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I am submitting herewith a thesis written by Christopher D. McAllister entitled "Interaction of Herbicides and Early-Season Insecticides on Thrips Populations and Plant Growth Characteristics on Herbicide-Tolerant Transgenic Cotton." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment for the degree of Master of Science, with a major in Entomology and Plant Pathology.

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Interaction of Herbicides and Early-Season Insecticides on Thrips Populations and Plant Growth Characteristics on Herbicide-Tolerant Transgenic Cotton

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Christopher D. McAllister
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Dedication

This thesis is dedicated to my grandparents,

Robert and Gladys McAllister,

for all their prayers and love.

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Abstract

Cotton (*Gossypium hirsutum* L.) is produced in seventeen states from Virginia to California. In 1999, the United States produced approximately $3.8 billion dollars of cotton. Cotton production in Tennessee in 1999 was valued at $142 million.

Major pests of cotton in Tennessee include boll weevil, bollworm, tobacco budworm, plant bugs, stink bugs, and thrips. Thrips are the first insects that attack young cotton seedlings soon after the plants emerge from the soil. Cotton insects in the United States caused approximately $581.5 million in lost lint yield. Losses due to weeds, however, are not as easy to quantify. The most current yield losses that could be found were from 1994, when estimated yield losses caused by weeds in Tennessee were $1.4 million. In Tennessee, growers spent $16.4 million on herbicides in 1994.

Cotton producers have wanted a post emergence herbicide option for weed control because of the ease of application. Previously, growers had to rely upon directed sprays to protect the plants from herbicide contact. Prior to 1995, cotton was the only major agronomic crop without a registered post emergence herbicide available to producers. However, with the introduction of the BXN® and Roundup Ready® transgenic varieties of cotton in 1995 and 1997, respectively, producers now have more options for weed control. The premise behind these two types of cotton is that a gene has been inserted into the plant

that inhibits certain enzymatic pathways, which makes the plant tolerant to foliar applications of the herbicides bromoxynil or glyphosate.

Research was conducted at both Jackson and Milan, Tennessee, in 1999 and 2000. Three experiments were conducted each year. The objectives of this research were to evaluate the: (1) efficacy of several early-season insecticides for thrips control under two herbicide programs, (2) effects of insecticide on cotton growth, development, and yield, and (3) possible interactions among the insecticides and Roundup Ultra®, Buctril®, or conventional herbicides.

All insecticide-treated plants had significantly lower amounts of thrips feeding injury in 1999 and 2000. Both adult and larval thrips were affected by insecticide treatment during this study. Densities of adult and larval thrips on aldicarb-treated plants were consistently lower than on untreated plants. In 1999 and 2000, all insecticide treatments protected young plants from thrips feeding. Insecticide-treated plants also had greater amounts of leaf area in each year. Stand densities were not affected by insecticide treatment during 1999 and 2000 at Jackson or Milan. Phorate-treated plants had consistently fewer blooms and a higher node of first position square in 1999 and 2000, indicating a delay in maturity. Lint yields were not affected by insecticide treatment in two of three tests in 1999, while in 2000, two of three tests had higher lint yields. When herbicides were evaluated for impact against stand densities, thrips feeding damage, leaf area, node of first position square, blooms, thrips numbers, and yield, no significant effects were observed.

Insecticides have been evaluated previously, but trials were conducted using conventional cotton varieties. This research will be useful in updating Tennessee's state cotton insecticide recommendations for herbicide-tolerant cotton varieties.

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Chapter I

LITERATURE REVIEW

Cotton (*Gossypium hirsutum* L.) is believed to have been introduced into the United States from the West Indies (Frisbie et al. 1989). Cotton was grown in the Indus Valley around 3000 B.C., and India became a major exporter of finished cotton textiles. Indian cotton was either of two species: *G. herbaceum* L. or *G. arboreum* L., both known as 'Old World' types (Frisbie et al. 1989). 'New World' cotton types are *G. barbadense* L. and *G. hirsutum*. *G. barbadense*, known as 'Sea Island' cotton, produced a long, silky, highly valuable fiber. *G. barbadense* was grown along the Carolina coast and on nearby off shore islands during the late 1700s. However, *G. hirsutum* would become the choice of cotton growers in the United States, and was first grown as far north as the southern border of Pennsylvania (Frisbie et al. 1989).

Cotton is grown worldwide between 42°N and 33°S latitude. The major cotton-producing countries are China, the former Soviet Union, and the United States, each of which produces more than 1.8 million metric tons annually (Munro 1994). Within the United States, 17 states produce cotton. In 1999, total United States harvested cotton acreage was 5,415,098 hectares valued at $3,836,490,000 (USDA 2000). In 1999, Tennessee harvested 228,647 hectares of cotton (Anonymous 2000).

Cotton grows in a predictable sequence of events. Once planted, the cotton seed germinates within 4 days under optimal growing conditions, but germination can be delayed up to 4 weeks in unfavorable conditions (Tharp 1960). Seed germination is favored by adequate soil moisture, high soil oxygen, and soil temperatures above 18°C (65°F). Germination may be hindered by poor seed quality, drought, flooding, soil crusting, residual herbicide, and cool temperatures (Oosterhuis 1990). Cotton is usually planted between March and May, when temperatures reach about 16°C (61°F) and is harvested between September and November (Munro 1994). In Tennessee, cotton is usually planted between mid to late April and mid May (University of Tennessee Agricultural Extension Service 1999).

After emergence, the cotton seedling has two cotyledonary leaves that unfold. Cotton has two types of branching: monopodial and sympodial. Monopodial branching refers to vegetative branch growth and sympodial branching refers to fruiting branch growth. The first four to six nodes above the cotyledons are vegetative branches. The subsequent nodes produce both fruiting and vegetative branches. A leaf and flower bud develop at each node along each sympodial branch. Three triangular bracts protect the flower bud (known as a 'square'). At dawn, the bud opens as a white flower. Flowers are self-pollinated although some insect pollination may occur. By the next day, the petals turn pink-red and fall unless trapped by the bracts (Oosterhuis 1990). Inside the boll, cotton fibers develop until it cracks open (Munro 1994, Tharp 1960).

Cotton producing states lost 7.66% ($581,456,519) of their cotton yield to insect pests in 1999. In Tennessee, cotton producers lost 9.99% ($34,814,789) of their cotton yield to insects (Williams 2000). Hargreaves (1948) reported 1,326 species of insects occurred on cotton. However, only a small number of these insects are of economic importance (Matthews 1994). Insects that caused the most damage to cotton in Tennessee in 1999 were boll weevil, the bollworm, tobacco budworm, plant bugs, stink bugs, and thrips (Williams 2000).

Thrips are usually the first insects to attack seedling cotton after plant emergence (Newsom et al. 1953, Gaines 1959). It is important to control thrips in cotton because the damage they cause to plants reduces stands, delays fruiting, harvest, and maturity (Hawkins et al. 1966, Watts 1937). Thrips damage cotton seedlings by feeding and destroying leaf tissue resulting in ragged and crinkled leaves. Heavy populations of thrips destroy leaf buds and can cause excessive vegetative branching ('crazy cotton') in the plants (Watson 1965). Also, if thrips are not controlled, the delay in maturity increases the amount of insecticide needed to control the boll weevil (Hawkins et al. 1966, Watts 1937).

The insecticides used in this research can be classified into foliar sprays, in-furrow granules, in-furrow sprays, and seed treatments. A foliar spray is applied in droplets onto the foliage of plants. In-furrow granules and sprays are applied into the furrow along with the seed during planting. A seed treatment is applied directly to the seed before planting.

Seed treatments, foliar sprays, and in-furrow granule insecticide applications have been used to protect cotton seedlings from thrips damage for many years (Beckham 1970, Parencia et al. 1957, Watson 1965). Parencia et al. (1957) identified several advantages to using seed treatments instead of conventional chemical control (dusts and sprays) of early-season cotton insects. After the cotton has achieved a stand, the producer may not have to be concerned with insect control for approximately 60-100 days after planting (Oosterhuis 1990). Use of farm equipment could be shifted to perform other necessary farm operations. Beckham (1970) stated that in-furrow applications of granule insecticides have resulted in less phytotoxicity to plants than when an insecticide was applied as a seed treatment.

Along with insect pests, cotton producers encounter other 'pests' such as weeds. The ten most troublesome weeds of cotton in Tennessee are common cocklebur (*Xanthium strumarium* L.), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), annual morningglories (*Ipomoea* spp.), smooth pigweed (*Amaranthus hybridus* L.), Johnsongrass (*Sorghum halepense* (L.) Pers.), prickly sida (*Sida spinosa* L.), goosegrass (*Eleusine indica* (L.) Gaertn.), spotted spurge (*Euphorbia maculata* L.), nutsedge (*Cyperus* spp.), and, velvetleaf (*Abutilon theophrasti* Mediculis) (Dowler 1998, Weed Science Society of America 2000). Estimated yield losses in Tennessee due to weeds in cotton were $1.4 million in 1994. Tennessee cotton growers spent an estimated $16.4 million on herbicides in 1994 (Dowler 1995).

Weeds may be controlled by tillage and with the use of chemical herbicides. Herbicides can be categorized by the time of their application. Pre-plant incorporated herbicides are usually applied into the soil and incorporated by tillage before the seed is planted. Preemergence herbicides are applied to the soil surface after planting but before emergence of the crop or weed. Post-emergence herbicides are applied after the crop and weeds have emerged (Anderson 1996, Keeley and Thullen 1993).

BXN® refers to the transgenic cotton which uses Buctril® (bromoxynil) herbicide. Roundup Ready® refers to the transgenic cotton which uses Roundup® (glyphosate) herbicide. With the introduction of BXN® (bromoxynil-tolerant) and Roundup Ready® (glyphosate-tolerant) cotton varieties in 1995 and 1997, respectively, weed control in cotton became easier and more efficient for the producer (Welch et al. 1997, Hagedorn 1997). In Tennessee, bromoxynil controls several annual broadleaf weed species such as cocklebur, annual morningglories, lambsquarters (*Chenopodium* spp.), and velvetleaf. Glyphosate controls annual grasses (johnsongrass) and several annual broadleaf weed species, such as cocklebur, pigweed (*Amaranthus* spp.), sicklepod (*Cassia obtusifolia* L.), and copperleaf (*Acalypha* spp.) (University of Tennessee Agricultural Extension Service 2001).

Roundup Ready® cotton contains a gene that makes the plant tolerant to broadcast applications of Roundup®. A gene was inserted into the plant to express the glyphosate tolerant 5-enolpyruvylshikimate-3-phosphate synthase

(EPSP-synthase). Glyphosate binds to the EPSP-synthase, which inhibits the synthesis of the aromatic amino acids tyrosine, phenylalanine, and tryptophan (Nida et al. 1996, Kishore et al. 1992). These are essential to the plant for protein synthesis, cell wall formation, and defense against pathogens and insects and hormone production (Duke 1988). BXN® cotton contains a gene that encodes for a specific nitrilase that changes bromoxynil into 3,5-dibromo-4-hydroxybenzoic acid (Stalker et al. 1988), which makes the cotton plant tolerant to broadcast applications of bromoxynil.

