COMPARISON OF GLUFOSINATE-TOLERANT, GLYPHOSATE-TOLERANT, AND NON-TRANSGENIC COTTON WEED CONTROL SYSTEMS

by

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CHAPTER I

REVIEW OF LITERATURE

Cotton (*Gossypium* spp. L.), a broadleaf perennial with a fibrous seed covering, was domesticated from wild varieties indigenous to Mesoamerica, northern South America, and the Caribbean into a valuable agronomic crop (Wendel et al. 1992). The two species that currently dominate worldwide production are upland (*G. hirsutum* L.) and Pima (*G. barbadense* L.) cotton, which is also called extra-long staple or Egyptian cotton (Lee 1984). Pima cotton has long, strong, and fine fibers, but produces relatively low yields; therefore, the majority of cotton production comes from upland cotton (Wendel et al. 1992). Cotton is harvested for the seed and the fibrous seed covering. After harvest, cotton is ginned to separate the fibrous seed covering (lint) from the seed and the lint is made into yarn for textile purposes.

Cotton provides the world's most important textile fiber and is the second most valuable oil and meal seed (Wendel et al. 1992). In 2002, consumers used an estimated 15 kilograms of cotton per capita, which most likely came in the form of a finished product (Bastos et al. 2003). According to the USDA (2002), the major end uses of cotton include apparel, home furnishings, industrial uses, nonwovens, and carpet that account for 53%, 29%, 10%, 5%, and 3% of cotton use, respectively. Industrial uses include linens for hotels and hospitals, rope, tents, and canvas bags, while nonwovens include diapers and facial wipes.

To meet the demands for products containing cotton, production is found worldwide. Seventy-seven percent of cotton production comes from the following seven countries: China, United States, India, Pakistan, Uzbekistan, Turkey, and Australia (Roberson 1998). In the 2001/2002 worldwide growing season, the world total cotton production was over 98 million 218-kilogram bales (NASS 2003).

In the United States, over 5.6 million hectares of cotton (upland and Pima) were planted in 2002, 5 million hectares were harvested, and 17.1 million bales were produced (NASS 2003). The Southwest (Texas, Kansas, and Oklahoma) consistently dominates the amount of planted cotton in the United States; however, the West (California, Arizona, and New Mexico) had the greatest increase in planted area since the 1960's (Mehlhorn et al. 2000).

Texas had the greatest United States upland cotton production in 2002 with 2.3 million hectares planted and 1.8 million hectares harvested. Twenty-four percent of total Texas cropland was planted in cotton in 2002, producing 5 million bales of cotton (TASS 2003). In Texas, 44% of the total harvested hectares of upland cotton were irrigated; however, 62% of the total upland cotton production came from irrigated land (TASS 2003). In terms of upland cotton production, eight of the top ten Texas counties in 2001 and all of the top ten counties in 2002 were found on the Texas High Plains (TASS 2003).

Cotton is an economically significant crop. The United States is the world leader in cotton exports with 11 million bales shipped to other countries in

2001/2002 (NASS 2003). In 2002, the United States cotton production had a value of over $3.5 billion, and was as much as over $6.7 billion in 1994 (NASS 2003). The value of upland cotton production in Texas was over $580 million in 2001 and over $919 million in 2002 (TASS 2003).

Weeds can be detrimental to crop production due to competition for water, nutrients, and sunlight. According to Anderson (1996), a weed is any plant growing where it is not wanted, and in general, adversely affects the use, economic value, and aesthetic aspect of the land and waters it infests. In cotton, competition with weeds results in fewer and less mature bolls per plant and lower lint quality (Abernathy and McWhorter 1992). Competition can be defined as two or more plants growing in close proximity to each other and drawing on the same limited-supply resource pool (Coble and Byrd 1992). According to Coble and Byrd (1992), the weed species, density, and duration of the population determine the competitive damage to cotton. The more competitive species with the greatest density and longest duration will cause the most significant reduction in cotton production. Cotton must be kept weed-free for a period after emergence in order to avoid crop loss. The more competitive the weed species, the longer the weed-free period must be (Coble and Byrd 1992).

Different cotton weed management strategies have been studied; however, there is little data making comparisons across weed control systems that include glufosinate-tolerant cotton. The objective of this study was to compare weed control, lint yield, and net returns above weed control system costs in glufosinate- and glyphosate-tolerant, and conventional cotton weed management systems.

According to Oerke and Dehne (2004), the estimates of the loss potentials of weeds worldwide averaged 34%. As many as 30 genera of annual and perennial grass, sedge, and broadleaf weed species have been identified in cotton fields across the United States. Over 100 of these species are considered troublesome weeds in cotton (Holm et al. 1977). As reported for 2002, the genera of weeds that caused the greatest average percent cotton crop loss in the United States were *Ipomoea*, *Amaranthus*, *Cyperus*, *Xanthium*, and *Senna* (Byrd 2003).

Devil's-claw [*Proboscidea louisianica* (Mill.) Thellung], also known as unicorn-plant, is a troublesome weed native to the southwestern United States that is now found from Florida to California and north to Minnesota (Riffle et al. 1990). According to Correll and Johnston (1979), devil's-claw is a coarse, viscid-pubescent annual with prostrate or ascending branches up to 1 m long and orbicular-reniform to broadly ovate leaves up to 30 cm wide.

Devil's-claw can compete with cotton resulting in a detrimental effect on cotton production. In a study of soil-water content, cotton and devil's-claw depleted the total amount of water equally by the end of the growing season; however, devil's-claw depleted the water earlier in the season when compared to cotton (Riffle et al. 1990). According to Mercer et al. (1990), devil's-claw will reduce cotton boll weight at a distance up to 50 cm on either side of the weed.

Riffle et al. (1989) found that a density of 5.5 ± 1.1 devil's-claw per meter square caused lint yield reductions after 4 weeks of interference, and lint yield would be reduced by about 5% for each week of interference. In 2002, *Proboscidea* spp. infested 0.6 million of the 2.1 million total cotton hectares in Texas (Byrd 2003).

One of the most common weeds invading Texas cotton is Palmer amaranth (*Amaranthus palmeri* S. Wats.) (Morgan et al. 1998b). Palmer amaranth is a branched, erect annual with alternate, rhombic-ovate to rhombic-lanceolate leaves and staminate and pistillate flowers on separate plants (Correll and Johnston 1979). Palmer amaranth is a troublesome weed that has the ability to produce large numbers of seed as demonstrated by Keeley and Thullen (1989) who reported up to 25.8 million seed per hectare.

According to Morgan et al. (2001), Palmer amaranth competition decreased cotton canopy volume up to 45%, which was due to a reduction in cotton canopy width and not height. Palmer amaranth has been found to cause up to 11% reduction in lint yield for each additional weed per 10 m of row (Rowland and Murray 1998). In addition to yield losses, Palmer amaranth can cause problems with the mechanical harvest of cotton. In one study, harvesting time increased 2- to 3.5-fold due to stoppages for removal of lodged stalks in the stripper (Smith et al. 2000). Although Palmer amaranth reduced the yield of cotton, it did not effect fiber quality (Morgan et al. 1998a; Rowland and Murray 1998). According to Byrd (2003), 2 million of the 2.1 million total cotton hectares in Texas are infested with *Amaranthus* spp.

Silverleaf nightshade (*Solanum elaeagnifolium* Cav.) is a noxious weed found in the Southwestern United States (Gunn and Gaffney 1974), including Texas, where it is considered one of the most troublesome perennial weeds in cotton (Elmore 1986). According to Correll and Johnston (1979), silverleaf nightshade is a silvery pubescent perennial with oblong to linear leaves with wavy margins and violet flowers. Silverleaf nightshade produces a deep root system, which allows it to compete for water with crops that have a shallow root system. Silverleaf nightshade has been reported to have roots at depths below 3 m (Davis et al. 1945), while cotton seldom exceeds depths of 1.5 m (Stockton et al. 1967).

Since silverleaf nightshade competes with cotton for water, this is most critical to dryland cotton growth where water is most limiting. One study found soil water content in dryland conditions was reduced more when cotton was grown in the presence of silverleaf nightshade rather than grown alone (Green et al. 1988). This competition for water will lead to a reduction of cotton production. Smith et al. (1990) found a 9% to 21% yield loss for each additional 1 kg of silverleaf nightshade dry weight per 10 m of row. Green et al. (1987) reported a 1.54% reduction in cotton lint yield for each silverleaf nightshade plant per 10 m of row.

