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Evaluation of Bt cottons for heliothine complex control and yield potential in Tennessee

Randy Sherman Jones

To the Graduate Council:

I am submitting herewith a thesis written by Randy Sherman Jones entitled "Evaluation of Bt cottons for heliothine complex control and yield potential in Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Entomology and Plant Pathology.

Gary L. Lentz, Major Professor

We have read this thesis and recommend its acceptance:

Jerome F. Grant, Charles D. Pless

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Associate Vice Chancellor and Dean of the Graduate School

EVALUATION OF Bt COTTONS FOR HELIOTHINE COMPLEX CONTROL AND YIELD POTENTIAL IN TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Randy Sherman Jones

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DEDICATION

My deepest love and gratitude to my grandparents

Carolyn Weprin Sherman

and

Danny (Pop) Sherman

who have given me invaluable educational opportunities.

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ABSTRACT

Cotton insect pests cost farmers beltwide $1.68 billion in 1995 due to yield losses, and insecticide and insecticide application costs. With increased insect resistance and environmental concerns, new and innovative control methods are needed. Several Bt cotton lines have been developed which carry an insecticidal protein from a soil bacterium inside the plant, which is toxic to many lepidopteran cotton pests. Bt cottons were evaluated for resistance to injury from the bollworm, *Helicoverpa zea* Boddie, and tobacco budworm, *Heliothis virescens* F., which are lepidopterans collectively called the Heliothine complex.

Data indicate that Bt cotton lines suffered significantly less Heliothine complex injury to squares and bolls throughout the season than conventional cultivars. Bt cotton lines did not require insecticide treatments for the Heliothine complex to prevent yield loss. These studies indicate that Bt cottons could play an important role in future cotton pest management and reduce insect control costs in production agriculture.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

LITERATURE REVIEW

Gossypium (cotton) is a large genus comprised of almost 40 species. Many species are well known in agriculture as the world's commercial cotton crop. However, most species are less well known and are part of the native vegetation in various parts of the world, like Australia, Mexico and Africa (Fryxell 1986). Upland cotton, *Gossypium hirsutum* L., was introduced into the United States during the colonization period; the first records of cotton growth were from the Virginia colony in 1607. The cotton species currently grown in the United States is believed to be native to the West Indies. Due to natural crosses and plant breeding efforts, many types of Upland cotton have been developed, including those commonly planted today (Brown and Ware 1958). In addition to its fiber, cotton is important for oil used in cooking and cottonseed meal used for dairy feed.

Cotton is presently grown under both humid and semiarid conditions as a herbaceous annual. In its wild state it is a perennial woody shrub preferring a semidesert habitat and long hot season (Tharp 1965). Tennessee cotton production is hampered by a short growing season and a lot of wet, cool weather in both spring and fall (Shelby 1996).

Global cotton production is expected to expand to an output of 95 to 100 million bales by the year 2000 (Barlowe 1995). Cotton is important to the economy of the United States, with cotton crop production on nearly 18 million hectares yielding 19 million bales in 1995 (Williams 1996). Cotton production is extremely important to the economy of Tennessee. During 1995, 726,000 bales were produced from 739,200 hectares of cotton (Williams 1996). The total value of production of cottonseed and cotton lint was $253,451,402.70 in Tennessee during 1994 (Williams 1995).

Management of cotton insects is a major component of cotton production because insects attack the crop from seedling to maturity (Lentz et al. 1993). Insect pests cost Tennessee farmers an average of $21.31 per hectare in 1995 (Williams 1996). About 100 species of insects and mites attack cotton, but only a few attack consistently and seriously enough to be classified as key pests (Reynolds et al. 1982). Among the key pests of cotton are bollworm (*Helicoverpa zea* Boddie), tobacco budworm (*Heliothis virescens*

F.), boll weevil (*Anthonomus grandis grandis* Boheman) and plant bugs (*Lygus* spp.). Bollworm and tobacco budworm are normally present in the same fields so these insects are commonly referred to as the Heliothine complex (Anonymous 1992). The Heliothine complex was the number one cotton pest in the United States in 1995 causing a total yield reduction of 3.97%. Tennessee producers experienced 10.8% yield loss due to the Heliothine complex in 1995, and spent $14.08 per hectare on its control (Williams 1996).

Bollworm adults are moths with light brown or olive green wings mottled with darker brown and an irregular dark band across the white hind wings (Anonymous 1994). Tobacco budworm adults have olive front wings with diagonal dark bands and are slightly smaller than bollworm adults (Anonymous 1992).

Females of each moth species lay approximately 1,000 eggs during 8 days. Eggs are small, white, and dome-shaped, then develop reddish-brown bands prior to hatching. Terminal buds are the preferred ovipositional sites in cotton, but lateral buds, bracts, squares, leaves, stems, blooms and bolls are also egg-laying areas (Anonymous 1994). Small larvae are normally concealed in small squares or rolled-up leaves of the terminal (Anonymous 1992). Larvae of the two species are so similar in the first two instars that they are difficult to distinguish. Expert analysis under magnification is necessary to pinpoint distinctions between the two. Tobacco budworm larvae longer than 12mm have a tooth-like projection on each mandible which is absent on bollworms. When fully grown both larval species reach 44mm long and vary in color from light green to brown, green, pink and black (Anonymous 1994, Roberts and Lentz 1995). A new way to distinguish between bollworms and budworms is a squashblot immunoassay which distinguishes eggs of *Helicoverpa zea* and *Heliothis virescens* (Greenstone 1995). Both species overwinter in the pupal stage in the top 5-10 centimeters of soil in cotton fields and around other host plants. The first generation of Heliothine complex uses wild host plants like clover, while the second generation infests corn and cotton in mid-June. Early generations are primarily bollworms. Budworm numbers increase later in the season.