Herbicide-resistant crops have both advantages and disadvantages. One advantage is the weed management options growers have in rotating crops and herbicides. Crop and herbicide rotation may slow the development of herbicide-resistant weeds. Environmentally benign herbicides have several general traits: shorter residual period, which would limit the buildup of herbicide residues in the environment; reduced leaching in the soils, thus preventing the movement of herbicide residues into ground water; low vapor pressure which reduces drift from the application area; a single herbicide could be effective against a broad-spectrum of weeds; and low mammalian toxicity (Burnside 1992).
Disadvantages of herbicide-resistant crops include weed population shifts where weeds may become resistant to a single mode of action of a herbicide, herbicide drift from ground and aerial applications to non-herbicide tolerant crops, and miscommunication with herbicide applicators resulting in the spraying of non-herbicide tolerant crops resulting in severe crop injury or loss (Byrd 1995).

With the relatively new introduction of transgenic cotton varieties, research is needed on the effects of these varieties on early-season insect populations, various cotton plant growth parameters, and any herbicide and insecticide interactions. The objectives of this research were to evaluate insecticides for: (1) efficacy against thrips, (2) effects on cotton growth, development, and yield, and (3) possible interactions with Roundup Ultra®, Buctril®, or conventional herbicides.

Chapter II

GLYPHOSATE-TOLERANT (ROUNDUP READY®) COTTON EVALUATED FOR EFFECTS ON EARLY-SEASON THRIPS (THYSANOPTERA: THRIPIDAE) AND SELECTED COTTON GROWTH PARAMETERS

i. Introduction

Two tillage systems are presently used in cotton: conventional tillage and no-tillage. In a conventional-tillage system, a producer tills the soil to prepare a seed bed into which to plant seed. A main reason for tillage is for weed control. In a no-tillage system, the soil is not disturbed by tillage, with the seed being planted directly into the soil with a no-till planter. Herbicides are used in both tillage systems.

No-tillage has several advantages over conventional tillage. These include reduction in soil erosion; elimination of seed bed preparation; production of cotton on slopes which would not be possible with conventional tillage; improved uptake of both soil water and nutrients by plants; and reduced labor inputs when compared to conventional tillage (Bradley 1992). Other aspects (i.e., insect control) of cotton production are similar for both conventional- and no-tillage systems. Roundup Ready® and BXN® cotton systems can be adapted for either conventional- or no tillage production. A five-year study conducted from 1985 to 1989 investigating conventional- and no-tilled cotton systems reported no significant differences in yield between the tillage systems (Yoo et al. 1995). This current study, however, did not investigate the effects of tillage on insects and plant growth parameters. Objectives of this research were to evaluate several early-season insecticides for: (1) efficacy of against thrips, (2) effects on cotton growth, development, and yield, and (3) for interactions between insecticides and Roundup Ultra® or conventional herbicides.

ii. West Tennessee Experiment Station

a. Materials and Methods

One field study was conducted at the West Tennessee Experiment Station (WTES) in Jackson, TN, and one was conducted at the Milan Experiment Station (MES) in Milan, TN, in 1999 and 2000. Experimental design, treatments, and methodologies for both years at the same location were similar except where noted below. Cotton was planted according to University of Tennessee cotton production recommendations.

1. 1999

Cotton was planted on 14 May 1999 using an International® 900 2-row planter in tilled soil using the Roundup Ready® cotton cultivar Paymaster 1220RR. Treatments were arranged as a split plot design, replicated five times. Two herbicide treatments were main plots and eight insecticide treatments were subplots. The conventional herbicide main-plots received a preemergence application of fluometuron (Cotoran 4L®) at 2.8 liters/ha + metolachlor (Dual 8E®) at 1.8 liters/ha + pendimethalin (Prowl 3.3EC®) at 1.2 liters/ha in a 186 liters/ha broadcast application. Glyphosate (Roundup Ultra®) was applied at 2.3 liters/ha in a 187 liters/ha broadcast application to glyphosate main-plots 24 DAP. The insecticides, rates, and methods of application (MOA) evaluated in 1999 are shown in Table 1. Plots were two rows wide (96.5 cm spacing) by 12.2 m long. Seed treatments were applied to the seed in a slurry of imidacloprid 480F or acephate 90S three days prior to planting. In-furrow sprays were applied at planting in 60.7 liters/ha, 4.8 Kph, and at 138 kPa. Ridomil Gold® [pentachloronitrobenzene (PCNB)] at 9.0 kg/ha was applied to all plots at planting to reduce the incidence of seedling disease. An acephate foliar spray was applied to cotton seedlings at the first true leaf stage on 28 May, 14 days after planting (DAP) at the rate of 132 liters/ha in a 25.4 cm band using a 2-row boom with one nozzle per row.

Adult and larval thrips were sampled beginning 27 May and ending 15 June. Thrips were sampled 13, 17, 21, 27, and 32 DAP. Four plants (2 plants/row) were randomly pulled from each plot, placed into 0.47 liter jars labeled with plot number and containing approximately 150 ml of 70% ethanol. In the laboratory, each plant sample was thoroughly washed with 70% ethanol. The ethanol was poured from the jars and filtered through a standard US Sieve No. 100. Any remaining thrips were rinsed from the jar with ethanol into the

Table 1. Insecticide and herbicide treatments evaluated in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 1999 and 2000).

Insecticide Treatments[1]	**MOA**[2]	**Rate (kg ai**[3]**/ha)**
Imidacloprid 2F	IFS	0.056
Disulfoton 15G	IFG	1.12
Imidacloprid 480F	ST	2.49[4]
Acephate 90S	IFS	1.12
Acephate 90S +	ST	3.99[4]
Acephate 90S	FS	0.22
Aldicarb 15G	IFG	0.56
Phorate 20G	IFG	1.12
Untreated	--	--

[1]Insecticide treatment plus glyphosate (Roundup Ultra®) at 2.3 liters/ha (24 DAP in 1999; 22 DAP in 2000) or conventional herbicide (metolachlor (Dual 8E®) at1.8 liters/ha + pendimethalin (Prowl®) at 1.2 liters/ha + fluometuron (Cotoran®) at 2.8 liters/ha) in a 187 liters/ha broadcast application (at planting).

[2]MOA= Method of Application: IFS= in-furrow spray (Applied in 60.7 liters/ha at 4.8 Kph and 138 kPa); IFG= in-furrow granule; ST= seed treatment; FS= foliar spray (applied in 132 liters/ha in a 25.4 cm band in 1999 and as a 194 liters/ha broadcast application in 2000).

[3]ai= active ingredient.

[4]g ai/kg seed.

sieve and back-rinsed from the sieve through a funnel into 20-ml scintillation vials. More ethanol was added to the vials for storage. A label noting collection date, location, and plot was placed into each vial.

Thrips counts were made as follows. Alcohol was carefully removed from the upper 2/3 of the scintillation vial with a pipette. The remaining contents were poured and rinsed into a petri dish, and thrips were counted with a binocular stereo microscope. The number of larvae and adults were individually recorded. The plants in 3.05 m of row were counted in two rows per plot 17 DAP. Stand counts were made by placing a 3.05-m wooden pole between the rows, counting the number of all healthy plants per 3.05 m in each row and averaging the counts. Stand counts are an indicator of the health of the cotton plants. Thrips feeding damage is a visual assessment of the amount of injury to the plants caused by thrips. Thrips feeding damage to plants was rated 25 DAP using a scale from 1-5, with 1 representing no damage and 5 representing severe damage. Five plants per plot were measured (cm) for plant height 34 DAP and averaged. The 3.05 m wooden pole was marked with five randomly placed marks (6.4 cm, 15.2 cm, 108.6 cm, 134.6 cm, and 287.0 cm) along its length. The plant nearest to each mark was measured.

The amount of total leaf area is an indicator of overall plant health which is a measure of thrips injury to developing leaves and to determine any inhibition of plant growth due to any treatment affect. Leaf area was measured 38 DAP. All true leaves greater than the size of a United States quarter were removed from four plants. The leaf blades were pulled from their petioles, arranged between two plastic sheets, and measured with a Delta T Area Meter (Cambridge, England) attached to an Ikegami® Video screen and to an Ikegami model ITC-410 camera (Ikegami Tsushinki Co. LTD. Japan). The total leaf area for each sample was measured in square centimeters and recorded.

Node of first position square is a measure of plant maturity and was determined on five plants per plot 46 DAP. The same 3.05-m wooden pole used to select plants for plant heights was used to randomly select plants upon which to determine the first fruiting node with a first position square.

Data on blooms were collected to determine if insecticide treatments affected plant maturity. The number of pink and red blooms per 3.05 m of row was counted 61 and 63 DAP. The number of all blooms (white, pink, and red) per 3.05 m of row were counted 66 DAP. The first two bloom counts were summed (61 and 63 DAP). All three bloom counts were summed (61, 63, and 66 DAP). Pink, red, and desiccated blooms on the ground that were within the 3.05 m of row, were pulled from the boll or picked off the ground as they were counted and placed at the end of each plot to avoid being recounted. Plots were harvested 125 and 135 DAP (20 September and 1 October) DAP using a John Deere 9930 2-row spindle picker modified for small plot harvesting.

2. 2000

Cotton was planted on 11 May in tilled soil using the Roundup Ready® cotton cultivar Sure-Grow® 125BR as described for 1999 with the following modifications. The insecticides, rates, and methods of application (MOA) are shown in Table 1. Seed treatments were applied nine days before planting. In-furrow sprays were applied in 60.7 liters/ha at 4.8 Kph, and at 138 kPa. Ridomil Gold® [pentachloronitrobenzene (PCNB)] at 9.0 kg/ha was applied to all plots at planting to prevent seedling disease. Conventional herbicide main plots received a preemergence application of fluometuron 4L at 2.8 liters/ha, metolachlor 8E at 1.8 liters/ha, and pendimethalin 3.3EC at 1.2 liters/ha in a 186 liters/ha broadcast application. Glyphosate was applied to the glyphosate–treated main plots at the rate of 2.3 liters/ha in a 186 liters/ha broadcast application. An acephate 90S foliar spray was applied to cotton seedlings at the first true leaf stage 14 DAP at the rate of 194 liters/ha in a broadcast application. A second acephate 90S foliar spray application was made 19 DAP in the same manner.

Thrips were sampled beginning 24 May and ending 12 June. Thrips were sampled 12, 17, 22, 27, and 32 DAP. The same procedure to sample, process, and count thrips used in 1999 was used in 2000. Stands were counted in 3.05 m of row in each of the two rows 13 DAP. Thrips feeding damage was rated 26 DAP. Plant heights were measured on five plants per plot 28 DAP. The amount of total leaf area was measured 28 DAP. Node of first position square was determined 55 DAP. Blooms were counted 66, 73, and 77 DAP. Plots were harvested 131 and 144 DAP (20 September and 3 October). All data were analyzed using split-plot ANOVA and means separated using Duncan's New Multiple Range Test ($P<0.05$) (SAS Institute 1999). Means in all data tables were averaged across both main plot herbicide treatments.

b. Results

Impact of herbicide on insecticide efficacy was statistically non-significant at both Jackson and Milan in 1999 and 2000. The data that are presented only present impact of insecticide on thrips densities and growth parameters.