Common cocklebur is a troublesome weed that can compete with cotton for water and nutrients. Common cocklebur (*Xanthium strumarium* L.) is a taprooted annual with alternate, irregularly toothed to lobed leaves and prickly, burlike fruit (Correll and Johnston 1979). One common cocklebur plant per 15 m of row reduced seed cotton yields from 72 to 115 kg/ha when allowed to compete season-long (Snipes et al. 1982). Snipes et al. (1987) reported that maximum seed cotton yields were obtained when plots remained free of common cocklebur for 8 to 10 weeks after planting, and seed cotton yields did not increase in longer weed-free periods. However, cotton can withstand 2 to 4 weeks of common cocklebur competition without reducing yields. As reported by Byrd (2003), *Xanthium* spp. infested approximately 1.5 million of the 5.5 million total cotton hectares in the United States in 2002, which included 0.4 million of the 2.1 million total cotton hectares in Texas.

Weeds can decrease crop production, which results in an income reduction and severe economic impacts. In 1991, $4.1 billion were lost due to weeds in 46 crops grown in the United States (Bridges 1992). According to Abernathy and McWhorter (1992), a $300 million crop loss per year is the result of weeds influencing cotton growth and development. In the United States, approximately $2.3 million and $1.2 million were lost due to reductions for grass contamination in cotton bales classed in 2001 and 2002, respectively. Texas accounted for reductions of approximately $217,000 in 2001 and $371,000 in 2002 (Byrd 2003). Weed management systems must be developed to reduce the economic losses caused by weed competition in cotton.

There are many methods of weed control including cultural, biological, mechanical, and chemical (Anderson 1996). Cultural weed control utilizes practices that are less favorable for weeds, yet more advantageous for crops. This includes row spacing and crop selection favorable for a critical weed-free period, as well as crop rotations and smother crops. Narrow-row spacing creates canopy closure early in the season causing low-light conditions that prevent newly emerging weed seedlings from developing (Gunsolus 1990). According to Bussan et al. (1993), selection of a crop variety that emerges and quickly produces leaf area might increase it's ability to compete with and suppress weeds.

Biological weed control uses natural enemies, or biotic agents, such as herbivorous animals, insects, nematodes, and pathogens to help reduce weed populations. According to Orr and Morey (1974), the leaf-feeding, parasitic nematode *Orrina phyllobia* severely stunted or killed silverleaf nightshade. The phytopathogenic bacterium *Pseudomonas syringae* pv. *tagetis* (PST) caused a reduction in the physical size and seed production of Canada thistle [*Cirsium arvense* (L.) Scop.] (Hoeft et al. 2001) and caused disease and injury in woollyleaf bursage [*Ambrosia grayi* (A.Nels.) Shinners] (Sheikh et al. 2001). Daniels and Weise (1967) reported a seed weevil (*Microlarinus lareynii* Jac. Du Val) that feeds on punturevine (*Tribulus terrestris* L.) seed bur, thus preventing new seed from germinating.

Mechanical weed control is the physical removal or prevention of weeds by hand-pulling, hoeing, mowing, flooding, smothering, burning, and machine tilling. One form of machine tilling used in cotton production is cultivation.

Snipes and Mueller (1992) reported at least one cultivation was necessary to decrease weed densities and optimize yields. Prior to the development of effective cotton herbicides, growers relied on cultivations and hand hoeing for weed control; however, a major shortcoming of mechanical weed control alone is the poor control in the crop row (Coates et al. 1998).

Chemical weed control utilizes phytotoxic chemicals, referred to as herbicides, to kill or suppress weeds. An increased use in herbicides began in 1944 with the discovery of 2,4-D [(2,4-dichlorophenoxy)acetic acid] and MCPA [(4-chloro-2-methylphenoxy)acetic acid], and has dramatically increased in time with new herbicide developments (Anderson 1996). In Texas, at least one herbicide application was made to 90% of the total cotton hectares in 2001 and as much as 97% in 1999 (TASS 2003).

Herbicides can be applied in cotton as preplant (PP), preplant incorporated (PPI), preemergence (PRE), postemergence-topical (POST), and postemergence-directed (PDIR). Herbicides that are applied PPI are sprayed prior to planting and incorporated into the soil in order to control germinating weeds and in some cases reduce herbicide degradation and volatility. Dinitroaniline herbicides such as trifluralin [2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine] and pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] are the most commonly used PPI herbicides due to their cost, effectiveness, and reliability in controlling small-seeded broadleaf weeds and grasses. These two herbicides were applied to over 2.1 million hectares of planted cotton in Texas in 1994 (Smith et al. 1996).

Preplant incorporated herbicides applied alone do not effectively control larger-seeded annual weeds such as annual morningglories (Wilcut et al. 1997); therefore, a wide variety of PRE herbicides are often used in addition to PPI herbicides to broaden the spectrum of weeds controlled. Herbicides applied PRE are sprayed on the soil surface after planting prior to the crop and weed emergence. In order for PRE herbicides to be effective, applications must be incorporated by rainfall or irrigation (Stickler et al. 1969). This allows the herbicide to be absorbed by the germinating weed seedling just below the soil surface, as well as reduces herbicide degradation due to volatilization and photodegradation (Walker and Roberts 1975; Moyer 1987).

According to Buchanan (1992), both soil-applied and postemergence-applied herbicides are necessary for effective weed control systems. Before the introduction of herbicide-tolerant cotton, only selective herbicides were applied POST, while PDIR herbicides were primarily non-selective. Selective herbicides kill weeds with little to no effect on the crop, allowing them to be applied topically. Non-selective herbicides injure or kill both the weed and crop; therefore, they must be directed under the crop canopy rather than topically applied. Although POST applications tend to provide better weed coverage and require less equipment than PDIR applications, a limited number of broad-spectrum, selective herbicides available for POST applications make PDIR herbicides a viable option for weed control in non-transgenic cotton. The only other option for postemergence weed control in cotton is cultivation and hand hoeing. These may be effective in controlling weeds in the furrow; however, escapes in the row may be prevalent.

Pyrithiobac {2-chloro-6-[(4,6-dimethoxy-2-pyrimidinyl)thio]benzoic acid, sodium salt} and MSMA (monosodium methanearsonate) are selective herbicides that can be applied POST on cotton. MSMA controls annual broadleaf and grass weeds including common cocklebur, entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray), Johnsongrass [*Sorghum halapense* (L.) Pers.], crabgrasses (*Digitaria* spp.), goosegrass [*Eleusine indica* (L.) Gaertn.], and nutsedges (*Cyperus* spp.) (Jordan et al. 1993d; Nimbal et al. 1995) but increases the potential for crop injury when applied over-the-top of cotton (Baker et al. 1969; Keeley and Thullen 1971; Shankle et al. 1996; Snipes and Byrd 1994).

Visual cotton injury from POST applications of MSMA may occur; however, this does not always result in a reduction in yields. Visual symptoms of cotton injury from POST applications of MSMA noted by Snipes and Byrd (1994) include slight crop stunting, reddening of stems, and darkening of the foliage. Monks et al. (1999) found 0 to 44% cotton injury 2 weeks after treatment when MSMA was applied POST 4 to 5 weeks after planting. This resulted in a reduction in seed cotton yield at one of two locations of the study. Jennings et al. (1998) also found no reduction in lint yield when compared to the non-treated check, and Snipes and Byrd (1994) reported a reduction in seed cotton yield in only one of five years.

Pyrithiobac was commercially introduced in 1996 for control of annual broadleaf weeds including morningglory spp., common cocklebur, devil's-claw, lanceleaf sage (*Salvia reflexa* Hornem.), Venice mallow (*Hibiscus trionum* L.), and Palmer amaranth (Crawford et al. 1989; Dotray et al. 1996; Jordan et al. 1993c; Keeling 1996; Hirai et al. 2002; Osborne et al. 1999; Reinhart 1996). Pyrithiobac has been labeled for PRE and POST applications in cotton at any growth stage from emergence to 60 days prior to harvest. Limitations of pyrithiobac include no control of perennial weeds, reduced activity on larger weeds, and carryover potential to rotation crops (Jordan et al. 1993b; Keeling 1996).

Although visual injury may occur from pyrithiobac applications, crop recovery occurs and no reductions in yield are generally observed (Dotray et al. 1996; Jordan et al. 1993a). Monks et al. (1999) observed 0 to 16% injury to cotton two weeks after pyrithiobac treatment; however, this injury did not result in yield loss. In a study of cotton injury from early- and late-season pyrithiobac applications, there was no difference in plant development, lint yield, and fiber quality when compared to the untreated check at either application timing (Shankle et al. 1996).