Larvae of the Heliothine complex feed on squares and bolls of cotton plants. Larvae feed where the egg is deposited and tunnel through small squares and terminal buds. Larger larvae feed on blooms, squares and bolls. Damaged squares turn yellow, the bracts flare open, then fall off the plant. One larva can destroy up to three bolls and ten squares (Anonymous 1994). Feeding can lead to secondary damage by providing entry for fungi and bacteria which produce boll rots. Secondary damage occurs in irrigated cotton or during wet periods (Anonymous 1992).

Insecticide use to control Heliothines is historically influenced by the presence of insecticide-resistant tobacco budworm and the boll weevil. Resistant populations are those which can survive exposure to recommended rates of normally effective pest control products (Staetz 1995). The Boll Weevil Eradication Program eliminated the boll weevil as a key cotton pest in most of the southeastern United States, and the program is expanding. Pest management in the southeast, in the absence of the boll weevil, is now dominated by Heliothine pests. Because they are increasingly more resistant to all classes of insecticide chemistry and are difficult to control with traditional topical insecticides, tobacco budworm populations are now becoming a limiting factor to profitability of cotton production in some United States regions (Mascarenhas et al. 1994, Luttrell and Herzog 1994). These chemicals include pyrethroids, carbamates, organophosphates and organochlorines (Graves et al. 1994, Kanga et al. 1995a,b). Pyrethroid-resistant tobacco budworms have been found at several locations in West Tennessee suggesting the possibile development of resistant tobacco budworm strains (Anonymous 1995). In 1995, resistance levels of tobacco budworm to pyrethroids were in the 25% range in Tennessee. Some scientists have speculated that we have lost a new class of insecticides with each ten years of use due to insects developing resistance to them (Malkin 1995).

Topical applications of insecticidal proteins (delta-endotoxins) from *Bacillus thuringiensis* var. *kurstaki* Berliner (Bt), a natural insect pathogenic soil bacterium, have been used more than thirty years in the United States to control insect pests (Buehler 1993). Bt was discovered in Germany in 1911 where it was used to kill larvae of the flour moth, *Anagasta kuehniella* (Zeller). It was registered as a biopesticide in 1938 in France and in 1961 in the United States. The World Health Organization (WHO) spread 226,795 kilograms of Bt across West Africa in 1983 to control disease-carrying blackflies. Thousands of kilograms have been applied topically to vegetables, trees, and crop plants each year in the United States (Witt 1990). Bt is the most widely used biological insecticide for control of agricultural pests in the United States (Mascarenhas et al. 1994). Farmers use topical applications of Bt to protect cotton and tobacco from budworm and looper damage, and fruit growers use it for protection against leaf rollers (Witt 1990).

Bt proteins have many characteristics which make them ideal as insecticides. They are highly specific for certain insects and are safe for mammals, fish, birds and several beneficial insects (Buehler 1993). Bt kills only lepidopteran caterpillars and a few mosquitos, flies, and beetles (Witt 1990). Because the active part of Bt is protein, it breaks down quickly in both the environment and animal digestive systems (Fischhoff 1992). Bioinsecticides are attractive because of human safety and low toxicity to non-target organisms like beneficial parasitic and predatory insects (Uyeda et al. 1994).

Unfortunately, topical use of Bt is limited by the high cost of production and the brief half life of the protein (Buehler 1993). Topical Bt must be used in combination with low to moderate amounts of traditional insecticide to get satisfactory control. The performance of the application is also highly dependent on timing the treatment to egg hatch (Johnson et al. 1994, Klein et al. 1995) because efficacy is low against larger larvae (Ali and Young 1996). Bt does not affect other cotton pests, such as boll weevils, aphids, thrips or whiteflies which can damage cotton plants.

Because Bt genes and proteins are the basis for many commercial microbial insecticides, their properties are well known. Genetic engineering may potentially alleviate problems with topical Bt. Genetic engineering has generated an exciting new technology that may prove to be an enormous aid for the management of insect pests in cotton (Herzog 1995).

Genetic engineering of plants to produce new varieties requires the cooperation of several scientific disciplines and requires an enormous investment of money, time and expertise. Scientists have devised methods to introduce new genetic material directly into a plant's DNA (Trolinder 1995). Researchers can now isolate and manipulate genes that control a specific characteristic. These genes can then be introduced into a new cell lacking this characteristic and grow into a whole plant with the new trait. Tobacco plants were the first species to be genetically altered by this method (Grissom 1991). Plants that have been genetically modified are referred to as transgenic (Benedict et al. 1993b).

Plant engineers at Monsanto Co., based in St. Louis, have used *Agrobacterium tumefaciens* Smith and Townsend, a plant bacterium, to transfer genetic material which controls a trait. To transfer this material, first DNA with the desired traits is placed into *Agrobacterium* (Grissom 1991). The stem section of a young seedling plant is cut into little sections in the presence of the treated *Agrobacterium* (Trolinder 1995). The bacterium then enters the plant cells and joins the new DNA section to the plant cell's DNA. The cells divide in a tissue culture and follow the normal process of development, so each new plant cell carries the added DNA. The cells become plantlets and finally adult plants with the new traits (Thomas 1993, Trolinder 1995). The process of transferring a gene into a plant cell and then having the cell regenerate into a mature plant takes about one year (Meredith 1995).