1. Insecticide Efficacy on Thrips

1999

The mean number of adult thrips was significantly affected by insecticide treatment on four of five sample dates (Table 2). On 27 May (13 DAP), 31 May (17 DAP), and 10 June (27 DAP) population densities of adult thrips on all insecticide-treated plants were significantly lower than on untreated plants. On 31 May (17 DAP) and 10 June (27 DAP), no significant differences were detected among insecticide treatments. Densities of adult thrips were not significantly different between treated and untreated plots on 4 June (21 DAP). By 15 June (32 DAP), only disulfoton-, acephate, aldicarb-, and phorate-treated plots were significantly reducing adult thrips populations when compared to untreated plants.

Table 2. Effects of early-season insecticides on the number of adult thrips in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of adult thrips/4 plants				
			27 May	31 May	4 June	10 June	15 June
Imidacloprid 2F	IFS	0.056	3.2 bc[4]	0.8 b	0.6 a	0.3 b	4.7 abc
Disulfoton 15G	IFG	1.12	4.4 b	1.1 b	0.7 a	0.2 b	3.7 bcd
Imidacloprid 480F	ST	2.49[3]	2.9 bcd	0.6 b	0.4 a	0.5 b	5.5 ab
Acephate 90S	IFS	1.12	1.8 cd	0.3 b	1.1 a	0.5 b	3.6 bcd
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	1.12	3.6 bc	0.0 b	0.1 a	0.3 b	4.0 abcd
Aldicarb 15G	IFG	0.56	0.9 d	0.3 b	0.4 a	0.1 b	3.0 cd
Phorate 20G	IFG	1.12	3.4 bc	0.7 b	0.7 a	0.1 b	2.2 d
Untreated	--	--	9.0 a	2.7 a	1.1 a	1.4 a	5.9 a

[1]MOA= Method of Application: IFS= in-furrow spray; IFG= in-furrow granule; ST= seed treatment; FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Larval thrips were significantly affected by insecticide treatment on three of five sample dates (Table 3). On 31 May (17 DAP), 4 June (21 DAP), and 10 June (27 DAP), insecticide-treated plants had significantly fewer thrips than untreated plants; however no significant differences among treatments were observed. On 27 May (13 DAP) and 15 June (32 DAP), no significant differences in densities of larval thrips were found.

2000

The mean number of adult thrips was significantly affected by treatment on all five sampling dates (Table 4). On 24 May (13 DAP), plants treated with disulfoton, imidacloprid ST, acephate, acephate +acephate, aldicarb, and phorate had significantly lower numbers of adult thrips than untreated plants. By 29 May (18 DAP), adult thrips populations were significantly lower in insecticide-treated plots than in untreated plots. On 2 June (22 DAP), plants treated with acephate, acephate+acephate, aldicarb, and phorate had significantly fewer thrips than imidacloprid IFS-treated and untreated plants. Disulfoton- and imidacloprid ST-treated plants had significantly fewer thrips than imidacloprid IFS-treated plants but were not different from untreated plants. By 7 June (27 DAP), acephate+acephate was the only treatment that had significantly fewer thrips than untreated plants. On the last sampling date, 13 June (32 DAP), adult thrips populations were significantly greater in untreated plots than in any insecticide-

Table 3. Effects of early-season insecticides on the number of larval thrips in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of larval thrips/4 plants				
			27 May	31 May	4 June	10 June	15 June
Imidacloprid 2F	IFS	0.056	0.0 a	0.0 b[4]	2.8 b	0.9 b	0.8 a
Disulfoton 15G	IFG	1.12	0.0 a	0.3 b	0.9 b	0.4 b	0.7 a
Imidacloprid 480F	ST	2.49[3]	0.0 a	0.1 b	1.2 b	0.5 b	1.3 a
Acephate 90S	IFS	1.12	0.0 a	0.0 b	0.5 b	0.9 b	1.0 a
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	1.12	0.0 a	0.1 b	0.1 b	0.4 b	0.2 a
Aldicarb 15G	IFG	0.56	0.0 a	0.0 b	0.3 b	0.3 b	0.6 a
Phorate 20G	IFG	1.12	0.1 a	0.0 b	0.4 b	0.3 b	0.3 a
Untreated	--	--	0.1 a	4.0 a	18.1 a	8.6 a	1.0 a

[1]MOA= Method of Application: IFS= in-furrow spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 4. Effects of early-season insecticides on the number of adult thrips in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of adult thrips/4 plants				
			24 May	29 May	2 June	7 June	13 June
Imidacloprid 2F	IFS	0.056	6.1 ab[4]	4.1 b	3.6 a	5.1 a	2.8 b
Disulfoton 15G	IFG	1.12	4.1 bc	3.4 bc	1.4 bc	3.0 bc	1.4 b
Imidacloprid 480F	ST	2.49[3]	3.8 bcd	2.1 cde	1.4 bc	5.4 a	2.4 b
Acephate 90S	IFS	1.12	0.4 e	0.9 de	0.6 c	2.8 bc	1.2 b
Acephate 90S+	ST	3.99[3]					
Acephate 90S	FS	0.22	2.5 cde	1.9 cde	0.6 c	1.8 c	1.5 b
Aldicarb 15G	IFG	0.56	0.6 de	0.8 e	0.3 c	1.9 bc	1.1 b
Phorate 20G	IFG	1.12	1.9 cde	2.6 bcd	0.7 c	2.6 bc	1.5 b
Untreated	--	--	9.0 a	6.9 a	2.7 ab	3.9 ab	7.6 a

[1]MOA= Method of Application: IFS= in-furrow spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

treated plots; however, densities were not significantly different among insecticide-treatments.

The mean number of larval thrips was affected by insecticide treatment on four of five sample dates (Table 5). Densities of larval thrips were greater on untreated plants than on any insecticide-treated plants on the last four sample dates. Numbers of larval thrips on 29 May (18 DAP) were significantly greater on imidacloprid IFS-treated plants than on any other insecticide-treated plants. By 2 June (22 DAP), densities of larval thrips on acephate-treated plants were significantly lower than densities on imidacloprid IFS-treated plants, but not different from densities on other insecticide-treated plants. On 7 June (27 DAP), imidacloprid IFS- and imidacloprid ST-treated plants had significantly greater densities of thrips than plants treated with other insecticides. On 13 June (32 DAP), imidacloprid IFS- and imidacloprid ST-treated plants had significantly greater numbers of larval thrips than other treated plants.

2. Insecticide Effects on Plant Parameters

1999

All treated plants had significantly less thrips feeding damage than non-insecticide-treated plants (Table 6). Acephate- and aldicarb-treated plants had significantly less thrips feeding damage than other insecticide-treated and untreated plants. Stand densities and plant heights were not affected by insecticide treatment (Table 6). All insecticide-treated plants had significantly

Table 5. Effects of early-season insecticides on the number of larval thrips in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	24 May	Mean number of larval thrips/4 plants 29 May	2 June	7 June	13 June
Imidacloprid 2F	IFS	0.056	0.0 a	5.4 b[4]	17.2 b	10.7 c	10.6 b
Disulfoton 15G	IFG	1.12	0.1 a	2.5 c	4.4 bc	4.9 d	3.0 c
Imidacloprid 480F	ST	2.49[3]	0.0 a	1.5 c	5.6 bc	16.0 b	13.6 b
Acephate 90S	IFS	1.12	0.0 a	0.8 c	0.5 c	1.4 d	1.3 c
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	0.22	0.0 a	1.7 c	3.0 bc	2.0 d	2.6 c
Aldicarb 15G	IFG	0.56	0.0 a	1.1 c	1.5 bc	1.4 d	3.7 c
Phorate 20G	IFG	1.12	0.0 a	1.1 c	3.5 bc	2.0 d	2.0 c
Untreated	--	--	0.2 a	32.2 a	64.5 a	44.6 a	20.2 a

[1]MOA= Method of Application: IFS= in-furrow-spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 6. Insecticides and rates evaluated for impact on thrips feeding damage and cotton growth parameters in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Thrips damage rating	Mean number of plants/3.05 m of row	Mean plant heights (cm)/5 plants	Mean leaf area (cm^2)/4 plants	Mean node of FPS[5]/ 5 plants
Imidacloprid 2F	IFS	0.056	2.7 bc[4]	28.0 a	31.1 a	1299.2 ab	5.3 b
Disulfoton 15G	IFG	1.12	3.0 b	28.4 a	29.6 a	1108.9 b	5.8 ab
Imidacloprid 480F	ST	2.49[3]	2.7 bc	26.9 a	30.6 a	1336.4 a	5.5 b
Acephate 90S	IFS	1.12	2.1 d	27.5 a	30.7 a	1185.4 ab	5.8 ab
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	0.22	2.6 c	27.5 a	30.8 a	1242.8 ab	5.5 b
Aldicarb 15G	IFG	0.56	1.8 d	28.7 a	31.7 a	1182.0 ab	5.4 b
Phorate 20G	IFG	1.12	2.9 bc	28.3 a	31.3 a	1233.6 ab	6.1 a
Untreated	--	--	3.9 a	27.5 a	29.8 a	925.7 c	5.3 b

[1]MOA= Method of Application: IFS= in-furrow spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg of seed.
[4]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).
[5]FPS= First Position Square.

greater leaf area than untreated plants (Table 6). However, only disulfoton - and imidacloprid ST-treated plants differed from each other, while no differences occurred among other treated plants. The node of first position square was significantly higher on phorate-treated plants than on untreated or imidacloprid IFS-, imidacloprid ST-, acephate+acephate-, and aldicarb-treated plants (Table 6).

On 14 July (61 DAP), most insecticide-treated plants had significantly fewer blooms than untreated plants; however, no difference was found between imidacloprid IFS-treated and untreated plants (Table 7). By the second sampling date, 16 July (63 DAP), only phorate-treated plants had fewer blooms than untreated plants. Disulfoton-, acephate-, and phorate-treated plants had significantly fewer blooms than untreated plants once the 14 July and 16 July counts were summed. On the third bloom count (19 July, 66 DAP), both acephate+acephate- and phorate-treated plants had fewer blooms than untreated plants. Imidacloprid IFS-treated plants had more blooms than all treatments except disulfoton-treated and untreated plants. After summing all three bloom counts, disulfoton-, acephate-, acephate+acephate-, and phorate-treated plants were the only treatments that had significantly fewer blooms than untreated plants.