Prior to the introduction of pyrithiobac, graminicides such as fluazifop-P-butyl {(R)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid}, clethodim {(E,E)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}, and sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} were the only selective POST herbicides used in broadleaf crops like cotton without potential injury. Thus, the development of pyrithiobac allowed for control of not only grass weeds, but also broadleaf weeds in cotton (Jordan et al. 1993c).

According to Reinhart (1996), a typical pyrithiobac program includes a base PRE and/or PPI program of a grass plus broadleaf herbicide and an early POST application of pyrithiobacWhen MSMA is used in conjunction with pyrithiobac, weed control is increased without increasing injury or decreasing yield any greater than MSMA applied alone (Jennings et al. 1998; Monks et al. 1999). Therefore, a weed control system for conventional, non-transgenic cotton would include a residual, soil-applied herbicide followed by an early POST application of pyrithiobac tank-mixed with MSMA.

With the development of transgenic biotechnology, cotton was altered for the resistance to non-selective, broad-spectrum herbicides. This allowed non-selective herbicides that were typically applied PDIR in non-transgenic cotton to be applied POST. The first herbicide resistant cotton cultivar that was released in 1995 was a bromoxynil-tolerant (BXN^{TM}) cultivar, which allowed applications of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) to be applied from preplant to 60 days prior to harvest (Collins 1996). Bromoxynil is a non-selective herbicide that may be applied POST on transgenic, bromoxynil-tolerant cotton. Although studies performed on the Texas High Plains reported control of annual weeds such as devil’s-claw, common cocklebur, and lanceleaf sage with bromoxynil (Keeling 1996; Jones et al. 1996), bromoxynil-tolerant cotton will no longer be available in 2005 due to better herbicide-tolerant cotton options.

Glyphosate [*N*-(phosphonomethyl)glycine] is a non-selective, systemic herbicide that controls a variety of annual and perennial broadleaf, grass, and sedge weeds. The development of transgenic crops that are resistant to glyphosate allows glyphosate to be applied POST. Glyphosate inhibits aromatic amino acid biosynthesis at the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) enzyme in the shikimate pathway; however, cotton tolerance was developed by inserting a gene that encodes for a glyphosate-resistant EPSPS enzyme (Ganesh et al. 1992; Klee et al. 1987; Suh et al. 1993; Thompson et al. 1987). Glyphosate-tolerant (Roundup Ready^{TM}) cultivars of cotton were introduced in 1997, allowing glyphosate to be applied POST until the four-leaf cotton growth stage. After the four leaf stage, glyphosate must be applied PDIR to prevent crop injury (Brown and Bednarz 1998; Jones and Snipes 1999; Kalaher et al. 1997; Light et al. 2003; Pline et al. 2002).

Glyphosate does not provide residual control, so it is often used in conjunction with residual herbicides for season-long control with high yields (Brecke and Colvin 1997; Isgett et al. 1997; Keeling et al. 1996). Keeling et al. (1998) found that the addition of glyphosate to standard soil-applied, residual herbicides controlled Palmer amaranth and devil's-claw escapes. A disadvantage for a POST only program is the potential for yield loss due to early-season weed competition before the herbicides are applied (Askew and Wilcut 1999). Therefore, a reliable weed control system for glyphosate-tolerant cotton appears to be a PPI application of residual herbicides followed by POST and PDIR applications of glyphosate.

Glufosinate [2-amino-4-(hydroxymethylphosphinyl)butanoic acid] is a naturally occurring compound that has been isolated from the bacteria *Streptomyces viridochromogenes* and *Streptomyces hygroscopicus* (Tachibana and Kaneko 1986). This non-selective herbicide controls a variety of annual and perennial broadleaf and grass weeds by inhibiting glutamine synthetase (Burns et al. 2002). Glutamine synthetase catalyzes the conversion of glutamate plus ammonia to glutamine for nitrogen metabolism (Bellinder et al. 1985). This results in a reduction of glutamine and additional glutamate that are necessary for the production of some amino acids used in plant activity.

In order for glufosinate to be used POST, glufosinate-tolerant (LibertyLink^{TM}) crops were developed. These transgenic crops have a gene inserted that codes for phosphinothricin acetyltransferase, an enzyme that acetylates the free amino acid group of glufosinate, thus rendering the herbicide inactive (Droge et al. 1992; Blair-Kerth et al. 2001). A glufosinate-tolerant Coker 312 cultivar of cotton was first developed, and no visual injury or yield reduction was observed (Blair-Kerth et al. 2001). Burns et al. (2002) observed no visual injury and no reduction in yield or fiber quality in two glufosinate-tolerant stripper cultivars.

Glufosinate provides effective weed control, but this control is improved with the addition of residual herbicides. Culpepper et al. (2002) reported 90, 78, and 12% late-season control of Palmer amaranth, southern crabgrass (*Digitaria ciliaris* Retz.), and Florida pusley (*Richaradia scabra* L.), respectively, when two applications of glufosinate were used alone; however, weed control improved to near 100% with the addition of soil applied herbicides. Glufosinate applications in combination with trifluralin provided season-long Palmer amaranth, devil's-claw, and silverleaf nightshade control (Dotray et al. 2002). Therefore, applications of a residual herbicide PPI followed by POST applications of glufosinate appear to be the best weed control system in glufosinate-tolerant cotton.

Studies have been conducted to compare weed control efficacy, crop tolerance, and net returns with various weed control systems. In one study, bromoxynil and glyphosate did not visibly injure their respective transgenic cotton, and annual grass and broadleaf weeds were controlled at least 90% late-season by all herbicide systems that included soil-applied herbicides followed by an early POST application (Culpepper and York 1999). Askew et al. (2002) reported glyphosate programs had as high or higher net returns than bromoxynil, pyrithiobac, or fluometuron plus MSMA PDIR programs. These comparisons included non-transgenic and transgenic, glyphosate- and bromoxynil-tolerant cotton. This agrees with Scott et al. (2001) who found lower management costs in glyphosate-tolerant cotton when compared to non-transgenic and bromoxynil-tolerant cotton, and higher lint yield and net returns in that same comparison. In contrast, York and Culpepper (1999) observed no difference in yields and returns when comparing across conventional, BXN^{TM}, and Roundup Ready^{TM} cotton weed control systems.

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CHAPTER II

COMPARISON OF CONVENTIONAL AND GLUFOSINATE- AND GLYPHOSATE-TOLERANT COTTON WEED MANAGEMENT SYSTEMS

Abstract

Two irrigated and two dryland studies were conducted in 2003 and 2004 to compare net returns between glufosinate- and glyphosate-tolerant, and conventional cotton weed management systems. Herbicides within each weed control system were sprayed as needed based on recommended label rates and limitations, and were made independent of the weed control inputs within other systems. Weed control system costs were calculated using seed costs including technology fees, herbicide and application costs, and mechanical inputs, and lint yields were determined. The net returns above weed control system costs in 2003 with the glyphosate-tolerant system was $1,514/ha in the Lubbock irrigated study, while the glufosinate-tolerant system and conventional system were $1,131 and $889/ha, respectively. The net returns above weed control system costs were similar and ranged from $780 to $854/ha in 2004. Net returns above weed control system costs were similar for all three systems when averaged over years at the Lubbock dryland location and in 2003 at a second dryland location

near Lockett. The glufosinate- and glyphosate-tolerant systems had similar net returns when averaged over years at an irrigated study near New Deal, and were greater than the conventional system. Unlike the other three trials, the conventional weed control system generated greater net returns above weed control system costs at Lockett in 2004 compared to the glyphosate-tolerant system. The glyphosate-tolerant system generally required less input to maintain effective weed control compared to the glufosinate-tolerant system, while the glufosinate-tolerant system required less input compared to the conventional system.

Nomenclature.

Glufosinate; glyphosate; MSMA; pyrithiobac; trifluralin; common cocklebur, *Xanthium strumarium* L. #[1] XANST; devil's-claw, *Proboscidea louisianica* (Mill.) Thellung # PROLO; Palmer amaranth, *Amaranthus palmeri* S. Wats. # AMAPA; silverleaf nightshade, *Solanum elaeagnifolium* Cav. # SOLEL; cotton, *Gossypium hirsutum* L. 'FM 989', 'FM 989 RR', 'FM 981 LL'

Additional Index Words.

