.N. 2001. Broadleaf weed control in ultra narrow row bromoxynil-resistant cotton (*Gossypium hirsutum*). Weed Technol. 15:497-504.

Riffle, M.S., D.S. Murray, J.F. Stone, and D.L. Weeks. 1990. Soil-water relations and interference between devil's-claw (*Proboscidea louisianica*) and cotton (*Gossypium hirsutum*). Weed Sci. 38:39-44.

Rogers, J.B., D.S. Murray, L.M. Verhalen, and P.L. Claypool. 1996. Ivyleaf morningglory (*Ipomoea hederacea*) interference with cotton (*Gossypium hirsutum*). Weed Technol. 10:107-114.

Rummel, D.R. and M.D. Arnold. 1992. Status of the puncturevine seed weevil in the Texas Sounthern High Palins. Southern Entomologist Scientific Note. Vol. 17 no. 4.

Rushing, D.W., D.S. Murray, and L.M. Verhalen. 1985. Weed interference with cotton (*Gossypium hirsutum*). II. Tumble Pigweed (*Amaranthus albus*). Weed Sci. 33:815-818.

Scott, G.H., S.D. Askew, and J.W. Wilcut. 2002. Glyphosate systems for weed control in glyphosate-tolerant cotton (*Gossypium hirsutum*). Weed Technol. 16:191-198.

Sheikh, T., T.A. Wheeler, P.A. Dotray, and J.C. Zak. 2001. Biological control of woollyleaf bursage (*Ambrosia grayi*) with *Pseudomonas syringae* pv. *tagetis*. Weed Technol. 15:375-381.

Smith, C.W. and J.T. Cothren (eds.). 1999. Cotton: Origin, History, Technology, and Production. John Wiley & Sons, Inc. New York, NY. p. vii.

Smith, C.W., R.G. Cantrell, H.S. Moser, and S.R. Oakley. 1999. History of Cultivar Development in the United States. *In* C.W. Smith and J.T. Cothren (eds.). Cotton: Origin, History, Technology, and Production. John Wiley & Sons, Inc. New York, NY. p. 99-171.

Smith, D.T., R.V. Baker, and G.L. Steele. 2000. Palmer amaranth (*Amaranthus palmeri*) impacts on yield, harvesting, and ginning in dryland cotton (*Gossypium hirsutum*). Weed Technol. 14:122-126.

Snipes, C.E. and T.C. Mueller. 1992. Cotton (*Gossypium hirsutum*) yield response to mechanical and chemical weed control systems. Weed Sci. 40:249-254.

Snipes, C.E., D.L. Colvin, M.G. Patterson, and S.H. Crawford. 1992. Cotton (*Gossypium hirsutum*) yield response to cultivation timing and frequency. Weed Technol. 6:31-35.

Steckel, G.J., L.M. Wax, F.W. Simmons, and W.H. Phillips, II. 1997. Glufosinate efficacy on annual weeds is influenced by rate and growth stage. Weed Technol. 11:484-488.

Supak, J.R., C.G. Anderson, and W.D. Mayfield. 1992. Trends in Cotton Production: History, Culture, Mechanization, and Economics. *In* C.G. McWhorter and J.R. Abernathy (eds.) Weeds of Cotton: Characterization and Control. The Cotton Foundation. Memphis, TN. p. 9-45.

Tharp, B.E., O. Schabenberger, and J.J. Kells. 1999. Response of annual weed species to glufosinate and glyphosate. Weed Technol. 13:542-547.

Walker, R.H. 1995. Preventative Weed Management. *In* A.E. Smith. Handbook of Weed Management Systems. Marcell Dekker, Inc. New York, NY. p. 35-50.

Welch, A.K., P.R. Rahn, R.D. Voth, J.A. Mills, and C.R. Shumway. 1997. Evaluation of preplant and preemergence herbicides in Roundup Ready® cotton. Proc. Beltwide Cotton Conf. p. 784-785.

Willis, J.B., B.J. Fast, S.W. Murdock, and D.S. Murray. 2004. Palmer amaranth interference with Roundup Ready Flex cotton. Proc. South. Weed Sci. Soc. 57;36.

Wilson, H.P., T.E. Hines, R.R. Bellinder, and J.A. Grande. 1985. Comparisons of HOE-39866, SC-0224, paraquat, and glyphosate in no-till cron (*Zea mays*). Weed Sci. 33:531-536.

PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Texas Tech University or Texas Tech University Health Sciences Center, I agree that the Library and my major department shall make it freely available for research purposes. Permission to copy this thesis for scholarly purposes may be granted by the Director of the Library or my major professor. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my further written permission and that any user may be liable for copyright infringement.

Agree (Permission is granted.)

___Max Batla___________________________ ____4/25/06_____
Student Signature Date

Disagree (Permission is not granted.)

_______________________________________ _______________
Student Signature Date