Imidacloprid IFS- and aldicarb-treated plots had significantly higher first harvest lint yields than untreated plots (Table 8). Phorate-treated plots had yields significantly lower than imidacloprid IFS-, disulfoton-, imidacloprid ST,

Table 7. Insecticides and rates evaluated for impact on bloom production in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

		Rate	Mean number of blooms/3.05 m of row				
Treatment	**MOA[1]**	**(kg ai[2]/ha)**	**14 July**	**16 July**	**Total (2)**	**19 July**	**Total (3)**
Imidacloprid 2F	IFS	0.056	17.9 ab[4]	7.5 a	25.4 ab	15.1 a	40.5 a
Disulfoton 15G	IFG	1.12	10.7 c	6.2 ab	16.9 bc	11.8 abc	28.7 c
Imidacloprid 480F	ST	2.49[3]	11.4 bc	8.4 a	19.8 abc	11.2 bc	31.0 abc
Acephate 90S	IFS	1.12	9.9 c	4.7 b	14.6 c	9.9 bc	24.5 c
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	0.22	10.8 c	8.1 a	18.9 abc	8.6 c	27.5 c
Aldicarb 15G	IFG	0.56	12.4 bc	6.3 ab	18.7 abc	10.9 bc	29.6 bc
Phorate 20G	IFG	1.12	3.1 d	1.9 c	5.0 d	5.2 d	10.2 d
Untreated	--	--	20.0 a	5.9 ab	25.9 a	13.2 ab	39.1 ab

[1]MOA= Method of Application: IFS= in-furrow spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/ kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 8. Insecticides and rates evaluated for impact on lint yield of Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Lint 1[4]	Lint 2	Total Yield
Imidacloprid 2F	IFS	0.056	511 ab[5]	115 c	626 a
Disulfoton 15G	IFG	1.12	499 abc	144 b	643 a
Imidacloprid 480F	ST	2.49[3]	499 abc	118 c	617 a
Acephate 90S	IFS	1.12	464 bcd	130 bc	594 a
Acephate 90S +	ST	3.99[3]			
Acephate 90S	FS	0.22	493 abc	131 bc	623 a
Aldicarb 15G	IFG	0.56	514 a	120 bc	634 a
Phorate 20G	IFG	1.12	442 d	168 a	610 a
Untreated	--	--	459 cd	120 bc	579 a

[1]MOA= Method of Application: IFS= in-furrow spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]kg/ha.
[5]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

acephate+acephate-, and aldicarb-treated plots. By second harvest, lint yields from phorate-treated plots were significantly greater than both treated and untreated plots. No differences in total yields occurred among treated and untreated plots.

2000

All insecticide-treated plants had significantly less feeding damage than untreated plants (Table 9). Acephate-treated plants had the least amount of feeding damage with aldicarb-treated plants having the next least amount of injury. Of the treated plants, imidacloprid IFS-, disulfoton-, and phorate-treated plants had the most feeding injury. Stand densities were significantly less among imidacloprid ST- and acephate+acephate-treated plants than in all other treated and untreated plots (Table 9). Plant heights were not significantly affected by insecticide treatments (Table 9). All treated plants had significantly more leaf area than untreated plants, but no differences occurred among treated plants (Table 9). Insecticide had no significant effect on node of first position square (Table 9).

Significant differences occurred on all bloom count dates and totals for treated plants and untreated plants (Table 10). On 17 July (66 DAP), aldicarb-treated plants had a significantly higher number of blooms than all other plants; however, phorate-treated plants had significantly fewer blooms than imidacloprid IFS-, imidacloprid ST-, acephate+acephate-, aldicarb-treated and untreated plants. Seven days later, phorate-treated plants had significantly fewer blooms

Table 9. Insecticides and rates evaluated for impact on thrips feeding damage and cotton growth parameters in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Thrips damage rating	Mean number of plants/ 3.05 m of row	Mean plant heights (cm)/5 plants	Mean leaf area (cm^2)/4 plants	Mean node of FPS[5]/ 5 plants
Imidacloprid 2F	IFS	0.056	2.7 b[4]	44.4 a	11.3 a	192.84 a	6.9 a
Disulfoton 15G	IFG	1.12	2.5 bc	45.9 a	12.4 a	212.10 a	6.8 a
Imidacloprid 480F	ST	2.49[3]	2.3 cd	39.1 b	11.5 a	195.63 a	6.4 a
Acephate 90S	IFS	1.12	1.3 f	44.2 a	12.1 a	249.31 a	6.5 a
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	0.22	2.1 d	37.3 b	11.1 a	228.56 a	6.6 a
Aldicarb 15G	IFG	0.56	1.7 e	44.3 a	11.9 a	232.66 a	6.1 a
Phorate 20G	IFG	1.12	2.6 b	44.2 a	12.3 a	195.79 a	6.8 a
Untreated	--	--	3.8 a	44.7 a	11.2 a	117.76 b	6.8 a

[1]MOA= Method of Application: IFS=in-furrow spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg/seed.
[4]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).
[5]FPS= First Position Square.

Table 10. Insecticides and rates evaluated for impact on bloom production in Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of blooms/3.05 m of row 17 July	24 July	Total (2)	28 July	Total (3)
Imidacloprid 2F	IFS	0.056	6.7 b[4]	28.3 a	35.0 ab	73.1 a	108.1 ab
Disulfoton 15G	IFG	1.12	4.4 bc	22.2 a	26.6 b	72.9 a	99.5 ab
Imidacloprid 480F	ST	2.49[3]	5.1 b	25.7 a	30.8 ab	72.7 a	103.5 ab
Acephate 90S	IFS	1.12	3.4 bc	22.6 a	26.0 b	62.9 ab	88.9 b
Acephate 90S +	ST	3.99[3]	5.9 b	22.1 a	28.0 b	70.8 a	98.8 ab
Acephate 90S	FS	0.22					
Aldicarb 15G	IFG	0.56	10.4 a	28.5 a	38.9 a	73.8 a	112.7 a
Phorate 20G	IFG	1.12	1.1 c	14.4 b	15.5 c	54.5 b	70.0 c
Untreated	--	--	5.1 b	26.3 a	31.4 ab	65.6 ab	97.0 ab

[1]MOA= Method of Application: IFS= in-furrow spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/ kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

than other treated plants and untreated plants. By totaling bloom counts one and two, once again phorate-treated plants had significantly fewer blooms than other treated plants. By 28 July (73 DAP), no significant differences occurred between treated and untreated plants. By totaling all three counts, aldicarb-treated plants had significantly more total blooms than either acephate- or phorate-treated plants; however, phorate-treated plants had significantly fewer total blooms than any other treated or untreated plants.

Plots treated with imidacloprid IFS, disulfoton, acephate+acephate, and aldicarb had significantly higher first harvest yields than either phorate-treated or untreated plots (Table 11). By second harvest, phorate-treated plots had higher yields than all other treated and untreated plots. Imidacloprid IFS-, disulfoton-, acephate+acephate-, and aldicarb-treated plots had significantly higher total lint yields than untreated plots.

iii. Milan Experiment Station

a. Materials and Methods

1. 1999

This study was conducted at the Milan Experiment Station, Milan, TN. Experimental design, treatments, and methodologies for both years were similar except where noted below. The Roundup Ready® cotton cultivar Paymaster 1220RR was planted 12 May with a John Deere® 7100 planter using no-till practices. Plots were four rows wide (101.6 cm spacing) by 9.1 m long. All data

Table 11. Insecticides and rates evaluated for impact on lint yield of Roundup Ready® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Lint 1[4]	Lint 2	Total Yield
Imidacloprid 2F	IFS	0.056	958 ab[5]	112 cd	1070 a
Disulfoton 15G	IFG	1.12	952 ab	124 bcd	1076 ab
Imidacloprid 480F	ST	2.49[3]	915 abc	110 d	1025 abc
Acephate 90S	IFS	1.12	865 bc	131 bc	996 bc
Acephate 90S +	ST	3.99[3]			
Acephate 90S	FS	0.22	940 ab	135 b	1075 ab
Aldicarb 15G	IFG	0.56	1005 a	118 bcd	1123 a
Phorate 20G	IFG	1.12	819 c	164 a	983 bc
Untreated	--	--	836 c	121 bcd	957 c

[1]MOA= Method of Application: IFS= in-furrow spray; IFG= in-furrow granule; ST= seed treatment; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]kg/ha.
[5]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

were collected from the two center rows. Treatments were arranged in a split plot design and replicated five times. Two herbicide treatments were the main plots and seven insecticide treatments were the subplots. The insecticides, rates, and methods of application (MOA) evaluated in 1999 are shown in Table 12. Because of no-till practices, all plots received a burndown application of glyphosate at 2.3 liters/ha 34 days before planting (8 April) to remove existing weeds. At planting, all plots received an in-furrow application of Terraclor Super X ® 18.8G [pentachloronitrobenzene (PCNB)] at the rate of 6.2 kg/ha to reduce the incidence of seedling disease. All plots received another burndown application of glyphosate at 1.8 liters/ha to remove any existing weeds. Conventional herbicide plots received a preemergence application of fluometuron (Cotoran 4L®) at 1.7 kg ai/ha plus pendimethalin (Prowl 3.3EC®) at 2.8 liters/ha. Glyphosate was applied as a post-directed application to glyphosate plots at 1.8 liters/ha in a 93.3 liters/ha broadcast application on 23 June (42 DAP) and 7 July (56 DAP). Seed treatments were applied to seed in a slurry of imidacloprid 480F or acephate 90S one day before planting. In-furrow sprays were applied at planting at the rate of 60.7 liters/ha, 4.8 Kph, and at 138 kPa. Foliar sprays were applied 13 DAP at a rate of 132 liters/ha, 4.8 Kph, and at 276 kPa in a 25.4 cm band using a 2-row boom with one nozzle per row. Adult and larval thrips were sampled and counted 25 May (13 DAP), 31 May (19 DAP), 4 June (23 DAP), 9 June (28 DAP), and 15 June (34 DAP). Stand counts were taken in the two

Table 12. Insecticide and herbicide treatments evaluated in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 1999 and 2000).

Insecticide Treatments[1]	**MOA**[2]	**Rate (kg ai**[3]**/ha)**
Disulfoton 15G	IFG	1.12
Imidacloprid 480F	ST	2.49[4]
Acephate 90S	IFS	1.12
Acephate 90S +	ST	3.99[4]
Acephate 90S	FS	0.22
Aldicarb 15G	IFG	0.56
Phorate 20G	IFG	1.12
Untreated	--	--

[1]Insecticide treatments plus glyphosate (Roundup Ultra ®) at the rate of 1.8 liters/ha (42 and 56 DAP in 1999; 42 DAP in 2000) or conventional herbicide fluometuron (Cotoran 4L®) at 1.7 kg ai/ha plus pendimethalin (Prowl 3.3EC®) at 2.8 liters/ha (applied at planting).
[2]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray (rate of 32.7 liters/ha, 4.8 Kph, 138 kPa); FS= foliar spray (at a rate of 132 liters/ha in a 25.4 cm band in 1999 and as a 194 liters/ha broadcast application in 2000).
[3]ai= active ingredient.
[4]g ai/kg seed.

center rows at 19 DAP. Thrips damage ratings were made 27 DAP. Plant heights were measured on 5 plants per plot on 18 June (36 DAP). Four plants per plot were collected and leaf area measured 39 DAP. Node of first position square was taken on 5 plants per plot 45 DAP. Blooms were counted in 3.05 m of one row 59, 61, and 64 DAP. Plots were harvested 161 and 169 DAP (4 October and 12 October 1999) using a John Deere® 9930 2-row spindle picker modified for plot harvesting.