Biotechnology, economic analysis, genetically modified crop, herbicide tolerant crop, LibertyLink, net returns, Roundup-Ready

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

Abbreviations.

fb, followed by; PDIR, postemergence-directed; POST, postemergence-topical; PPI, preplant incorporated

Introduction

Weeds can be detrimental to crop production due to competition for water, nutrients, and sunlight. In cotton, weed competition results in fewer and less mature bolls per plant and lower lint quality (Abernathy and McWhorter 1992). Cotton must be kept weed-free for a period of time after emergence in order to avoid crop loss (Coble and Byrd 1992). Effective weed management systems are a must in order to reduce the economic losses caused by weed competition in cotton.

Pyrithiobac and MSMA are selective herbicides that can be applied POST in cotton. Pyrithiobac controls annual broadleaf weeds including morningglories (*Ipomoea* spp.), common cocklebur (*Xanthium strumarium* L.), Palmer amaranth (*Amaranthus palmeri* S. Wats.), devil's-claw [*Proboscidea louisianica* (Mill.) Thellung], lanceleaf sage (*Salvia reflexa* Hornem.), and Venice mallow (*Hibiscus trionum* L.) (Dotray et al. 1996; Hirai et al. 2002; Jordan et al. 1993; Keeling 1996; Reinhart 1996). MSMA controls annual broadleaf and grass weeds including common cocklebur, Johnsongrass [*Sorghum halapense* (L.) Pers.], crabgrasses (*Digitaria* spp.), goosegrass [*Eleusine indica* (L.) Gaertn.], and nutsedges (*Cyperus* spp.) but increases the potential for crop injury when applied over-the-top of cotton (Baker et al. 1969; Keeley and Thullen 1971; Shankle et al. 1996; Snipes and Byrd 1994). When MSMA is used in conjunction with pyrithiobac, weed control is increased without increasing injury or decreasing yield any greater than MSMA applied alone (Jennings et al. 1998; Monks et al. 1999).

Glyphosate is a non-selective, systemic herbicide that has activity on a variety of annual and perennial broadleaf, grass, and sedge weeds. The development of transgenic cotton that is resistant to glyphosate (Roundup Ready^{TM}) allows this herbicide to be applied POST until the four-leaf cotton growth stage. After the four-leaf stage, glyphosate must be applied PDIR to reduce the risk of crop injury (Brown and Bednarz 1998; Jones and Snipes 1999; Kalaher et al. 1997; Light et al. 2003). Glyphosate does not provide soil residual weed control; therefore, it is often used in conjunction with residual herbicides for season-long control (Isgett et al. 1997; Keeling et al. 1996; Keeling et al. 1998).

Glufosinate is a non-selective herbicide that has activity on a variety of annual and perennial broadleaf and grass weeds; however, applications to most weeds must be made early for control to be effective (Baughman et al. 2004; Burns et al. 2002). In order for glufosinate to be used POST over a crop, glufosinate-tolerant (LibertyLink^{TM}) crops had to be developed (Droge et al. 1992; Blair-Kerth et al. 2001). Appropriate use of glufosinate provides effective weed control, but season-long control is improved with the addition of residual herbicides (Culpepper et al. 2002; Dotray et al. 2002).

Effective weed control, yield, and net returns from various weed control systems have been reported with some comparisons made across those systems. Comparable annual grass and broadleaf weed control has been reported in bromoxynil, glyphosate, and conventional weed management systems (Culpepper and York 1999) and glufosinate, glyphosate, and conventional weed management systems (Thomas et al. 2004). Additional studies observed no differences in yields and returns when comparing across conventional and bromoxynil- and glyphosate-tolerant cotton weed control systems (York and Culpepper 1999) and conventional and glyphosate-tolerant weed management systems (Wilcut et al. 2003). In contrast, other studies reported glyphosate programs had greater lint yield and net returns compared to bromoxynil and conventional programs (Askew et al. 2002; Bryant et al. 2004; Savage and Harlan 2004; Scott et al. 2001).

Weed control and economic returns within transgenic and non-transgenic weed control systems has been studied, but there is no data comparing net returns across weed management systems that include glufosinate-tolerant cotton. The objective of this research was to compare weed control, lint yield, and net returns above weed control system costs in glufosinate- and glyphosate-tolerant, and conventional cotton weed management systems.

Materials and Methods

Field studies were conducted at three locations in 2003 and 2004. The Texas Agricultural Experiment Station near Lubbock, TX is on an Acuff clay loam soil (fine-loamy, mixed, thermic Aridic Paleustalfs) with less than 1.0% organic matter and pH 7.6. The Texas Tech University Research Farm near New Deal, TX is on a Pullman clay loam soil (fine, mixed, thermic Torrertic Paleustalfs) with 1.5% organic matter and pH 7.5. The Texas Agricultural Experiment Station near Lockett, TX is on a Miles fine sandy loam soil (fine-loamy, mixed, superactive, thermic Typic Paleustalfs) with 0.1% organic matter and pH 5.9. An irrigated experiment was evaluated at Lubbock and New Deal locations, and a dryland experiment was evaluated at the Lubbock and Lockett locations.

In all experiments, the cotton cultivars used were from the FiberMax germplasm. The non-transgenic and glyphosate-tolerant cotton cultivars were FM 989 and 989RR, respectively, while the glufosinate-tolerant cultivar was FM 981LL. A randomized complete block design with a split-plot arrangement was used. The main plots were cotton cultivar with three treatments (or subplots) randomized within each main plot. The subplots consisted of a weed-free check, a weedy check, and a weed control system. Trifluralin at 0.84 kg ai/ha (pendimethalin at 1.1 kg ai/ha at Lockett) was applied PPI to a depth of 5 cm with a rolling cultivator to the entire study area. The weed-free checks were maintained by hand hoeing and minimal cultivation (and a clethodim application at 0.18 kg ai/ha plus 1% v/v crop oil concentrate[2] at Lockett). Specific treatments for each weed control system were dependent upon the cotton cultivar and were applied as needed according to recommended label rates and limitations in order to safely and effectively control the weeds.

Lubbock Irrigated Experiment.

An irrigated experiment was conducted in 2003 and 2004 on a site with a natural infestation of devil's-claw at approximately 10 to 15 plant/m^2, Palmer amaranth at approximately 100 to 125 plant/m^2, and silverleaf nightshade (*Solanum elaeagnifolium* Cav.) at approximately 5 to 10 plant/m^2. The main plots were 8.1 m by 30.5 m on 102-cm rows. The subplots were 8.1 m by 6.1 m for the weed-free check, and 8.1 m by 12.2 m for the weedy check and weed control system. Weed control inputs and timings for each weed management system are listed in Table 2.1. All POST herbicide applications were made using a tractor-mounted compressed-air sprayer delivering 140 L/ha at 207kPa with 110015 flat-fan nozzles[3] or CO_2 backpack sprayer delivering 140 L/ha at 129 kPa with 80015 flat-fan nozzles[4]. All PDIR herbicide applications were made

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[2] Agri-dex, containing heavy range paraffinic oil, polyol fatty acid esters, and polyethoxylated derivitives. Helena Chemical Co., 225 Schilling Boulevard., Suite 300, Collierville, TN 38017.

[3] TeeJet® TurboTee 110015 nozzles, Spraying Systems Co.®, P.O. Box 7900, Wheaton, IL 60189-7900.

[4] TeeJet® 80015VS nozzles, Spraying Systems Co.®, P.O. Box 7900, Wheaton, IL 60189-7900.

using a hooded sprayer[5] delivering 140 L/ha at 129 kPa with recommended nozzles.

The Lubbock irrigated experiment received 234 mm of total rainfall in 2003 and was irrigated an additional 305 mm. Rainfall in 2004 was 868 mm with an additional 80 mm irrigated. This experiment was planted May 5 and harvested October 24 in 2003, and planted May 6 and harvested November 3 in 2004. The middle four rows of the 8-row plots were harvested with a 2-row plot stripper[6].

New Deal Experiment.

An irrigated trial was conducted in 2003 and 2004, which had a natural infestation of common cocklebur, approximately 30 to 50 plant/m^2. The main plots were 4.1 m by 39.6 m on 102-cm rows. The subplots were 4.1 m by 6.1 m for the weed-free check, and 4.1 m by 27.4 m for the weedy check and weed control system. Weed control inputs and timings for each system are listed in Table 2.1. All POST herbicide applications were made as described previously. All PDIR herbicide applications were made using a CO_2 backpack sprayer with hooded drops delivering 140 L/ha at 129 kPa.

The New Deal experiment received 277 mm of total rainfall in 2003 and was irrigated an additional 100 mm. Rainfall in 2004 was 973 mm with an

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[5] Redball™ 420 lay-by hooded sprayer, Redball, LLC, P.O. Box 159, Benson, MN 56215.