To alleviate the demand for extensive chemical insecticide spraying, genetic engineering techniques have isolated a specific gene from Bt and facilitated the transfer of Bt genes into the DNA of cotton plants. Having this DNA expressed within the plant may overcome the limitations of topical applications of this insecticide (Buehler 1993). Bt was first successfully introduced into tobacco plants in 1987 by Plant

Genetic Systems, a Belgian biotechnology company (Grissom 1991). The genetic engineering of cotton to introduce genes for resistance to lepidopteran pests offers an alternative to heavy dependence on conventional insecticides (Jenkins et al. 1993). The Bt cotton expresses its insecticidal activity in every plant tissue and provides protection against lepidopteran pests like the Heliothine complex throughout the growing season (Fischhoff 1992).

In 1988, initial cotton plants with the modified gene were produced. The Bt genes were originally introduced in only limited cotton cultivars, mainly Coker 312 and its sister lines (El-Zik and Thaxton 1995). In 1989, these plants were evaluated in the greenhouse, where notable insect control was observed. Those initial lines were then evaluated under field conditions (Deaton 1991). In the summer of 1989, Jenkins and Parrott conducted the world's first field test of Bt cotton. They found it provided no better insect control than did the control strain (Jenkins and Parrott 1990). Since the initial production of transgenic plants in 1988, Monsanto has improved Bt genes for better performance (Deaton 1991), and considerable effort has been expended to research the new technology. In a large scale Bt cotton production experiment in Mississippi (2800 hectare blocks), Bt cotton rendered effective control of tobacco budworm the entire season, even when populations attained densities 10 times those usually resulting in insecticide applications (Worley et al. 1996). In addition to efficacy trials, several other types of research projects have been undertaken which will help to understand the new technology and what to expect from it in commercial production use (Herzog 1995).

Transgenic (Bt) cotton plants expressing the insecticidal protein from the Bt bacterium have been shown to affect Heliothine larvae in several ways. The Bt delta-endotoxin proteins are toxic to many lepidopteran larvae when ingested by causing rapid midgut paralysis, altered midgut pH, and altered permeability and disintegration of the midgut epithelium (Meeusen and Warren 1989). Larvae undergo gut paralysis and cease feeding within 2 hours or less after ingestion of the protein (Benedict et al. 1993b).

Studies of larvae have shown that crawling, feeding, resting and spinning-down (departing the plant by dropping down a thread or crawling off the plant) behaviors are altered on Bt cotton (DeSpain et al. 1993). On Bt lines the percentage of time larvae spent feeding on flower buds was reduced from 50% to 18%, and resting on leaves increased from 33% to 60%. Larvae on transgenic lines spun-down and abandoned plants more frequently than larvae on control plants (Benedict et al. 1992a,b, 1993b, Halcomb et al. 1994). Reduced feeding and increased plant abandonment on some transgenic lines may be partially due to midgut paralysis.

Larvae of pink bollworm, *Pectinophora gossypiella* Saunders, penetrate the bolls of transgenic lines as readily as they do bolls of control cotton; however, inside the bolls they do little damage (Wilson et al. 1992). When 3-day old diet-fed tobacco budworm larvae were placed on Bt cotton tissue and allowed to grow, no larvae survived; however, larvae did pupate after feeding on non-transgenic cotton. When 6-day old diet-fed tobacco budworm larvae were placed on plant tissue for 6 days, larvae were significantly smaller on transgenic lines than non-transgenic cotton. All transgenic lines produced significantly fewer and smaller larvae than non-transgenic controls (Benedict et al. 1992a). Eight-day old larvae on non-Bt cotton could potentially move to a Bt cotton plant and damage the fruit (Parker and Luttrell 1995). Though control of the bollworm was marginally less (4%) than tobacco budworm, this lowered control was not considered statistically significant (Jenkins et al. 1992). The Bt endotoxin could reduce larval damage and increase yield by poisoning and killing the insect directly, or indirectly by changing larval behavior which may increase larval mortality (Benedict et al. 1992a).

Economic injury levels and economic thresholds will need to be increased for the Heliothine complex on transgenic cotton because larvae must feed on plants to become exposed to the toxin. Larvae feeding on Bt cotton will not survive past the neonate stage so their feeding will be superficial and not lead to fruit loss. Therefore, thresholds should be based on injury to plants and not larval densities (Ring et al. 1993, DuRant 1994). Thresholds based on egg counts or the presence of small larvae become poor predictors of economic loss with Bt cotton and should instead be established on terminal and small square damage (Phillips 1995).

The transgenic Bt lines also were highly resistant to leaf feeding by the cabbage looper (*Trichoplusia ni* Hubner) (Benedict et al. 1991), the beet armyworm (*Spodoptera exigua* Hubner) (Harris et al. 1996), and the saltmarsh caterpillar [*Estigmene acrea* (Drury)] as determined by minimal damage to Bt cotton leaves and nearly complete defoliation on control leaves (Wilson and Flint 1991). Bt cotton also is effective against pink bollworm and cotton leafperforator (*Bucculatrix thurberiella* Busck) (Wilson et al. 1992).