2. 2000

Cotton was planted on 12 May using no-till practices using the cultivar Sure Grow ® 125BR as described in 1999 with the following modifications. All plots received a burndown application of sulfonium at a rate of 1.9 liters/ha in a 93.3 liters/ha broadcast application 23 days before planting (19 April). Conventional herbicide plots received an at-planting, preemergence broadcast application of fluometuron (Cotoran 4L®) at 1.7 liters/ha + pendimethalin (Prowl 3.3EC®) at 2.8 liters/ha + paraquat dichloride salt (Gramoxone®) at 1.2 liters/ha. Glyphosate was applied at 1.8 liters/ha in a 93.3 liters/ha broadcast application on 22 June (42 DAP) to the glyphosate plots. Plots were four rows wide (101.6 cm spacing) by 9.1 m long. All data were collected from the two center rows. Insecticides, rates, and methods of application (MOA) evaluated in 2000 are shown in Table 12. Seed treatments were applied to seed in a slurry of imidacloprid 480F or acephate 90S ten days before planting. In-furrow sprays were applied at planting at the rate of 42.0 liters/ha, 4.8 Kph, and at 138 kPa. Foliar sprays were applied 15 and 20 DAP as a 194 liters/ha broadcast application. Thrips were sampled 26 May (14 DAP), 31 May (19 DAP), 6 June (25 DAP), and 12 June (31 DAP). Data on stand counts (19 DAP), thrips damage rating (25 DAP), plant heights (31 DAP), leaf area (25 DAP), node of first position square (59 DAP), and blooms (68, 73, and 80 DAP) were all collected as described in 1999. Plots were harvested 129 and 145 DAP (18 September and 3 October). All data were analyzed using split plot Analysis of Variance (ANOVA) and means were separated using Duncan's New Multiple Range Test ($P<0.05$).

b. Results

1. Insecticide Efficacy on Thrips Control

1999

Significant differences in the mean numbers of adult thrips were observed on three of five sample dates (Table 13). On 25 May (13 DAP), densities of adult thrips were significantly greater on imidacloprid ST-treated plants than on other treated or untreated plants. On 31 May (19 DAP), all insecticide-treated plants had significantly fewer thrips than untreated plants, but no significant differences among treated plants were found. On 4 June (23 DAP) and 9 June (28 DAP), no significant differences among treated and untreated plants were noted. By 15 June (34 DAP), adult thrips densities were significantly greater on imidacloprid

Table 13. Effects of early-season insecticides evaluated on the number of adult thrips in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 1999).

		Rate	Mean number of adult thrips/4 plants				
Treatment	**MOA[1]**	**(kg ai[2]/ ha)**	**25 May**	**31 May**	**4 June**	**9 June**	**15 June**
Disulfoton 15G	IFG	1.12	6.6 bc[4]	1.4 b	21.0 a	12.0 a	10.8 b
Imidacloprid 480F	ST	2.49[3]	19.1 a	1.9 b	18.0 a	13.9 a	17.6 a
Acephate 90S	IFS	1.12	5.8 bc	1.3 b	21.8 a	13.3 a	13.0 ab
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	0.22	9.2 b	0.9 b	17.6 a	12.0 a	12.6 ab
Aldicarb 15G	IFG	0.56	4.6 c	1.4 b	15.9 a	10.4 a	14.2 ab
Phorate 20G	IFG	1.12	7.5 bc	1.3 b	17.0 a	10.3 a	12.9 ab
Untreated	--	--	8.4 bc	4.0 a	20.9 a	11.8 a	15.5 ab

[1]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray; FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

ST-treated plants than on disulfoton-treated plants, but no significant differences were observed among other treatments.

Significant differences in the mean number of larval thrips on four of five sample dates (Table 14) were observed. On 31 May (19 DAP) and 15 June (34 DAP), all insecticide-treated plants had significantly fewer thrips than untreated plants, but with no differences among treatments.

On 4 June (23 DAP), all insecticide treatments significantly reduced populations of larval thrips. Imidacloprid ST- and phorate-treated plants had lower densities than acephate- and aldicarb-treated plants, but no significant differences among other treatments were observed. On 9 June (28 DAP), imidacloprid ST-treated plants had significantly lower larval thrips densities than plants treated with acephate+acephate or aldicarb. However, disulfoton-, acephate-, and phorate-treated plants did not significantly differ from each other in the number of larval thrips but had lower densities than untreated plants. On 15 June (34 DAP), all insecticide treatments significantly lowered larval thrips densities when compared to untreated plants, but no differences among treated plants were observed.

2000

Densities of adult thrips were significantly affected on all four sampling dates (Table 15). On 26 May (14 DAP), aldicarb-treated plants had significantly fewer adult thrips than imidacloprid-, acephate-, phorate-treated and untreated

Table 14. Effects of early-season thrips insecticides evaluated on larval thrips in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ ha)	Mean number of larval thrips/4 plants: 25 May	31 May	4 June	9 June	15 June
Disulfoton 15G	IFG	1.12	0.3 a	1.1 b[4]	14.6 cd	16.8 bc	16.2 b
Imidacloprid 480F ST[1]	ST	2.49[3]	0.3 a	0.2 b	3.9 d	9.8 c	17.9 b
Acephate 90S IFS[2]	IFS	1.12	0.3 a	1.2 b	27.6 b	25.3 b	26.9 b
Acephate 90S ST[1] +	ST	3.99[3]					
Acephate 90S FS[3]	FS	0.22	0.4 a	0.3 b	13.0 cd	18.0 bc	23.3 b
Aldicarb 15G	IFG	0.56	0.5 a	0.9 b	18.3 bc	27.8 b	29.2 b
Phorate 20G	IFG	1.12	0.5 a	0.5 b	5.5 d	15.5 bc	12.2 b
Untreated	--	--	0.9 a	9.9 a	65.6 a	68.7 a	60.1 a

[1]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 15. Effects of early-season insecticides evaluated on the number of adult thrips in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 2000).

		Rate	Mean number of adult thrips/4 plants			
Treatment	**MOA[1]**	**(kg ai[2]/ ha)**	**26 May**	**31 May**	**6 June**	**12 June**
Disulfoton 15G	IFG	1.12	12.4 bc[4]	7.5 abc	7.5 ab	12.3 ab
Imidacloprid 480F	ST	2.49[3]	21.4 a	10.6 a	12.7 a	14.5 a
Acephate 90S	IFS	1.12	15.8 ab	8.2 abc	8.7 ab	10.8 ab
Acephate 90S +	ST	3.99[3]				
Acephate 90S	FS	0.22	12.3 bc	5.6 bc	8.0 ab	6.8 b
Aldicarb 15G	IFG	0.56	7.9 c	3.7 c	6.4 b	7.1 b
Phorate 20G	IFG	1.12	14.3 b	7.8 abc	9.6 ab	9.8 ab
Untreated	--	--	16.1 ab	8.9 ab	6.9 b	7.9 ab

[1]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

plants. On 31 May (19 DAP), aldicarb-treated plants had significantly fewer adult thrips than imidacloprid ST-treated plants.

On 6 June (25 DAP), aldicarb-treated plants had fewer thrips than imidacloprid ST-treated plants, but no significant differences among all other treated and untreated plants were observed. On 12 June (31 DAP), acephate+acephate- and aldicarb-treated plants had significantly fewer thrips than imidacloprid ST-treated plants, but were not significantly different from other insecticide treatments or no treatment.

The mean numbers of larval thrips were significantly different among treatments on all sample dates (Table 16). On 26 May (14 DAP) and 31 May (19 DAP), populations of larval thrips were not significantly different among insecticide treatments, but were significantly different from no insecticide treatment. On 6 June (25 DAP), all insecticide-treated plants, except acephate-treated plants, had fewer larval thrips than untreated plants. On 12 June (31 DAP), only imidacloprid ST- and acephate+acephate-treated plants had significantly fewer larval thrips than untreated plants.

2. Insecticide Effects on Plant Parameters

1999

All treated plants had less feeding injury than untreated plants (Table 17). Imidacloprid ST-treated plants had significantly less feeding damage than any other treatment. Stand densities were not significantly affected by chemical

Table 16. Effects of early-season insecticides evaluated on larval thrips in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ ha)	Mean number of larval thrips/4 plants 26 May	31 May	6 June	12 June
Disulfoton 15G	IFG	1.12	1.0 b[4]	4.3 b	7.0 b	20.1 bcd
Imidacloprid 480F	ST	2.49[3]	0.4 b	1.7 b	11.0 b	11.6 cd
Acephate 90S	IFS	1.12	1.5 b	6.2 b	19.1 a	34.3 a
Acephate 90S +	ST	3.99[3]				
Acephate 90S	FS	0.22	1.6 b	5.4 b	2.6 b	8.0 d
Aldicarb 15G	IFG	0.56	0.6 b	3.6 b	4.6 b	20.7 bc
Phorate 20G	IFG	1.12	1.6 b	3.2 b	6.6 b	19.5 bcd
Untreated	--	--	5.5 a	20.5 a	22.0 a	30.7 ab

[1]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 17. Insecticides and rates evaluated for impact on thrips feeding damage and cotton growth parameters in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Thrips damage rating	Mean number of plants/3.05 m of row	Mean plant heights (cm)/5 plants	Mean leaf area (cm^2)/4 plants	Mean node of FPS[5]/5 plants
Disulfoton 15G	IFG	1.12	3.1 bc[4]	15.2 a	20.9 a	512.0 abc	5.5 b
Imidacloprid 480F	ST	2.49[3]	2.2 d	15.8 a	19.9 ab	617.5 a	5.4 bc
Acephate 90S	IFS	1.12	3.1 b	16.8 a	18.8 bc	441.9 bc	5.7 b
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	0.22	3.1 bc	16.8 a	18.9 b	499.7 abc	5.5 bc
Aldicarb 15G	IFG	0.56	2.9 bc	13.5 a	21.3 a	497.8 abc	5.4 bc
Phorate 20G	IFG	1.12	2.8 c	15.8 a	19.3 b	558.0 ab	6.4 a
Untreated	--	--	3.9 a	15.3 a	17.6 c	399.9 c	5.1 c

[1]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray: and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).
[5]FPS= First Position Square.

treatment (Table 17). Heights of plants treated with acephate were not significantly different from untreated plants while all other treated plants were significantly taller than untreated plants (Table 17). Imidacloprid ST- and phorate-treated plants had significantly more leaf area than untreated plants (Table 17). Imidacloprid ST-treated plants had significantly more leaf area than acephate-treated plants. None of the remaining treatments differed from each other.