[6] John Deere 482 cotton stripper, Deere and Co., 501 River Drive, Moline, IL 61265.

additional 50 mm irrigated. This experiment was planted May 5 and harvested October 24 in 2003, and planted May 6 and harvested November 3 in 2004. Two meters of the middle two rows of the 4-row plots were hand-harvested.

Lubbock Dryland Experiment.

A dryland experiment was conducted in 2003 and 2004 with the same weed population dynamics as the adjacent irrigated experiment. The main plots and subplots were identical to the irrigated experiment as described previously. Weed control system inputs and timings are listed in Table 2.2. All POST and PDIR herbicide applications were made as described previously in the Lubbock irrigated experiment.

Rainfall totals were the same as the Lubbock irrigated experiment. This experiment was planted May 15 and harvested October 4 in 2003, and planted May 12 and harvested October 21 in 2004. Two meters of the middle four rows of the 8-row plots were hand-harvested.

Lockett Experiment.

A dryland experiment was conducted in 2003 and 2004, which had a natural infestation of Palmer amaranth at approximately 25 to 75 plant/m^2, southern crabgrass [*Digitaria ciliaris* (Retz.) Koel.] at 25 to 75 plant/m^2, field sandbur (*Cenchrus incertus* M.A. Curtis) at <1 plant/m^2, and puncturevine

(*Tribulus terrestris* L.) at <1 plant/m^2. The main plots were 4.1 m by 30.5 m on 102-cm rows in 2003 and 8.1 m by 45.8 m on 102-cm rows in 2004. The subplots were 4.1 m by 6.1 m for the weed-free check, and 4.1 m by 12.2 m for the weedy check and weed control system in 2003. In 2004, all subplots were 8.1 m by 15.3 m. Weed control system inputs and timings are listed in Table 2.2. All POST and PDIR herbicide applications were made as described previously in the New Deal experiment.

Rainfall totals were 330 mm in 2003 and 813 mm in 2004. This experiment was planted May 27 and harvested November 21 in 2003, and planted May 18 and harvested October 8 in 2004. Two 102-cm rows by 1.5 m were hand-harvested in 2003, and four rows by 15.3 m were harvested with a mechanical stripper in 2004.

Visual weed control ratings were performed near harvest in the Lubbock irrigated, Lubbock dryland, and New Deal experiments. Visual weed control ratings were based on a scale of 0 to 100%, where 0% = no weed control and 100% = complete control (Frans et al. 1986). Burr cotton samples were ginned for percent lint and seed turnout, which were used to calculate lint and seed yields. Gross returns included both lint and seed returns. Lint returns were calculated using the loan price[7] based on lint quality[8], while seed returns were

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[7] Commodity Credit Corporation (CCC) loan rates 2003-2004 and 2004-2005 crop, Plains Cotton Cooperative Association, 3301 East 50th Street, Lubbock, TX 79408-2827.

based on a price of $121/Mg of seed. Total weed control system costs included seed plus any applicable technology fees, herbicide, application, cultivation, and hand hoeing costs (Table 2.3). Net returns above weed control system costs were calculated as gross returns minus total weed control system costs for each individual program. Total production costs were not taken into account.

An analysis of variance was performed on weed control, lint yield, and net returns above weed control system costs using PROC MIXED in SAS (1988). Arcsine square root transformations were performed on all weed control data prior to analysis. For clarity, non-transformed data are presented with statistical interpretation based upon transformed data.

Results and Discussion

An experiment by year by cultivar by treatment interaction was observed for lint yield and net returns above weed control system costs; therefore, analyses were performed for each experiment. In each experiment, data were pooled over years when there was no year interaction for weed control, lint yield, and net returns above weed control system costs.

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[8] High volume instrument (HVI) lint quality analysis, International Textile Center, P.O. Box 45019, Lubbock, TX 79409-5019.

Lubbock Irrigated Experiment.

Palmer amaranth and devil's-claw control was averaged over years because no year by cultivar interactions were observed. A year by cultivar interaction was observed for end of season silverleaf nightshade control. Therefore, control of this weed was examined by year. A year by cultivar interaction was observed for lint yield; therefore, years were held constant and analyzed for cultivar by treatment interactions. In each year, cultivar by treatment interaction was not significant; therefore, treatment means were averaged within a cultivar and cultivar means were averaged within a treatment. Net returns above weed control system costs were analyzed separately by year because a year by cultivar interaction was observed.

When averaged over years, Palmer amaranth and devil's-claw were controlled 97% to 99% in all weed control systems (Table 2.4). Dotray et al. (1996) reported a similar trend in a conventional weed control system, while Keeling et al. (1996) and Dotray et al. (2002) reported a similar trend in glyphosate- and glufosinate-tolerant cotton weed control systems. The glyphosate-tolerant weed control system achieved 90% control of silverleaf nightshade in 2003, while the glufosinate-tolerant system and the conventional system controlled silverleaf nightshade 69% and 50%, respectively. In 2004, silverleaf nightshade was controlled at least 97% and control was similar for all three weed control systems. Increased herbicidal activity observed in 2004 may have resulted from the lack of plant stress from frequent and above normal rainfall (Boydston 1990; Boydston 1992; Dickson et al. 1990; Reynolds et al. 1988). Thus allowing increased control with the glufosinate and conventional systems (Coetzer et al. 2001; Light et al. 1999; Peterson and Hurle 2001).

Lint yields in 2003 were greater in the glyphosate-tolerant cotton (1,142 kg lint/ha) compared to the other two cultivars (Table 2.5). In observations of the same cultivars used in this study, Gannaway et al. (2004) reported a similar trend with glyphosate-tolerant cotton yielding 1,468 to 2,121 kg lint/ha. The glufosinate-tolerant and conventional cotton produced 1,156 to 1,627 kg/ha and 1,367 to 1,816 kg/ha, respectivey. The glufosinate-tolerant cultivar in this study was in seed block fields in the spring of 2003 (J. K. Dever, personal communication). This may explain the delayed emergence and stand development observed, which probably affected yields because of the slow start. Hsi and Reeder (1953) reported seed from freshly-opened bolls resulted in the most intense dormancy, and Wanjura et al. (1969) reported the most rapidly-emerging seedlings generated the majority of cotton. There were no differences in lint yield across all three cultivars in 2004 and yields ranged from 704 to 779 kg/ha when averaged over treatments. These results agree with Thomas et al. (2004) who reported no difference in yields between glufosinate- and glyphosate-tolerant weed management systems. In 2004, lint yields were lower in all three cultivars possibly due to a combination of cotton lost on the ground following a snow storm between defoliation and harvest and lower than average late-season heat units (Haldenby 2004). When averaged over cultivar, weed control system and weed-free lint yields were 973 and 1,027 kg/ha in 2003 and 749 and 745 kg/ha in 2004, respectively, and were not different within years. Therefore, the weed management system did not cause a reduction in yield due to herbicide injury nor weed competition compared to the weed-free plots.

Total weed control system costs included seed price plus applicable technology fees, herbicide plus application costs, cultivation costs, and hand hoeing costs (Table 2.6). Total weed control system costs were $161/ha in the glyphosate-tolerant cotton in 2003, while the glufosinate-tolerant and conventional costs were $200 and $234/ha, respectively. The net returns above weed control system costs were $1,514/ha in the glyphosate-tolerant system in 2003 (Table 2.7). Lower net returns above weed control system costs were observed in the glufosinate-tolerant and conventional systems ($889 to $1,131/ha). Scott et al. (2001) also reported lower management costs and greater net returns in glyphosate-tolerant cotton when compared to non-transgenic cotton. The weed control system costs across weed management systems in 2004 ranged from $201 to $207/ha (Table 2.6). The net returns above weed control system costs were similar in 2004 and ranged from $780 to $854/ha (Table 2.7). Differences in net returns above weed control system costs in 2003 were mainly the result of greater lint yield and not reduced input costs.

New Deal Experiment.

A year by cultivar interaction was observed for common cocklebur control; therefore, control was analyzed within each year. In lint yield analysis, a year by cultivar by treatment interaction was observed; therefore, cultivar by treatment interaction for yield means was examined each year. In both years, treatment means were compared within a cultivar and cultivar means were compared within a treatment because a cultivar by treatment interaction was observed. A year by cultivar interaction was not significant for net returns above weed control system costs; therefore, net returns were averaged over years.

The glyphosate-tolerant weed management system controlled common cocklebur 97% in 2003, which was greater than the 70% control achieved in the glufosinate-tolerant system and the 9% control achieved in the conventional weed management system (Table 2.4). In 2004, the glufosinate-tolerant and glyphosate-tolerant systems controlled common cocklebur at least 96%, while the conventional system provided 33% control. Reduced common cocklebur control in the glufosinate-tolerant system in 2003 may be the result of lower herbicide activity due to higher temperatures and below average rainfall.