Insect-resistant cotton also controls Heliothine complex populations that are losing their sensitivity to chemical insecticides (Fischhoff 1992). Increased interest in alternative control measures to conventional insecticides has been boosted by high levels of insecticide resistance developed by some populations of tobacco budworm (Mascarenhas and Luttrell 1995, Graves et al. 1995). Their resistance to pyrethroid insecticides has continually increased since 1987 (Graves et al. 1993). During 1995, pyrethroid resistance in tobacco budworm was documented in Mississippi (Elzen 1996), Alabama (Bagwell et al. 1996) and Louisiana (Bagwell et al. 1996, Holloway et al. 1996). Transgenic cotton should increase the useful life of pyrethroids and other synthetic toxins by reducing the frequency and area sprayed with chemical insecticides (Benedict et al. 1992b, 1993b). Bt cotton will likely be employed rapidly in severe insect resistance regions. Resistance management strategies need to be developed to maintain or prolong the value of transgenic Bt varieties, as well as pesticide formulations containing Bt (Luttrell and Layton 1995, Kennedy and Whalon 1995).

Scientists have predicted that the target insects of Bt cotton, the Heliothine complex, will develop resistance to the Bt endotoxin if it is not properly managed (De Spain et al. 1993). Research is needed in the development and implementation of tactics that will slow or prevent the potential development of insect resistance to the Bt protein in cotton (Fischhoff 1992, Tabashnik 1992). The high level of insect suppression observed in transgenic cotton increases the possibility that the insect pest will develop resistance to the plant (Gould 1988). This possibility of resistance also suggests that the effectiveness of spray applications of all present commercial Bt based products may be lost due to this plant-induced resistance (De Spain et al. 1993, Benedict et al. 1992b).

Researchers have developed a strain of tobacco budworm in the laboratory which has a high level of resistance to several Bt toxins to determine the frequency of resistance in populations and how they are inherited (Gould et al. 1995). One suggestion to reduce resistance is to mix plantings of susceptible and resistant Bt plants to maintain insects with susceptible genes in the target insect population (Gould 1988). However, research showed mixed plantings may not provide acceptable control of Heliothine complex (DuRant 1995, DuRant and Roof 1996). Heliothine larvae can develop on non-Bt plants in the mixtures then move to Bt plants and cause damage and also be selected for resistance (Halcomb et al. 1996). While the effectiveness of the strategy has yet to be proved, a planned approach like seed-mixing is needed. Some alternative options are non-treated hectares near Bt hectares, and pyramiding with the Bt endotoxin gene.

When Bollgard cotton seed was marketed in 1996, it was available only to growers who attended educational meetings and completed a licensing agreement with Monsanto to ensure compliance with production guidelines and effective insect resistance management in the cotton. Growers are required to do one of two options: plant 1.6 hectares of conventional cotton not treated for Heliothine complex for every 40.5 hectares of Bt cotton or for every 40.5 hectares of Bt cotton plant 8.1 hectares without the Bt gene which can be treated with insecticides. These requirements are enforced so that insects without resistance to Bt can survive to dilute

Heliothine complex populations exposed to the Bt gene to delay development of resistance.

Gene pyramiding that produces multiple modes of action using naturally-occurring sources of plant resistance and Bt characteristics may be the most productive strategy to postpone the development of insect resistance to Bt cotton (Sachs et al. 1993). Adding Bt genes to glandless seeded cotton would further improve resistance to tobacco budworm/ bollworm and other susceptible lepidopteran pests (Benedict et al. 1993a). Other characteristics which may be pyramided include early maturity to avoid cotton damage by late-season pests (Robertson et al. 1993), nectariless cotton to reduce egg production (Wilson et al. 1992) and glaborous, glandless and high terpenoid content (high glanding) cotton (Stelly et al. 1994). Resistance management is a critical component of Bt cotton insect control (Luttrell and Layton 1995, Kennedy and Whalon 1995). With proper management and implementation, possible insect resistance to Bt will not be a commercial or technical problem that will restrict the efficacy or value of insect resistant cotton (Fischhoff 1992).

The tarnished plant bug (*Lygus lineolaris* Beauvois) and several stink bugs are incidentally controlled by applications of traditional insecticide directed at lepidopteran pests, and elimination of these applications may result in an increase of these pests (Wilson et al. 1992, Mahaffey et al. 1994, Turnipseed et al. 1995, Turnipseed and Green 1996, Luttrell et al. 1995, Layton 1995, 1996, Bacheler and Mott 1996). Some less recognized cotton insect pests could partially fill the ecological void that would be left by lepidopteran species. Bt cotton has no effect on cotton aphids, boll weevil, thrips or whiteflies which may damage the plants (Harris et al. 1996). In this way, Bt cotton will not deliver absolute freedom from insect pressure because secondary pests may rise to primary status.

Some controversy concerns the release of genetically engineered crops into the environment. Until these debates are settled, it is necessary to adhere to regulatory compliances for Bt cotton established by the USDA and EPA. To prevent possible accidental release, growers of Bt cotton were required in 1995 to contain pollen and seed distribution. This containment was accomplished by surrounding each experimental block with 12 border rows (12.2 m) of non-transgenic cotton and destroying seed after harvest. When

Bollgard was marketed in 1996, these requirements were not necessary.

The use of transgenic Bt genes in cotton production will provide important benefits to farmers, society and the environment. The most important advantage is that insect-resistant cotton offers an alternative to chemical insecticides for controlling lepidopteran insects, with a predicted reduction in total pesticide use with Bt cotton (Luttrell and Herzog 1994). This change has direct benefits to the grower, such as reduced human exposure to chemical insecticides and less effort and time spent on chemical control of lepidopterans (Fischhoff 1992). The producer can use less time moving, buying, mixing, and applying insecticides for Heliothine control. Transgenic Bt also eliminates the need for re-application after rain and insecticide degradation. Reduced use of chemical insecticides leads to reduced environmental impact of crop production practices and their related costs to wildlife and society (Benedict et al. 1992b, 1993b). Utilization of Bt cotton by producers will depend upon the annual Heliothine complex populations they experience and the availability and cost of this product.