Plants treated with disulfoton, acephate, and phorate had significantly higher nodes of first position square than untreated plants (Table 17). Insecticide treatments did not have any significant effect on bloom production on first, second, and the total from first and second counts (Table 18). By the third bloom count (19 July), plants treated with acephate, acephate+acephate, and phorate had significantly fewer blooms than imidacloprid ST-treated plants. However, none of the chemical treatments was significantly different from no treatment. When all three counts were summed, only disulfoton-, imidacloprid ST-, and aldicarb-treated plants had more blooms than phorate-treated plants. However, none of the other chemical treatments was significantly different from no treatment. All treated plots had higher first harvest and total yields than untreated plots (Table 19); however, no significant differences occurred in second harvest yields among treated and untreated plots.

Table 18. Insecticides and rates evaluated for impact on bloom production in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 1999).

		Rate	Mean number of blooms/3.05 m of row				
Treatment	MOA[1]	(kg ai[2]/ha)	14 July	16 July	Total (2)	19 July	Total (3)
Disulfoton 15G	IFG	1.12	1.1 a	1.5 a	2.6 a	5.1 abc[4]	7.7 abc
Imidacloprid 480F	ST	2.49[3]	1.2 a	1.5 a	2.7 a	6.7 a	9.4 a
Acephate 90S	IFS	1.12	1.4 a	0.7 a	2.1 a	2.4 c	4.5 cd
Acephate 90S+	ST	3.99[3]					
Acephate 90S	FS	0.22	0.8 a	0.7 a	1.5 a	3.5 bc	5.0 bcd
Aldicarb 15G	IFG	0.56	0.8 a	1.5 a	2.3 a	6.3 ab	8.6 ab
Phorate 20G	IFG	1.12	0.9 a	0.4 a	1.3 a	2.0 c	3.3 d
Untreated	--	--	1.6 a	0.8 a	2.4 a	4.5 abc	6.9 abcd

[1]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 19. Insecticides and rates evaluated for impact on lint yield Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Lint 1[4]	Lint 2	Total Yield
Disulfoton 15G	IFG	1.12	844 a[5]	105 a	949 a
Imidacloprid 480F	ST	2.49[3]	853 a	89 a	942 a
Acephate 90S	IFS	1.12	851 a	110 a	961 a
Acephate 90S+	ST	3.99[3]			
Acephate 90S	FS	0.22	852 a	118 a	970 a
Aldicarb 15G	IFG	0.56	873 a	119 a	992 a
Phorate 20G	IFG	1.12	891 a	104 a	995 a
Untreated	--	--	652 b	116 a	768 b

[1]MOA= Method of Application: IFG= in-furrow granule; ST=seed treatment; IFS= in-furrow spray; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]kg/ha.
[5]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

2000

All insecticide treatments had significantly less thrips feeding injury than untreated plants (Table 20). Imidacloprid ST-treated plants had significantly lower damage ratings than any other insecticide treatment. Stand densities were not significantly affected by insecticide treatment (Table 20). Only plants treated with disulfoton were significantly taller than acephate-treated and untreated plants (Table 20), while no other significant differences were found among treatments. Plants treated with imidacloprid ST, acephate, and aldicarb had significantly more leaf area than untreated plants (Table 20). Imidacloprid ST-treated plants had significantly more leaf area than acephate+acephate-treated plants. Plants treated with phorate had a significantly higher node of first position square than all treatments, with the exception of aldicarb-treated plants (Table 20). On 19 July, only plants treated with aldicarb had significantly more blooms than all other treated and untreated plants (Table 21). No significant differences among treatments were observed on the second, third, and total bloom counts. When first and second counts were summed, only aldicarb-treated plants had significantly more blooms than phorate-treated plants; however, no insecticide treatment was significantly different from untreated plants.

By first harvest, only disulfoton-, imidacloprid ST- and aldicarb-treated plots had higher yields than either phorate-treated or untreated plots (Table 22). At second and total harvest, there were no significant differences among insecticide-treated and untreated plants.

Table 20. Insecticides and rates evaluated for impact on thrips feeding damage and cotton growth parameters in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 2000).

Treatment	**MOA[1]**	**Rate (kg ai[2]/ha)**	**Thrips damage rating**	**Mean number of plants/3.05 m of row**	**Mean plant heights (cm)/5 plants**	**Mean leaf area (cm^2)/4 plants**	**Mean Node of FPS[5]/5 plants**
Disulfoton 15G	IFG	1.12	2.9 b[4]	28.0 a	17.5 a	165.9 abc	5.4 c
Imidacloprid 480F	ST	2.49[3]	1.9 d	29.8 a	15.9 ab	196.8 a	5.7 bc
Acephate 90S	IFS	1.12	3.0 c	28.6 a	13.3 b	167.2 ab	5.8 bc
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	0.22	2.7 bc	26.0 a	15.0 ab	156.1 bc	6.0 bc
Aldicarb 15G	IFG	0.56	2.5 c	29.6 a	14.5 ab	170.4 ab	6.2 ab
Phorate 20G	IFG	1.12	3.0 b	28.3 a	15.9 ab	163.9 abc	6.8 a
Untreated	--	--	3.5 a	29.4 a	12.5 b	132.9 c	6.0 bc

[1]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray; and FS= foliar spray.
[2]ai= active ingredient
[3]g ai/kg seed.
[4]Means within a column followed by the same are not significantly different (P>0.05, Duncan's New Multiple Range Test).
[5]FPS= First Position Square.

Table 21. Insecticides and rates evaluated for impact on bloom production in Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of blooms/3.05 m of row				
			19 July	24 July	Total (2)	31 July	Total (3)
Disulfoton 15G	IFG	1.12	11.3 bc[4]	31.4 a	42.7 ab	78.4 a	121.1 a
Imidacloprid 480F	ST	2.49[3]	12.0 b	31.6 a	43.6 ab	76.0 a	119.6 a
Acephate 90S	IFS	1.12	11.5 bc	29.0 a	40.5 ab	74.9 a	115.4 a
Acephate 90S +	ST	3.99[3]					
Acephate 90S	FS	0.22	10.7 bc	29.0 a	39.7 ab	68.9 a	108.6 a
Aldicarb 15G	IFG	0.56	16.3 a	33.6 a	49.9 a	69.6 a	119.5 a
Phorate 20G	IFG	1.12	7.1 c	23.3 a	30.4 b	66.0 a	96.4 a
Untreated	--	--	10.6 bc	27.3 a	37.9 ab	68.3 a	106.2 a

[1]MOA= Method of Application: IFG= in-furrow granule; ST=seed treatment; IFS= in-furrow spray; and FS= foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 22. Insecticides and rates evaluated for impact on lint yield of Roundup Ready® cotton (Milan Experiment Station, Milan, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Lint 1[4]	Lint 2	Total Yield
Disulfoton 15G	IFG	1.12	738 ab[5]	425 a	1163 a
Imidacloprid 480F ST[1]	ST	2.49[3]	741 ab	430 a	1171 a
Acephate 90S IFS[2]	IFS	1.12	710 abc	438 a	1148 a
Acephate 90S ST[1]+	ST	3.99[3]			
Acephate 90S FS[3]	FS	0.22	703 abc	422 a	1125 a
Aldicarb 15G	IFG	0.56	764 a	396 a	1159 a
Phorate 20G	IFG	1.12	626 c	470 a	1096 a
Untreated	--	--	673 c	391 a	1064 a

[1]MOA= Method of Application: IFG= in-furrow granule; ST= seed treatment; IFS= in-furrow spray; and foliar spray.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]kg/ha.
[5]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

iv. Summary

With respect to herbicide effects, the only variables that were significant were node of first position square (1999 WTES and 2000 MES) and plant heights (1999 MES). Herbicide did not affect any other variables. Densities of adult thrips were significantly affected at WTES and MES in 1999 and 2000. Due to the lack of adequate moisture in 1999, the thrips may have not found the smaller plants as attractive as a food source. Populations were higher in 2000 possibly due to warmer temperatures and adequate moisture to facilitate development during sampling periods. Populations of adult thrips at MES were higher, in part, due to field location. The field was located in a bottom land site surrounded by a wooded area with other crops growing in close proximity. These woods and other crops may have served as overwintering habitats for the thrips.

Insecticide treatments significantly reduced the amount of thrips feeding injury in each study. At WTES in 2000, only plants treated with imidacloprid ST and acephate+acephate had lower stand densities. However, in 1999 at WTES and 1999 and 2000 at MES, insecticide treatment had no significant effect on stand densities. Plant heights were not significantly affected by insecticide treatment at WTES in either 1999 or 2000. At MES, insecticide treatment did have a significant effect on plant height.

During each year at WTES, insecticide-treated plants had more leaf area than untreated plants. At MES in 1999 and 2000, imidacloprid ST-, acephate-, and aldicarb-treated plants had more leaf area than untreated plants. Plants treated with phorate had a significantly higher node of first position square in 1999 at WTES, 1999 and 2000 at MES, however no insecticide treatment affected the node of first position square at WTES in 2000.

At WTES and MES in 1999, bloom counts were lower than in 2000 at either location. Sampling for blooms was done over too short of a duration, which may have contributed to the lower number of blooms collected. Overall, phorate-treated plants had consistently fewer blooms than either treated or untreated plants. All insecticide treatments had higher yields at WTES and MES in 2000 and 1999, respectively, than no treatment. There was no statistical difference in total yield among treatments in 1999 at WTES. There were no statistical differences in second or total harvests in 2000 at MES.

Chapter III

BROMOXYNIL-TOLERANT (BXN®) COTTON EVALUATED FOR EFFECTS ON EARLY-SEASON THRIPS (THYSANOPTERA: THRIPIDAE) AND SELECTED COTTON GROWTH PARAMETERS

i. Introduction

Before the introduction of the BXN® transgenic technology in 1995, cotton producers relied on pre-plant incorporated and pre-emergence herbicides for early-season weed control. After the emergence of cotton from the soil, herbicides were applied as post-directed applications toward the base of the plants to prevent herbicide injury to the foliage. Growers have needed a post-emergence herbicide for broadleaf weed control in cotton because of the specialized equipment and time needed to protect cotton plants from coming in contact with herbicide (Askew and Wilcut 1999; Culpepper and York 1999).

Pendimethalin applied preplant incorporated plus fluometuron applied as preemergence controlled smooth pigweed (*Amaranthus hybridus* L.) and common lambsquarters (*Chenopodium albium* L.) 96-98% in non-transgenic cotton. By planting BXN 47® cotton and adding bromoxynil as an early post emergence treatment, control of prickly sida (*Sida spinosa* L.), pitted morningglory (*Ipomoea lacunose* L.), and smooth pigweed was 97-100, 97-99, and 99-100%, respectively (Culpepper and York 1999).

Research investigating herbicide and insecticide effects has been plentiful (York et al. 1991; York and Jordan 1992; and Allen and Snipes 1995). However, few studies have dealt with the effects of insecticides in conjunction with the BXN® cotton system. Mixing bromoxynil with different insecticides had no negative effects on the performance of insecticides used to control boll weevil (*Anthonomus grandis* Boheman), tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois), or tobacco budworm (*Heliothis virescens* (F.)) (Scott et al. 1996).