Lint yield in the glyphosate-tolerant weed control system was 769 kg/ha in 2003, which was greater than the lint yield in the glufosinate-tolerant system (431 kg/ha) and the conventional system (92 kg/ha) (Table 2.5). Lint yields were greatest in the glyphosate- (1,122) and glufosinate-tolerant (1,085 kg lint/ha) weed control systems in 2004. The yield differences observed in 2003 may be a combination of reduced weed control as well as delayed emergence and stand development observed in the glufosinate-tolerant cotton. The weed control system generated greater lint yields compared to the weed-free in the glyphosate-tolerant cotton in 2003 and the glufosinate- and glyphosate-tolerant cotton in 2004. These results are largely due to the intense weed competition that was not maintained effectively in weed-free plots with hand hoeing and cultivation alone. In addition, abundant soil disturbance from removal of large quantities of weeds may have caused plant stress in cotton. The weed-free produced greater lint yields compared to the weed control system in the conventional cotton in both years due to ineffective weed control in the systems.

Total weed control system costs across systems ranged from \$162 to \$193/ha in 2003 and \$134 to \$200/ha in 2004 (Table 2.6). When averaged over years, the glufosinate-tolerant and glyphosate-tolerant weed management systems had similar net returns above weed control system costs (Table 2.7). These systems produced over \$815/ha, which was greater than the net returns above weed control system costs produced in the conventional system (\$131/ha). These data agree with Savage and Harlan (2004) who reported \$215/A greater net returns in the glyphosate-tolerant weed management system than the conventional system. The primary factor that influenced the net returns above weed control system costs was lint yield.

Lubbock Dryland Experiment.

A year by cultivar interaction was observed for end of season Palmer amaranth, devil's-claw , and silverleaf nightshade control; therefore, control of these weeds was examined within each year. A year by treatment interaction was observed for lint yield; therefore, means were analyzed for cultivar by treatment interaction each year. There was no cultivar by treatment interaction in either year allowing treatment means to be averaged within a cultivar and cultivar means to be averaged within a treatment. A year by cultivar interaction was not significant for net returns above weed control system costs. Therefore, net returns above weed control system costs means were averaged over years.

Palmer amaranth and devil's-claw control ranged from 97 to 100% across all weed control systems in 2003 and 2004 (Table 2.4). Silverleaf nightshade was controlled more effectively in the glyphosate-tolerant system (91%) compared to the glufosinate-tolerant (80%) and conventional (64%) weed management systems in 2003. In 2004, silverleaf nightshade was controlled 91% to 98% and was similar across weed management systems. These results were similar to the trend observed in the Lubbock irrigated experiment.

When averaged across treatments, lint yield from glufosinate-tolerant, glyphosate-tolerant, and conventional cotton ranged from 221 to 254 kg/ha in 2003 and from 587 to 630 kg/ha in 2004 and were similar across cultivars (Table 2.5). These results are similar to Culpepper and York (1999) who reported no difference in yields between glyphosate-tolerant and conventional weed control systems. Lower lint yields observed in 2003 were due to below average seasonal rainfall. When averaged across cultivar, lint yield in the weed control system and weed-free plots were similar in 2003 and in 2004.

Total weed control system costs ranged from $130 to $171/ha in the glyphosate-tolerant system and $167 to $186/ha in the glufosinate-tolerant and conventional systems in 2003 and 2004 (Table 2.6). Net returns above weed control system costs were similar in all three weed management systems when averaged across years and ranged from $341 to $395/ha (Table 2.7). Wilcut et al. (2003) also reported no difference in net returns between conventional and glyphosate-tolerant weed management systems.

Lockett Experiment.

In lint yield analysis, a year by cultivar by treatment interaction was observed; therefore, cultivar by treatment interaction for yield means was examined each year. In 2003, cultivar by treatment interaction was not significant; therefore, treatment means were averaged within a cultivar and cultivar means were averaged within a treatment. A cultivar by treatment interaction was observed in 2004. A year by cultivar interaction was significant for net returns above weed control system costs; therefore, net returns were analyzed within each year.

When averaged across treatments, lint yield from glufosinate-tolerant, glyphosate-tolerant, and conventional cotton ranged from 250 to 311 kg/ha in

2003 and were similar across cultivars (Table 2.5). The conventional weed control system produced 716 kg lint/ha in 2004, which was greater than the lint produced in the glyphosate-tolerant system (464 kg/ha). The glufosinate-tolerant weed management system yielded 568 kg/ha and was similar to the other two systems. In contrast, Culpepper and York (1999) reported no difference in yield between a glyphosate-tolerant and conventional cotton weed management system. When averaged over cultivar, weed control system and weed-free lint yields were 309 and 239 kg/ha in 2003, respectively, and were not different. However, these results were low largely due to dry weather and the intense weed competition that was not maintained effectively. Lint yield in the weed control system was similar to the weed-free in the conventional cotton in 2004. Within the glufosinate- and glyphosate-tolerant cotton, the weed-free produced greater lint yield compared to the weed control system in 2004. The results observed in the glufosinate-tolerant cotton may be due to grass weed competition that resulted from ineffective early season grass weed control in the system. The results observed in the glyphosate-tolerant cotton may be due to green stem absorption and drift on the lower leaves from the PDIR application of glyphosate after the 4-leaf stage in the system (Pline et al. 2001; Pline et al. 2002; Wills 1978).

Total weed control system costs ranged from $152 to $249/ha in 2003 and $176 to $180/ha in 2004 (Table 2.6). Net returns above weed control system costs were similar in all three weed management systems in 2003 and ranged from $122 to $311/ha (Table 2.7). The conventional weed management system produced $830/ha in net returns above weed control system costs in 2004, which was greater than the $475/ha produced in the glyphosate-tolerant system. These results contrast those found by Wilcut et al. (2003) who reported no differences in net returns among non-transgenic and glyphosate-tolerant weed management systems. The glufosinate-tolerant weed management system produced $604/ha and was similar to the other two systems. Differences in net returns above weed control system costs in 2004 were mainly the result of greater lint yield and not input costs.

In summary, Palmer amaranth and devil's-claw control was comparable between systems while glyphosate systems were more consistent in controlling silverleaf nightshade and common cocklebur. Lint yields and net returns were as good or better with the glyphosate system than the other two systems with the exception of Lockett in 2004. Similar results were observed with the glufosinate system except at the Lubbock irrigated location in 2003. The conventional system did not perform as well as the other two systems at Lubbock irrigated (2003) or at New Deal in either year. Over all net returns followed the same pattern as lint yields. This would indicate that lint yield is the overriding factor more so than herbicide program cost in choosing the most economical weed management system. The glyphosate system generally required less input to maintain effective weed control compared to the glufosinate system, while the glufosinate system required less input compared to the conventional system.

Other than selecting a weed management system based on weed population dynamics, this may be the deciding factor when choosing a system, since similar net returns above weed control system costs are obtainable with all three weed control systems.

Table 2.1 . Weed control system inputs in the Lubbock irrigated and New Deal experiments in 2003 and 2004.[a]

		2003				2004			
Experiment	Weed control system	Treatment	Rate[b]	Application timing	Application date	Treatment	Rate	Application timing	Application date
Lubbock irrigated	glufosinate-tolerant	trifluralin	0.84	PPI	Apr 25	trifluralin	0.84	PPI	Feb 11
		glufosinate	0.47	POST	May 29	glufosinate	0.47	POST	Jun 1
		glufosinate	0.47	POST	Jun 12	glufosinate	0.47	POST	Jun 28
		cultivation			Jul 1	cultivation			Jul 19
		hand-hoe			Aug 14	hand-hoe			Aug 15
	glyphosate-tolerant	trifluralin	0.84	PPI	Apr 25	trifluralin	0.84	PPI	Feb 11
		glyphosate	0.84	POST	Jun 10	glyphosate	0.84	POST	Jun 1
		glyphosate	0.84	PDIR	Jun 30	glyphosate	0.84	PDIR	Jul 2
						glyphosate	0.84	PDIR	Aug 11
	conventional	trifluralin	0.84	PPI	Apr 25	trifluralin	0.84	PPI	Feb 11
		pyrithiobac+	0.07	POST	May 29	pyrithiobac+	0.07	POST	Jun 1
		MSMA	0.84			MSMA[c]	0.84		
		cultivation			Jun 16	cultivation			Jun 2
		cultivation			Jul 1	cultivation			Jul 2
		hand-hoe			Aug 14	cultivation			Jul 19
						hand-hoe			Aug 15
New Deal	glufosinate-tolerant	trifluralin	0.84	PPI	May 5	trifluralin	0.84	PPI	Apr 19
		glufosinate	0.47	POST	May 22	glufosinate	0.47	POST	May 25
		glufosinate	0.47	POST	Jun 16	glufosinate	0.47	POST	Jun 21
		cultivation			Jul 7	cultivation			Jul 20
						cultivation			Aug 17

Table 2.1 . Continued.