Chemical insecticides, such as pyrethroids, are relatively non-specific and also kill beneficial parasitic and predatory insects. Transgenic cotton has biological activity specific for Lepidoptera, therefore, some beneficial populations should increase in fields planted with transgenic cotton (Mascarenhas and Luttrell 1995, Sims 1995). Increased numbers of beneficial insects not only provide additional control of lepidopteran pests but also control some non-target pests, such as mites, which become problems when their natural predators are removed. Because Heliothine control is within the cotton plant, the cost of this control is the same regardless of varying pressures. Additionally, growing Bt cotton requires no special skills or technology to gain insect control. Bt cotton can increase farm profit by reducing insect pest losses, as well as additional costs avoided such as environmental pollution and impacts on human health and safety (Benedict et al. 1992b, 1993b). Bt cotton seed has an additional 'technology fee' added to the cost for the use of the Bt gene, which is approximately equal to three chemical insecticide applications. The use of Bt cottons will depend on the annual Heliothine complex pressure the farmer experiences, and the cost and availability of the Bt cotton.

Commercialization of two Bt cotton varieties is underway by Deltapine, and several varieties are anticipated from Hartz in 1997.

This research was designed to provide a more detailed understanding of the usefulness and efficacy of Bt cottons in Tennessee. The objectives of this research were to:

1. evaluate Bt cottons for Heliothine complex control,
2. determine if Bt cottons need remedial insecticide treatments to protect them from damage,
3. determine any yield benefits of Bt cottons under natural infestations, and
4. evaluate the influence of planting date on performance of NuCOTN 33B and Hartz Bt1215.

CHAPTER II

EVALUATION OF BOLLGARD COTTON FOR HELIOTHINE COMPLEX CONTROL AND YIELD POTENTIAL

i. INTRODUCTION

The development of transgenic Bt cotton varieties may be one of the most important events in cotton insect management in the last few decades. It is a gigantic step in the improvement of cotton production in the United States, and demonstrates that industry is meeting the challenge to develop new pest management technologies that reduce our reliance on chemical insecticide applications while improving worker protection and safety. Bt cotton varieties are expected to provide protection against several lepidopteran pests, including the tobacco budworm, bollworm, pink bollworm, loopers, armyworms, saltmarsh caterpillar, and cotton leafperforator. The bollworm/budworm complex (Heliothine complex) is the number one pest of cotton in Tennessee and the United States (Williams 1996). This complex is the focus of this study on the evaluation of Bt cotton.

Recent research has been directed towards the development of Bt cottons. Monsanto Agricultural Company has developed a Bollgard gene, which when inserted into cotton produces Bt toxins within the plant. This technology promises to provide the farmer with an effective, profitable, and environmentally friendly tool to control Heliothine complex pests in cotton (Kerby et al. 1995, Wofford 1995). Growers of Bollgard cotton may not have to apply topical insecticides to control Heliothine complex, and yield potential may be similar to conventional lines.

Little information is available on the performance of Bollgard cotton in West Tennessee. Thus, the objectives of this study were to:

1. assess the performance of the Bollgard gene in cotton for control of Heliothine complex,
2. determine if Bollgard cotton may need insecticide treatments to protect it from Heliothine complex damage, and
3. determine yield potential of Bollgard cotton under natural infestations and standard insecticide treatments.

ii. MATERIALS AND METHODS

In 1995, research was conducted at three locations in West Tennessee to assess the performance of Bollgard cotton for Heliothine control and yield, and to determine if this variety needs chemical insecticide treatments. The locations were Ames Plantation near Grand Junction, Milan Experiment Station in Milan, and the West Tennessee Experiment Station (WTES) in Jackson. Four treatments were evaluated at each location: 1) Bt cotton unsprayed, 2) Bt cotton sprayed with insecticides for Heliothine complex control at 2% damaged squares, 3) non-Bt cotton unsprayed (conventional variety name withheld by Monsanto), and 4) non-Bt cotton sprayed at 5% damaged square threshold. When Heliothine populations reached threshold levels in treatments #2 and #4, insecticides were applied. Insecticides used were cyfluthrin (Baythroid) and cyhalothrin (Karate), which are pyrethroids toxic to the Heliothine complex.

Treatments at WTES and Ames were replicated four times in a randomized complete block design, with four-row plots (rows were 0.97 m apart and 9.15 m long). Treatments at Milan were replicated three times in a randomized complete block design in eight-row plots (rows were 1.02 m apart and 9.15 m long). Differences in replicates were due to space constraints. At Milan, cotton was planted using the no-till method, which is planting cotton into last year's crop stubble. No-till planting does not affect cotton yields or insect populations in cotton (Shelby and Bradley 1996).

Cotton was planted on May 9 at WTES, May 11 at Milan and May 23 at Ames, according to University of Tennessee Extension recommendations for cotton production. Aldicarb (Temik) (3.92 kg/ha) was applied for thrips control. All experiments had 12 border rows of non-Bt cotton for pollen and seed containment to prevent accidental release as required by the USDA and EPA.