The current study was conducted to advance knowledge and determine if the efficacy of early-season thrips insecticides is affected by applications of bromoxynil within the BXN® cotton system. Specific objectives of this study were to evaluate early-season insecticides for: (1) efficacy against thrips, (2) effects on cotton growth, development, and yield, and (3) interactions between insecticides and Buctril® or conventional herbicides.

ii. West Tennessee Experiment Station

a. Materials and Methods

In 1999 and 2000, field studies were conducted at the West Tennessee Experiment Station (WTES), Jackson, Tennessee, to determine efficacy of various early-season insecticides and the effects of herbicides and insecticides on both thrips and cotton growth parameters under the BXN® cotton system. Experimental design, treatments, and methodologies were similar each year except where noted below.

1. 1999

The bromoxynil-tolerant cotton cultivar Stoneville BXN® 47 was planted 20 May in tilled soil using an International® 900 2-row planter according to University of Tennessee recommendations. Plots were two rows wide (96.5 cm spacing) by 12.2 m in length. Treatments were arranged in a split plot design with five replications. Two herbicide treatments were main plots and five insecticide treatments were subplots. The insecticides, rates, and methods of application (MOA) evaluated in 1999 are shown in Table 23.

Nine days before planting (11 May), seed treatments were applied in a slurry of acephate 90S or imidacloprid 480F. Ridomil Gold® [pentachloronitrobenzene (PCNB)] was applied at planting at a rate of 9.0 kg/ha to reduce the incidence of seedling disease. A dicrotophos foliar spray was applied 8 June (19 DAP) at the rate of 132 liters/ha in a 25.4 cm band using a two-row boom with one nozzle per row. Conventional herbicide plots received a preemergence application of fluometuron (Cotoran 4L®) at 2.8 liters/ha, pendimethalin (Dual 8E®) at 1.8 liters/ha, and metolachlor (Prowl 3.3 EC®) at 1.2 liters/ha in a 187 liters/ha broadcast application. Nineteen DAP (days after planting), bromoxynil (Buctril® 4EC) was applied at the rate of 1.2 liters/ha in a 160 liters/ha broadcast application to bromoxynil-herbicide main plots. All plots were sprayed with bromoxynil at 1.2 liters/ha in 187 liters/ha 33 DAP.

Table 23. Insecticide and herbicide treatments evaluated in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 1999 and 2000).

Insecticide Treatments[1]	MOA[2]	Rate (kg ai[3]/ha)
Acephate 90S +	ST	3.99[4]
Dicrotophos 8E	FS	0.28
Imidacloprid 480F	ST	2.49[4]
Aldicarb 15G	IFG	0.56
Phorate 20G	IFG	1.12
Untreated	--	--

[1]Insecticide treatments plus bromoxynil (Buctril®) herbicide at 1.2 liters/ha in a 160 liters/ha (19 DAP in 1999 and at the rate of 0.88 liter/ha in 186 liters/ha 25 DAP in 2000) broadcast application or conventional herbicide metolachlor (Dual 8E®) at 1.8 liters/ha + Prowl 3.3EC® at 1.2 liters/ha + fluometuron (Cotoran 4L®) at 2.8 liters/ha in a 187 liters broadcast application (at planting).

[2]MOA= Method of Application: ST= seed treatment; FS= foliar spray (applied in 132 liters/ha in a 25.4 cm band in 1999 and applied as a 194 liters/ha broadcast application in 2000); IFG= in-furrow granule.

[3]ai= active ingredient.

[4]g ai/kg of seed.

Thrips samples were collected 7 June (18 DAP), 11 June (22 DAP), 16 June (27 DAP), and 21 June (32 DAP). Thrips samples were collected, processed, and counted as described in Chapter II. Data on stand counts (14 DAP), thrips damage ratings (21 DAP), plant height measurements (28 DAP), leaf area (32 DAP), node of first position square (48 DAP), and bloom counts (64, 67, 70 DAP) were collected as described in Chapter II. Plots were harvested 125 and 135 DAP (20 September and 1 October) using a John Deere 9930 2-row picker modified for small plot harvesting.

2. 2000

Cotton was planted on 12 May. The insecticides, rates, and methods of application (MOA) evaluated in 2000 are shown in Table 23. Four days before planting on 8 May, seed treatments were applied to seed in a slurry of acephate 90S or imidacloprid 480F. Conventional herbicide main plots received a preemergence application of fluometuron 4L at 2.8 liters/ha, pendimethalin 8E at 1.8 liters/ha, and metolachlor 3.3EC at 1.2 liters/ha in a 187 liters/ha broadcast application. Twenty-five DAP, bromoxynil 4EC was applied to the bromoxynil plots at a rate of 0.88 liters/ha in a 186 liters/ha broadcast application. A dicrotophos 8E foliar spray was applied as a broadcast application to dicrotophos plots in 186 liters/ha at 4.8 Kph, and at 276 kPa, 14 and 19 DAP.

Thrips were sampled 24 May (12 DAP), 29 May (17 DAP), 2 June (22 DAP), 7 June (27 DAP), and 13 June (32 DAP). Stand counts were taken 18

DAP. Thrips damage was rated 25 DAP. Plant height measurements were made from 5 plants per plot 28 DAP. Total leaf area was measured 28 DAP. Node of first position square was determined and recorded from five plants per plot 50 DAP. Bloom counts were made 67, 74, and 78 DAP in the same manner as in 1999. Plots were harvested 132 and 145 DAP (20 September and 3 October). All data were analyzed using split plot Analysis of Variance (ANOVA) and means were separated using Duncan's New Multiple Range Test ($P<0.05$). Means in all data tables were averaged across both main plot herbicide treatments.

b. Results

Impact from herbicide effect was non-significant at Jackson in 1999 and 2000 under the BXN® system. Data will be presented on impact of insecticide on thrips densities and plant growth parameters.

1. Insecticide Efficacy on Thrips Control

1999

No significant differences among mean numbers of adult thrips on treated and untreated plants or within treated plants were detected (Table 24). Differences, however, were observed in densities of larval thrips on three of four sampling dates (Table 25). On 7 June (18 DAP), 11 June (22 DAP), and 16 June (27 DAP), all insecticide-treated plots had significantly fewer larval thrips than

Table 24. Effects of early-season insecticides on the number of adult thrips in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of adult thrips/4 plants 7 June	11 June	16 June	21 June
Acephate 90S +	ST	3.99[3]				
Dicrotophos 8E	FS	0.28	1.2 a[4]	0.5 a	3.1 a	5.8 a
Imidacloprid 480F	ST	2.49[3]	0.8 a	0.7 a	5.6 a	5.4 a
Aldicarb 15G	IFG	0.56	0.6 a	0.4 a	2.2 a	5.2 a
Phorate 20G	IFG	1.12	0.9 a	0.3 a	3.4 a	4.1 a
Untreated	--	--	1.3 a	1.3 a	7.0 a	5.9 a

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 25. Effects of early-season insecticides on the number of larval thrips in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of larval thrips/4 plants			
			7 June	11 June	16 June	21 June
Acephate 90S +	ST	3.99[3]				
Dicrotophos 8E	FS	0.28	3.1 b[4]	1.2 b	1.8 b	1.4 a
Imidacloprid 480F	ST	2.49[3]	0.2 c	1.2 b	5.9 b	2.6 a
Aldicarb 15G	IFG	0.56	0.2 c	1.3 b	2.1 b	1.1 a
Phorate 20G	IFG	1.12	0.7 bc	1.5 b	3.5 b	2.0 a
Untreated	--	--	16.1 a	30.8 a	16.0 a	2.4 a

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

untreated plots. Significant differences among insecticide treatments occurred on 7 June (18 DAP). By 21 June (32 DAP), no significant differences were observed between treated and untreated plants.

2000

Adult thrips densities in insecticide-treated plots were significantly lower on four of five sampling dates (Table 26). On 24 May (12 DAP), 29 May (17 DAP), and 13 June (32 DAP), densities of adult thrips on all insecticide-treated plants were significantly lower than on untreated plants. However, on 2 June (22 DAP), acephate+dicrotophos-, aldicarb-, and phorate-treated plants had significantly fewer thrips than either imidacloprid ST-treated or untreated plants. No significant differences were observed in numbers of adult thrips on 7 June (27 DAP).

On 29 May (17 DAP), 2 June (22 DAP), 7 June (27 DAP), and 13 June (32 DAP) densities of larval thrips were significantly lower in all insecticide-treated plots than in untreated plots, but no significant differences were detected among insecticide-treatments on 29 May and 2 June (Table 27). On 7 June (27 DAP) and 13 June (32 DAP), imidacloprid ST-treated plants had significantly greater densities of larval thrips than other insecticide treatments.

Table 26. Effects of early-season insecticides on the number of adult thrips in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of adult thrips/4 plants: 24 May	29 May	2 June	7 June	13 June
Acephate 90S +	ST	3.99 [3]					
Dicrotophos 8E	FS	0.28	2.2 b[4]	2.5 b	0.5 b	3.8 a	2.8 b
Imidacloprid 480F	ST	2.49 [3]	2.6 b	3.6 b	3.4 a	4.1 a	3.1 b
Aldicarb 15G	IFG	0.56	1.7 b	2.1 b	1.5 b	1.9 a	1.4 b
Phorate 20G	IFG	1.12	3.1 b	4.6 b	0.9 b	2.9 a	1.2 b
Untreated	--	--	18.9 a	10.5 a	3.6 a	3.6 a	10.7 a

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 27. Effects of early-season insecticides on the number of larval thrips in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of larval thrips/4 plants				
			24 May	29 May	2 June	7 June	13 June
Acephate 90S +	ST	3.99 [3]					
Dicrotophos 8E	FS	0.28	0.1 a	2.2 b[4]	3.5 b	4.7 c	5.8 c
Imidacloprid 480F	ST	2.49 [3]	0.0 a	2.1 b	9.4 b	19.6 b	11.3 b
Aldicarb 15G	IFG	0.56	0.0 a	1.2 b	4.1 b	4.3 c	5.5 c
Phorate 20G	IFG	1.12	0.0 a	2.2 b	3.4 b	4.0 c	4.2 c
Untreated	--	--	0.1 a	26.1 a	139.7 a	63.0 a	19.9 a

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means followed by the same letter within the same date are not significantly different (P>0.05 Duncan's New Multiple Range Test).

2. Insecticide Effects on Plant Parameters

1999

All insecticide-treated plants had significantly less thrips feeding damage than untreated plants (Table 28). Imidacloprid- and aldicarb-treated plants had the least amount of feeding damage of all treatments. Both acephate +dicrotophos- and imidacloprid-treated plants had higher stand densities than aldicarb-, phorate-treated, and untreated plants (Table 28). Plant heights were not significantly different among insecticide treatments (Table 28). All insecticide-treated plants had significantly more leaf area than untreated plants (Table 28). Node of first position square was not significantly affected by insecticide treatment (Table 28).

Insecticides did not affect bloom production on 23 July (Table 29). By 26 July, phorate-treated plants had significantly fewer blooms than imidacloprid-, aldicarb-treated, and untreated plants, but were not significantly different from acephate+dicrotophos-treated plants. The results were the same when first and second counts were totaled and compared. On the third (29 July) and total counts, no significant differences were observed among treated and untreated plants. No significant differences in lint yield from first, second, or total harvest occurred (Table 30).