		2003				2004			
Experiment	Weed control system	Treatment	Rate[b]	Application timing	Application date	Treatment	Rate	Application timing	Application date
	glyphosate-tolerant	trifluralin	0.84	PPI	May 5	trifluralin	0.84	PPI	Apr 19
		glyphosate	0.84	POST	May 28	glyphosate	0.84	POST	May 25
		glyphosate	0.84	POST	Jun 12	glyphosate	0.84	PDIR	Jun 21
		glyphosate	0.84	PDIR	Jul 11	cultivation			Aug 17
	conventional	trifluralin	0.84	PPI	May 5	trifluralin	0.84	PPI	Apr 19
		pyrithiobac+	0.07	POST	May 22	pyrithiobac+	0.07	POST	May 25
		MSMA	0.84			MSMA[c]	0.84		
		cultivation			Jun 16	cultivation			May 28
		cultivation			Jul 7	cultivation			Jun 23
						cultivation			Jul 20
						cultivation			Aug 17

[a] Abbreviations: PPI, preplant incorporated; POST, postemergence-topical; PDIR, postemergence-directed.

[b] Trifluralin, glufosinate, pyrithiobac, and MSMA rate in kg ai/ha; glyphosate rate is kg ae/ha.

[c] Application banded 51 cm on 102-cm rows.

Table 2.2 . Weed control system inputs in the Lubbock dryland and Lockett experiments in 2003 and 2004.[a]

		2003				2004			
Experiment	Weed control system	Treatment	Rate[b]	Application timing	Application date	Treatment	Rate	Application timing	Application date
			kg ai ha^{-1}				kg ai ha^{-1}		
Lubbock dryland	glufosinate-tolerant	trifluralin	0.84	PPI	Apr 25	trifluralin	0.84	PPI	Feb 11
		glufosinate	0.47	POST	May 29	glufosinate	0.47	POST	Jun 1
		glufosinate	0.47	POST	Jun 12	glufosinate	0.47	POST	Jun 28
		hand-hoe			Aug 14	cultivation			Jul 19
	glyphosate-tolerant	trifluralin	0.84	PPI	Apr 25	trifluralin	0.84	PPI	Feb 11
		glyphosate	0.84	POST	Jun 10	glyphosate	0.84	POST	Jun 1
						glyphosate	0.84	PDIR	Jul 2
	conventional	trifluralin	0.84	PPI	Apr 25	trifluralin	0.84	PPI	Feb 11
		pyrithiobac+	0.07	POST	May 29	pyrithiobac+	0.07	POST	Jun 1
		MSMA	0.84			MSMA[c]	0.84		
		cultivation			Jun 16	cultivation			Jun 2
		hand-hoe			Aug 14	hand-hoe			Jul 2
						cultivation			Jul 19
Lockett	glufosinate-tolerant	pendimethalin	1.1	PPI	Feb 19	pendimethalin	1.1	PPI	Mar 11
		glufosinate	0.47	POST	Jun 17	glufosinate	0.47	POST	Jun 10
		hand hoe			Aug 20	glufosinate	0.47	POST	Jul 7
	glyphosate-tolerant	pendimethalin	1.1	PPI	Feb 19	pendimethalin	1.1	PPI	Mar 11
		glyphosate[b]	0.84	POST	Jun 17	glyphosate	0.84	POST	Jun 10
		hand hoe			Aug 20	glyphosate	0.84	PDIR	Jul 7

Table 2.2 . Continued.

		2003				2004			
Experiment	Weed control system	Treatment	Rate[b]	Application timing	Application date	Treatment	Rate	Application timing	Application date
			kg ai ha^{-1}				kg ai ha^{-1}		
	conventional	pendimethalin	1.1	PPI	Feb 19	pendimethalin	1.1	PPI	Mar 11
		pyrithiobac	0.07	POST	Jun 17	pyrithiobac+	0.07	POST	Jun 10
		clethodim	0.18	POST	Jul 11	MSMA	0.84		
		hand hoe			Aug 20	clethodim	0.11	POST	Jul 7

[a] Abbreviations: PPI, preplant incorporated; POST, postemergence-topical; PDIR, postemergence-directed.

[b] Trifluralin, glufosinate, pyrithiobac, MSMA, and pendimethalin rate in kg ai/ha; glyphosate rate is kg ae/ha.

[c] Application banded 51 cm on 102-cm rows.

Table 2.3. Average commercial price for cotton seed, herbicide, application, and mechanical weed control from three local sources in 2003 and 2004.[a]

	seed[b]			herbicide									
Year	FM 989	FM 989 RR[c]	FM 981 LL[d]	trif.	pend.	gluf.[d]	glyph.	pyrith.	MSMA	cleth.	app.	cult.	hand hoe
	$/ha												$/hr[f]
2003	47.38	83.01	82.07	7.14	15.09	24.05	23.63	58.20	5.63	39.11	8.02	13.58	5.75
2004	49.85	93.65	92.59	7.33	15.83	22.49	22.10	27.53[e]	2.95[e]	23.48	8.64	14.81	5.75

[a] Abbreviations: FM, FiberMax; RR, Roundup Ready; LL, LibertyLink; trif., trifluralin; pend., pendimethalin; gluf., glufosinate; glyph., glyphosate; pyrith., pyrithiobac; cleth., clethodim; app., application; cult., cultivation.

[b] Seed price based on a seeding rate of 16.8 kg/ha.

[c] Price includes technology fees of $43.10 and $53.80 per 22.7-kg bag in 2003 and 2004.

[d] Price in 2003 is based on 2004 ratio to glyphosate products.

[e] Price based on 51 cm banded application on 102 cm rows.

[f] Cost in dollars per man hour.

Table 2.4 . Palmer amaranth, devil's-claw, silverleaf nightshade, and common cocklebur control near harvest in glufosinate-tolerant, glyphosate-tolerant, and conventional cotton weed management systems at several locations in 2003 and 2004.[a,b]

	Weed control	Palmer Amaranth			Devil's-claw			Silverleaf Nightshade			Common Cocklebur		
Experiment	system	2003	2004	Avg	2003	2004	Avg	2003	2004	Avg	2003	2004	Avg
		% Control											
Lubbock	glufosinate-tolerant	100	97	99 A	100	98	99 A	69 b	98 a	84	-	-	-
irrigated	glyphosate-tolerant	96	98	97 A	95	98	97 A	90 a	97 a	94	-	-	-
	conventional	100	98	99 A	100	96	98 A	50 c	98 a	74	-	-	-
New Deal	glufosinate-tolerant	-	-	-	-	-	-	-	-	-	70 b	96 a	83
	glyphosate-tolerant	-	-	-	-	-	-	-	-	-	97 a	97 a	97
	conventional	-	-	-	-	-	-	-	-	-	9 c	33 b	21
Lubbock	glufosinate-tolerant	100 a	98 a	99	100 a	98 a	99	80 b	98 a	89	-	-	-
dryland	glyphosate-tolerant	98 b	98 a	98	97 b	98 a	98	91 a	91 b	91	-	-	-
	conventional	100 a	98 a	99	100 a	97 a	98	64 c	96 a	80	-	-	-

[a] Abbreviations: Avg, 2003 and 2004 average.

[b] Means in a column within each experiment followed by the same uppercase letter if averaged over years or lowercase letter if analyzed by year are not different (P<0.05).