Plant height, number of nodes, and plant density were evaluated in mid June. Plant height and number of nodes were determined by randomly selecting 10 plants in each plot, measuring their height, and counting the number of nodes on each plant. Plant density was determined by randomly sampling two 3.1 m sections in each plot. Cotton was monitored weekly from pinhead square stage at the beginning of July through the end of August to characterize insect pressure and determine plant damage. Insect pressure and plant damage were evaluated by examining the top 15.2 cm of 20 plants per plot and recording the number of Heliothine eggs and larvae. One square and one boll from each of these 20 plants were then examined for Heliothine damage and the presence of large (greater than 0.32 cm) Heliothine larvae. A square was considered damaged if a Heliothine larva had eaten a hole large enough to cause the bracts to flare open and the plant to abort the square. A boll was considered damaged if a Heliothine larva had eaten through the carpel wall. Non-lepidopteran treatments for boll weevil and plant bug were applied across all experiments as needed. Boll weevils and plant bugs are the second and third most destructive cotton pests in West Tennessee and were eliminated to ensure cotton damage was caused mostly by Heliothine complex.

At WTES, the sprayed conventional plots were treated with cyfluthrin (0.18 L/ha) on July 14 and 18 and then with cyhalothrin (0.29 L/ha) on August 8 and 15. At Milan, the sprayed conventional plots were treated on July 12 and 19 with cyfluthrin. The sprayed conventional plots at Ames were treated with cyfluthrin on July 18 and with cyhalothrin on July 20 and August 1 and 15. The sprayed Bollgard plots at Ames were treated with cyhalothrin on August 1 and 15, then with cyfluthrin on August 21.

To determine cotton yields, the middle two (four at Milan) rows of each plot were machine harvested twice. Cotton at WTES was harvested on October 2 and 23, at Milan on October 9 and 30, and at Ames on October 13 and 30. The cotton lint yield from each harvest was ascertained and then combined to determine the total yield.

All data analyses were conducted using ANOVA and Fisher's Least Significant Difference test to determine differences among treatments. Data collected on eggs, larvae, damaged squares and damaged bolls were square root transformed for this test.

In 1996, Bollgard experiments were conducted at the same three locations with only a few modifications. At WTES and Milan, treatment #4 was sprayed at the same time as #2. At Ames, treatments #2 and #4 were sprayed when they reached 5% damaged square threshold. At WTES, only three replications of the four treatments were made, and rows were shortened to 8.2 m due to space constraints. At Milan, four replications were performed with four-row plots. No border rows were required. Ames had irregular plant heights within each row, possibly due to soil compaction prior to planting. Therefore, height and node data were not collected at this location.

Cotton was planted on May 16 at WTES, May 9 at Milan and May 3 at Ames according to University of Tennessee Extension recommendations for cotton production. Aldicarb (3.92 kg/ha) was applied for thrips control. Plots were evaluated, and cotton was monitored for the same data (such as plant density, yield, and number of eggs, larvae, damaged squares and damaged bolls) using similar methods as those described for 1995. During 1996, however, larval size was noted as neonate or larger (greater than 0.32 cm) to provide more accuracy. Neonate larvae would be expected on both conventional and Bollgard cotton because larvae must digest some Bt toxin to cause midgut paralysis and death. At Ames, sprayed conventional cotton had cyhalothrin (0.29 L/ha) applied on July 2, 11, and 17. No other locations received treatment.

To determine cotton yields, the middle two rows of each plot were machine harvested twice. Cotton at WTES was harvested on October 4 and 30, at Milan on October 7 and November 5, and at Ames on October 17 and November 4.

iii. RESULTS AND DISCUSSION

WTES LOCATION

In 1995, no significant differences in plant height, number of nodes or plant densities were detected among treatments (Table 1). Seasonal mean densities of eggs (Table 2) and larvae (Table 3) did not differ among treatments. No

Table 1. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. West Tennessee Experiment Station, Jackson, Tenn. 1995.

Cultivar/Treatment	Mean plant height (cm) June 12	Mean no. nodes June 12	Mean no. plants/3.1 m June 14
Bollgard cotton unsprayed	15.0	5.4	27.6
Bollgard cotton sprayed at 2% damaged squares	15.5	5.3	33.3
Conventional cotton unsprayed	15.5	5.4	30.9
Conventional cotton sprayed at 5% damaged squares	14.2	5.1	29.1
P > F	< 0.01	0.48	0.18

Table 2. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

	Mean no. eggs/20 terminals								Seasonal
Cultivar/Treatment	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.5	1.5	0.3	0.0	0.29
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0	0.0	1.8	0.8	0.0	0.0	0.33
Conventional cotton unsprayed	0.0	0.0	0.0	1.0	0.5	1.0	0.8	0.0	0.41
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	1.0	2.0	1.3	0.3	0.0	0.58
P > F	1.00	1.00	1.00	1.00	0.15	0.01	0.61	1.00	0.82

Table 3. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

	Mean no. larvae/20 terminals								Seasonal
Cultivar/Treatment	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.3	0.3	0.8 b[1/]	0.5	0.24
Bollgard cotton sprayed at 2% damaged squares	0.0	0.5	0.0	0.0	0.0	0.0	0.5 b	0.3	0.16
Conventional cotton unsprayed	0.5	0.0	0.3	0.0	0.5	0.8	1.8 a	0.8	0.59
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	0.5	0.8	0.8 b	0.8	0.36
P > F	0.48	0.16	0.48	1.00	0.77	0.54	0.03	0.53	0.18

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

differences in the seasonal mean densities of eggs among treatments indicate that Heliothine moths do not differentiate between Bollgard and conventional cottons. Although population densities of larvae were relatively low throughout the season, the sprayed conventional cotton required four insecticide applications because the 5% damaged square threshold was reached. The seasonal mean number of damaged squares (Table 4) and damaged bolls (Table 5) did not differ significantly among treatments.