2000

All insecticide-treated plants had significantly less thrips feeding injury than untreated plants (Table 31). Plants treated with acephate+dicrotophos,

Table 28. Insecticides and rates evaluated for impact on thrips feeding damage and cotton growth parameters in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Thrips damage rating	Mean number of plants/3.05 m of row	Mean plant heights (cm)/5 plants	Mean leaf area (cm^2)/4 plants	Mean node of FPS[5]/ 5 plants
Acephate 90S +	ST	3.99 [3]					
Dicrotophos 8E	FS	0.28	2.5 b[4]	29.3 b	16.1 a	942.2 a	6.9 a
Imidacloprid 480F	ST	2.49 [3]	1.6 c	34.4 a	15.7 a	847.6 a	7.1 a
Aldicarb 15G	IFG	0.56	1.8 c	25.3 c	15.7 a	1080.3 a	6.6 a
Phorate 20G	IFG	1.12	2.3 b	24.6 c	16.3 a	867.8 a	7.5 a
Untreated	--	--	3.3 a	26.3 c	14.9 a	606.8 b	6.8 a

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg of seed.
[4]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).
[5]FPS= First Position Square.

Table 29. Insecticides and rates evaluated for impact on bloom production in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

		Rate		Mean number of blooms/3.05 m of row			
Treatment	**MOA[1]**	**(kg ai[2]/ha)**	**23 July**	**26 July**	**Total (2)**	**29 July**	**Total (3)**
Acephate 90S +	ST	3.99[3]					
Dicrotophos 8E	FS	0.28	3.8 a	23.7 ab[4]	27.5 ab	56.2 a	83.7 a
Imidacloprid 480F	ST	2.49[3]	4.2 a	26.4 a	30.6 a	59.5 a	90.1 a
Aldicarb 15G	IFG	0.56	4.5 a	27.3 a	31.8 a	56.5 a	88.3 a
Phorate 20G	IFG	1.12	2.4 a	16.8 b	19.2 b	48.2 a	67.4 a
Untreated	--	--	5.5 a	26.7 a	32.2 a	53.7 a	85.9 a

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 30. Insecticides and rates evaluated for impact on lint yield of BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 1999).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Lint 1[4]	Lint 2	Total Yield
Acephate 90S +	ST	3.99[3]			
Dicrotophos 8E	FS	0.28	635 a[5]	69 a	704 a
Imidacloprid 480F	ST	2.49[3]	601 a	67 a	668 a
Aldicarb 15G	IFG	0.56	599 a	70 a	669 a
Phorate 20G	IFG	1.12	586 a	74 a	660 a
Untreated	--	--	542 a	68 a	610 a

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]kg/ha.
[5]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 31. Insecticides and rates evaluated for impact on thrips feeding damage and cotton growth parameters in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Thrips damage rating	Mean number of plants/3.05 m of row	Mean plant heights (cm)/5 plants	Mean leaf area (cm^2)/4 plants	Mean node of FPS[5]/ 5 plants
Acephate 90S +	ST	3.99[3]					
Dicrotophos 8E	FS	0.28	2.6 c[4]	36.4 a	10.9 a[2]	184.70 a	7.1 a
Imidacloprid 480F	ST	2.49[3]	2.5 c	37.8 a	10.9 a	163.83 a	6.4 a
Aldicarb 15G	IFG	0.56	2.3 c	39.1 a	7.7 c	176.05 a	7.0 a
Phorate 20G	IFG	1.12	2.9 b	40.0 a	10.0 ab	158.39 a	7.2 a
Untreated	--	--	3.9 a	39.1 a	9.4 b	53.09 b	6.5 a

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg of seed.
[4]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).
[5]FPS= First Position Square.

imidacloprid, and aldicarb all had significantly lower damage ratings than either phorate-treated plants or untreated plants. Stand densities were not significantly different between treated and untreated plants (Table 31). Plants treated with aldicarb were significantly shorter than other treated and untreated plants (Table 31). All treated plants had significantly more leaf area than untreated plants (Table 31). Node of first position square was not significantly affected by insecticide treatment (Table 31).

Phorate-treated plants had significantly fewer blooms on 17 July than all treated or untreated plants (Table 32). One week later, no significant differences were found between treated and untreated plants. When the first and second counts were summed, only imidacloprid-treated plants had significantly more blooms than phorate-treated and untreated plants. By 28 July, imidacloprid-treated plants had significantly more blooms than acephate+dicrotophos-, phorate-treated and untreated plants. When all three counts were summed, imidacloprid-treated plants had a higher number of blooms than acephate+dicrotophos-, phorate-treated and untreated plants. Lint yields at first harvest were significantly higher from insecticide-treated plots than from untreated plots (Table 33). Phorate-treated plots had lower yields than other insecticide treated plots. By second harvest, phorate-treated plots had significantly higher yields than imidacloprid-treated plots. All treated plots had higher total lint yields than untreated plots.

Table 32. Insecticides and rates evaluated for impact on bloom production in BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Mean number of blooms/3.05 m of row 17 July	24 July	Total (2)	28 July	Total (3)
Acephate 90S +	ST	3.99[3]					
Dicrotophos 8E	FS	0.28	3.5 a[4]	21.9 a	25.4 abc	63.8 bc	89.2 bc
Imidacloprid 480F	ST	2.49[3]	4.5 a	28.2 a	32.7 a	77.2 a	109.9 a
Aldicarb 15G	IFG	0.56	4.9 a	24.9 a	29.8 ab	69.9 ab	99.7 ab
Phorate 20G	IFG	1.12	0.6 b	17.4 a	18.0 c	56.8 c	74.8 c
Untreated	--	--	3.3 a	20.6 a	23.9 bc	60.8 bc	84.7 bc

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]Means within a date followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

Table 33. Insecticides and rates evaluated for impact on lint yield of BXN® cotton (West Tennessee Experiment Station, Jackson, TN, 2000).

Treatment	MOA[1]	Rate (kg ai[2]/ha)	Lint 1[4]	Lint 2	Total Yield
Acephate 90S +	ST	3.99[3]			
Dicrotophos 8E	FS	0.28	917 b[5]	160 abc	1077 a
Imidacloprid 480F	ST	2.49[3]	966 ab	152 bc	1118 ab
Aldicarb 15G	IFG	0.56	993 a	168ab	1161 a
Phorate 20G	IFG	1.12	795 c	177 a	972 c
Untreated	--	--	702 d	144 c	846 d

[1]MOA= Method of Application: ST= seed treatment; FS= foliar spray; and IFG= in-furrow granule.
[2]ai= active ingredient.
[3]g ai/kg seed.
[4]kg/ha.
[5]Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's New Multiple Range Test).

iii. Summary

The only variables that had significant herbicide effects were plant heights (in both 1999 and 2000) and thrips damage ratings (2000 only), while herbicide did not have a significant effect on any of the other variables. No insecticide treatment significantly affected adult thrips densities in 1999, but treatments did have an effect on densities in 2000. In addition, insecticide treatment did significantly reduce larval thrips densities in 1999 and 2000. Populations were higher in 2000 than in 1999 and may be attributed to the warmer winter temperatures. Research in Australia showed that aldicarb-protected plants have significantly fewer adult and larval thrips than unprotected plants (Sadras and Wilson 1998). Over the duration of this study, most insecticide-treatments consistently controlled thrips populations.

All insecticide treatments significantly decreased the amount of thrips feeding damage each year. In 1999, plants treated with aldicarb and phorate had lower stand densities, however, in 2000, no insecticide treatment affected stand densities. No effect was noticed on the heights of plants in 1999. In 2000, aldicarb-treated plants were significantly shorter than other insecticide-treated or untreated plants. Over both years, all insecticide-treated plants had more leaf area than untreated plants. This was due to the protection afforded to the plants by the insecticide, which lessened the amount of feeding injury caused by the thrips. No significant insecticide effect on node of first position square was observed in 1999 or 2000. Bloom counts were enhanced by insecticide treatment, except phorate, in 1999. In 2000, phorate-treated plants had fewer blooms only on 17 July, but no statistical differences were noted among the other bloom count dates. Dobson (1958) reported that phorate had a detrimental effect on the number of blooms. No significant differences in yield were noted on insecticide-treated plots in 1999. In 2000, all insecticide-treated plants had greater total yields than no treatment.

Chapter IV

CONCLUSIONS

Cotton is a vital part of Tennessee's economy with 228,647 hectares valued at $142 million harvested in 1999 (Williams 2000, Anonymous 2000). Thrips are usually the first insects to attack cotton seedlings after plant emergence (Burris et al. 1990, Gaines 1959).

In the early 1950s, the only recognized advantage of controlling thrips was to obtain more vigorous stands of cotton during the first 4 to 6 weeks of cotton growth. Newsom et al. (1953) recommended against chemical control of thrips, because insecticides had an adverse effect on populations of predaceous insects and resulted in heavy populations of pests such as the cotton aphid, spider mites, and tobacco budworm. Lincoln and Leigh (1957) reported that control of thrips rarely improved earliness, total yield, or cotton stands. In Louisiana, Burris et al. (1989) reported plant heights and yields increased 14% and 10%, respectively, where thrips were controlled. These tests were conducted using conventional cotton cultivars.

With the recent introduction of the transgenic herbicide-tolerant cotton cultivars Roundup Ready® and BXN®, research focus has shifted to the ways in which these cultivars fit into traditional cotton production practices. Much of the research has investigated weed control in the Roundup Ready® or BXN® systems. Few studies have been reported in which insecticide efficacy has been studied in these cultivars (Scott et al. 1996, Jordan et al. 1993, and Mizell 1998).

The current study will expand the knowledge of insecticide and herbicide effects in herbicide-tolerant transgenic cotton. This study will also aid in updating Tennessee's state extension recommendations with insecticides used in either Roundup Ready® or BXN® cotton systems. The objectives of this study were to evaluate early-season insecticides on Roundup Ready® or BXN® cotton for: (1) efficacy against thrips, (2) effects on plant growth, development, and yield, and (3) interactions among the insecticides and Roundup Ultra®, Buctril®, and conventional herbicides.

Herbicide selection did not have a significant effect on the efficacy of any of the early-season insecticides evaluated in the study. All insecticides controlled both adult and larval thrips throughout the sampling periods. In all tests, insecticide-treated plants had less thrips feeding injury and more leaf area compared to untreated plants.

In tests conducted at the West Tennessee Experiment Station and Milan Experiment Station, plants treated with phorate had higher nodes of first position square and consistently fewer blooms, indicating a delay in maturity. This finding confirmed the results of similar tests conducted at these stations in 1996 and 1997 (Mizell 1998).

Insecticide efficacy tests are important to cotton producers to enable them to effectively and economically manage early-season insects. With the rapid changes that are taking place in transgenic technology, it is important to keep research current in how herbicides used for weed control may influence insecticide efficacy under conventional, Roundup Ready®, or BXN® cotton production systems.

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