Table 2.5. Lint yield in the Lubbock irrigated, Lubbock dryland, New Deal, and Lockett experiments in 2003 and 2004.[a,b]

		2003			2004		
Experiment	Variety	System	Weed free	Average	System	Weed free	Average
		kg/ha					
Lubbock irrigated	glufosinate-tolerant	919	1,002	961 Y	791	767	779 X
	glyphosate-tolerant	1,176	1,108	1,142 X	727	791	759 X
	conventional	824	971	898 Y	731	676	704 X
	average	973 A	1,027 A		749 A	745 A	
New Deal	glufosinate-tolerant	431 ay	315 ax	373	1,085 ax	876 bx	981
	glyphosate-tolerant	769 ax	306 bx	538	1,122 ax	923 bx	1,022
	conventional	92 bz	289 ax	190	347 by	853 ay	600
	average	431	303		851	884	
Lubbock dryland	glufosinate-tolerant	224	236	230 X	617	637	627 X
	glyphosate-tolerant	251	258	254 X	592	669	630 X
	conventional	197	244	221 X	576	598	587 X
	average	224 A	246 A		595 A	635 A	
Lockett	glufosinate-tolerant	275	224	250 X	568 bxy	700 ax	634
	glyphosate-tolerant	362	260	311 X	464 by	723 ax	594
	conventional	290	231	261 X	716 ax	723 ax	720
	average	309 A	239 A		583	715	

[a] Treatment means in a column within each experiment followed by the same uppercase letter (X,Y,Z) if averaged over treatments or lowercase letter (x,y,z) if analyzed by treatment are not different ($P<0.05$).

[b] Variety means in a row within each year followed by the same uppercase letter (A,B,C) if averaged over variety or lowercase letter (a,b,c) if anaylyzed by variety are not different ($P<0.05$).

Table 2.6 . Returns and weed control system costs calculations for glufosinate-tolerant, glyphosate-tolerant, and conventional cotton weed control systems in the Lubbock irrigated, New Deal, Lubbock dryland, and Lockett experiments in 2003 and 2004.[a,b]

Experiment	Year	Weed control system	Lint price[c]	Lint returns[d]	Seed yield	Seed price	Seed returns[e]	Gross returns[f]	Seed costs[g]	Herb. costs[h]	Cult. costs[i]	Hoe costs[j]	Total costs[k]
			$/kg	$/ha	kg/ha	$/kg				$/ha			
Lubbock irrigated	2003	glufosinate-tolerant	1.239	1140.97	1562	0.121	189.48	1330.45	82.07	79.31	13.5802	25.35	200.31
		glyphosate-tolerant	1.241	1460.28	1772	0.121	214.84	1675.12	83.01	78.47	0.00	0.00	161.48
		conventional	1.168	963.61	1303	0.121	158.07	1121.69	47.38	87.01	27.1605	72.43	233.98
	2004	glufosinate-tolerant	1.147	907.20	1347	0.121	163.37	1070.57	92.59	78.25	14.8148	21.74	207.40
		glyphosate-tolerant	1.171	851.73	1080	0.121	130.99	982.73	93.65	108.20	0.00	0.00	201.85
		conventional	1.174	859.68	1128	0.121	136.82	996.50	49.85	55.11	29.6296	66.43	201.02
New Deal	2003	glufosinate-tolerant	1.162	502.07	525	0.121	63.69	565.76	82.07	79.31	13.58	0.00	174.96
		glyphosate-tolerant	1.116	859.66	1143	0.121	138.60	998.26	83.01	110.12	0.00	0.00	193.14
		conventional	1.148	105.97	145	0.121	17.54	123.51	47.38	87.01	27.16	0.00	161.56
	2004	glufosinate-tolerant	1.126	1222.49	1772	0.121	214.95	1437.44	92.59	78.25	29.63	0.00	200.47
		glyphosate-tolerant	1.145	1285.75	1552	0.121	188.26	1474.00	93.65	77.46	14.81	0.00	185.92
		conventional	1.144	396.97	526	0.121	63.74	460.71	49.85	55.11	59.26	0.00	164.22
Lubbock dryland	2003	glufosinate-tolerant	1.083	242.88	355	0.121	43.04	285.92	82.07	79.31	0.00	24.75	186.13
		glyphosate-tolerant	1.086	272.43	367	0.121	44.50	316.93	83.01	46.81	0.00	0.00	129.83
		conventional	1.128	222.35	307	0.121	37.18	259.54	47.38	87.01	13.5802	38.02	186.00
	2004	glufosinate-tolerant	1.094	676.18	1062	0.121	128.75	804.93	92.59	78.25	14.8148	0.00	185.65
		glyphosate-tolerant	1.119	663.80	879	0.121	106.55	770.35	93.65	77.46	0.00	0.00	171.11
		conventional	1.155	665.79	910	0.121	110.32	776.11	49.85	55.11	29.6296	32.62	167.21
Lockett	2003	glufosinate-tolerant	1.120	307.99	402	0.121	48.74	356.73	82.07	55.19	0.00	26.40	163.66
		glyphosate-tolerant	1.121	404.89	485	0.121	58.74	463.63	83.01	54.77	0.00	14.39	152.16
		conventional	1.111	322.30	398	0.121	48.16	370.45	47.38	136.47	0.00	64.71	248.56

Table 2.6 . Continued.

Experiment	Year	Weed control system	Lint price[b]	Lint returns[c]	Seed yield	Seed price	Seed returns[d]	Gross returns[e]	Seed costs[f]	Herb. costs[g]	Cult. costs[h]	Hoe costs[i]	Total costs[j]
			$/kg	$/ha	kg/ha	$/kg				$/ha			
	2004	glufosinate-tolerant	1.186	673.44	908	0.121	109.95	783.39	92.59	86.74	0.00	0.00	179.33
		glyphosate-tolerant	1.227	568.91	706	0.121	85.57	654.48	93.65	85.95	0.00	0.00	179.60
		conventional	1.230	879.88	1042	0.121	126.23	1006.11	49.85	126.20	0.00	0.00	176.05

[a] Only takes into account weed control system costs and not total production costs.

[b] Abbreviations: Herb., herbicide; Cult., cultivation.

[c] Lint price based on lint quality analysis.

[d] Lint returns = lint yield (Table 5) x lint price.

[e] Seed returns = seed yield x seed price.

[f] Gross returns = lint returns + seed returns.

[g] Seed costs based on 16.8 kg/ha seeding rate and includes technology fees of $43.10 and $53.80 per 22.7-kg bag in 2003 and 2004 for glyphosate-tolerant cotton.

[h] Herb. costs = season total herbicide + application costs.

[i] Cult. costs = season total cultivation costs.

[j] Hoe costs = timed man hours of hand hoeing x $/man hour.

[k] Total costs = seed costs + herb. costs + cult. costs + hoe costs.

Table 2.7 . Net returns above weed control system costs in the Glover farm irrigated, New Deal, Glover farm dryland, and Lockett experiments in 2003 and 2004.[a,b,c]

Weed Control	Lubbock irrigated			New Deal			Lubbock dryland			Lockett		
System	2003	2004	Avg	2003	2004	Avg	2003	2004	Avg	2003	2004	Avg
	$/ha											
glufosinate-tolerant	1,131 b	854 a	993	390	1,237	815 A	99	617	358 A	193 a	604 ab	399
glyphosate-tolerant	1,514 a	780 a	1,148	805	1,289	1,047 A	188	600	395 A	311 a	475 b	393
conventional	889 b	795 a	842	-37	296	131 B	74	607	341 A	122 a	830 a	476

[a] Only takes into account weed control system costs (Table 6) and not total production costs.

[b] Abbreviations: Avg, 2003 and 2004 average.

[c] Means in a column within each experiment followed by the same uppercase letter if averaged over years or lowercase letter if analyzed by year are not different ($P<0.05$).

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APPENDIX

COMMERCIAL PRICE OF SEED AND HERBICIDE

Table A.1. Average commercial price for cotton seed from three local sources in 2003 and 2004.[a]

	2003					2004				
Cultivar	Seed count	Tech fee	Seed price	Total price	Total price	Seed count	Tech fee	Seed price	Total price	Total price
	no./kg		$/bag		$/kg	no./kg		$/bag		$/kg
FM 989	10,154	-	63.95	63.95	2.82	10,154	-	67.30	67.30	2.96
FM 989 RR	10,419	43.10	68.95	112.05	4.94	10,419	53.80	72.63	126.43	5.57
FM 981 LL[b]	9,956	-	110.78	110.78	4.88	9,956	-	125.00	125.00	5.51

[a] Abbreviations: FM, FiberMax; RR, Roundup Ready; LL, LibertyLink; Tech, technology.

[b] Price in 2003 is based on 2004 ratio to glyphosate products.

Table A.2. Average commercial price for herbicide from three local sources in 2003 and 2004.

Year	trifluralin	pendimethalin	glufosinate	glyphosate	pyrithiobac	MSMA	clethodim
	$/L				$/g	$/L	
2003	4.07	5.38	10.30[a]	14.71	0.69	4.81	52.29
2004	4.18	5.64	9.63	13.76	0.65	5.04	50.25

[a] Price in 2003 is based on 2004 ratio to glyphosate products.

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