First-harvest yields (Table 6) were significantly lower on unsprayed Bollgard cottons than on conventional cottons. However, no significant differences were found among treatments at second, total and percent first harvest yields. Bollgard cotton yielded less than conventional cotton at first harvest and showed no significant difference in second and total harvest. No significant differences in total yields suggest that Bollgard cotton does not need insecticide treatments to preserve its yield.

In 1996, no significant differences in plant heights, number of nodes or plant densities (Table 7) were detected among treatments. Seasonal mean densities of eggs (Table 8) and larvae (Table 9) were not significantly different among treatments. Seasonal mean numbers of damaged squares were not

Table 4. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal Mean
	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	
Bollgard cotton unsprayed	0.0	0.0	0.0	0.5	1.0 a[1/]	0.0 b	0.5 b	0.0	0.25
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0	0.0	0.3 b	0.0 b	0.5 b	0.3	0.14
Conventional cotton unsprayed	0.5	0.0	1.0	0.3	0.3 b	1.3 a	1.3 a	0.0	0.59
Conventional cotton sprayed at 5% damaged squares	0.0	0.8	1.0	0.0	0.8 ab	1.8 a	2.0 a	0.3	0.84
P > F	0.48	0.48	0.34	0.20	< 0.01	0.02	0.03	0.73	0.12

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 5. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal Mean
	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.3	0.0 b[1/]	1.3	0.20
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0	0.0	0.3	0.0	0.0 b	1.0	0.16
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	0.5	0.0	1.3 a	2.3	0.51
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	0.0	0.3	1.8 a	1.5	0.45
P > F	1.00	1.00	1.00	1.00	0.20	0.17	0.02	0.80	0.08

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 6. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. West Tennessee Experiment Station, Jackson, Tenn. 1995.

Cultivar/Treatment	Lint yield (kg/ha) First	Second	Total	Percent first harvest
Bollgard cotton unsprayed	1014 c[1/]	273	1286	78.9
Bollgard cotton sprayed at 2% damaged squares	1054 bc	264	1318	80.2
Conventional cotton unsprayed	1158 a	224	1382	83.8
Conventional cotton sprayed at 5% damaged squares	1120 ab	211	1330	84.3
P > F	0.01	0.87	0.41	0.69

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 7. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. West Tennessee Experiment Station, Jackson, Tenn. 1996.

Cultivar/Treatment	Mean plant height (cm) June 12	Mean no. nodes June 12	Mean no. plants/3.1 m June 12
Bollgard cotton unsprayed	4.7	3.5	37.3
Bollgard cotton sprayed when conventional sprayed	4.8	3.5	36.5
Conventional cotton unsprayed	5.1	3.6	37.3
Conventional cotton sprayed at 5% damaged squares	5.2	3.7	35.8
P > F	0.56	0.87	0.99

Table 8. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean no. eggs/20 terminals								Seasonal
	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Bollgard cotton unsprayed	2.0	0.0	0.0	0.0	4.3	0.3	0.7	0.3	1.0
Bollgard cotton sprayed when conventional sprayed	0.3	0.0	0.0	0.0	4.7	1.3	1.7	0.0	1.0
Conventional cotton unsprayed	0.3	0.0	0.0	0.3	2.0	0.7	1.0	0.3	0.6
Conventional cotton sprayed at 5% damaged squares	0.3	0.0	0.0	0.3	1.3	1.0	0.7	0.7	0.5
P > F	0.23	1.00	1.00	0.25	0.31	0.02	0.69	0.73	0.32

Table 9. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean no. larvae/20 terminals								Seasonal
	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Bollgard cotton sprayed when conventional sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.3	0.2
Conventional cotton sprayed at 5% damaged squares	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.3	0.2
P > F	0.49	0.49	1.00	1.00	0.49	0.21	0.12	0.76	0.41

significantly different among unsprayed conventional cotton and unsprayed Bollgard cotton (Table 10). However, the seasonal mean number of damaged squares was significantly greater in sprayed conventional cotton than in either sprayed or unsprayed Bollgard cotton. Seasonal mean numbers of damaged bolls (Table 11) showed a similar trend, with significantly higher damage in both conventional treatments compared to either Bollgard treatment.

No significant differences were observed among lint yields (Table 12). No treatments received insecticide application, suggesting that conventional cottons were higher yielding. Thus, these conventional cottons were comparable in yield to Bollgard cotton despite significantly higher seasonal damage to conventional squares and bolls.

MILAN LOCATION

In 1995, no significant differences in plant heights or number of nodes (Table 13) were found among treatments. Although treatments had not yet been applied when density data were collected, plant densities were greater in sprayed conventional cotton than in Bollgard cotton, though unsprayed conventional cotton did not differ significantly.

Table 10. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal
	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Bollgard cotton unsprayed	0.3	0.0	0.0	0.0	0.3	0.0	0.3 b[1]	0.0	0.1 bc
Bollgard cotton sprayed when conventional sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b	0.0	0.0 c
Conventional cotton unsprayed	0.3	0.0	0.0	0.0	0.0	0.7	1.0 a	0.0	0.3 ab
Conventional cotton sprayed at 5% damaged squares	0.7	0.7	0.0	0.0	0.7	0.7	0.0 b	0.3	0.4 a
P > F	0.13	0.12	1.00	1.00	0.21	0.08	0.03	0.49	0.03

[1]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 11. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal
	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1]	0.0	0.0 c
Bollgard cotton sprayed when conventional sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b	0.0	0.0 c
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	0.0	1.0	0.0 b	0.3	0.2 b
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	0.0	1.0	1.0 a	0.7	0.3 a
P > F	1.00	1.00	1.00	1.00	1.00	0.37	< 0.01	0.57	< 0.01

[1]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 12. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. West Tennessee Experiment Station, Jackson, Tenn. 1996.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Bollgard cotton unsprayed	941	141	1082	87.2
Bollgard cotton sprayed when conventional sprayed	1008	119	1126	89.5
Conventional cotton unsprayed	1015	131	1146	88.6
Conventional cotton sprayed at 5% damaged squares	1022	140	1162	88.2
P > F	0.87	0.87	0.94	0.50

Table 13. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Mean plant height (cm) June 9	Mean no. nodes June 9	Mean no. plants/3.1 m June 14
Bollgard cotton unsprayed	16.0	4.6	30.3 b[1/]
Bollgard cotton sprayed at 2% damaged squares	17.3	4.3	31.7 b
Conventional cotton unsprayed	17.5	4.5	33.0 ab
Conventional cotton sprayed at 5% damaged squares	17.0	4.7	38.8 a
P > F	0.24	0.87	0.05

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Egg densities were not significantly different among treatments throughout the season (Table 14). Seasonal mean larval densities (Table 15) were significantly greater in conventional cottons than in the unsprayed Bollgard cotton. Most larvae observed in conventional cotton were developed beyond the neonate stage, while only neonate larvae were found in Bollgard cotton. Larval densities were low throughout the season at Milan, yet sprayed conventional cotton required two insecticide applications after reaching the 5% threshold level.

The seasonal mean number of damaged squares (Table 16) and bolls (Table 17) were significantly greater in conventional cottons than Bollgard cottons, which indicates that Bollgard cotton offers protection from Heliothine damage to squares and bolls throughout the season. First-harvest lint yields (Table 18) were significantly greater in conventional sprayed cotton than in either Bollgard cottons, and in unsprayed conventional cotton compared to unsprayed Bollgard cotton. Correspondingly, percent first harvest was significantly greater in conventional cottons than in Bollgard cottons. However, second-harvest lint yields were significantly greater in Bollgard cottons, and no significant differences among the total yields of the four treatments were

Table 14. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. Milan Experiment Station, Milan, Tenn. 1995.

	Mean no. eggs/20 terminals								Seasonal
Cultivar/Treatment	Jul 6	Jul 12	Jul 18	Jul 25	Aug 2	Aug 9	Aug 16	Aug 23	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	1.3	1.3	0.3	0.0	0.36
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0	0.0	2.0	1.0	0.7	0.0	0.46
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	1.0	0.7	0.0	0.0	0.21
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	0.7	0.7	0.3	0.0	0.21
P > F	1.00	1.00	1.00	1.00	0.23	0.66	0.63	1.00	0.58

Table 15. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. Milan Experiment Station, Milan, Tenn. 1995.

	Mean no. larvae/20 terminals								Seasonal
Cultivar/Treatment	Jul 6	Jul 12	Jul 18	Jul 25	Aug 2	Aug 9	Aug 16	Aug 23	Mean
Bollgard cotton unsprayed	0.3	0.0 b[1/]	0.0	0.0	0.0	0.0	0.0	0.0 b	0.00 c
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0 b	0.0	0.0	0.7	0.0	0.0	0.0 b	0.09 bc
Conventional cotton unsprayed	0.0	0.3 b	0.0	0.0	0.0	0.3	0.7	1.3 a	0.33 ab
Conventional cotton sprayed at 5% damaged squares	0.0	1.3 a	0.0	0.0	0.3	0.7	1.0	0.3 b	0.45 a
P > F	0.49	0.05	1.00	1.00	0.21	0.57	0.10	0.05	0.05

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 16. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal Mean
	Jul 6	Jul 12	Jul 18	Jul 25	Aug 2	Aug 9	Aug 16	Aug 23	
Bollgard cotton unsprayed	0.0	0.0	0.0 b[1/]	0.0	0.0	0.0	0.0	0.0	0.0 b
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0 b	0.0	0.3	0.0	0.0	0.0	0.04 b
Conventional cotton unsprayed	0.3	4.7	0.0 b	1.0	0.3	0.7	0.0	0.0	0.88 a
Conventional cotton sprayed at 5% damaged squares	0.7	5.3	2.0 a	0.0	0.0	0.0	0.0	0.3	1.04 a
P > F	0.28	0.08	0.04	0.49	0.76	0.49	1.00	0.49	0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 17. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal Mean
	Jul 6	Jul 12	Jul 18	Jul 25	Aug 2	Aug 9	Aug 16	Aug 23	
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1/]	0.3	0.04 b
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b	0.3	0.04 b
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	0.7	0.0	1.7 a	2.3	0.59 a
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	0.0	0.0	2.0 a	3.7	0.71 a
P > F	1.00	1.00	1.00	1.00	0.49	1.00	0.01	0.10	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 18. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Lint yield (kg/ha) First	Lint yield (kg/ha) Second	Lint yield (kg/ha) Total	Percent first harvest
Bollgard cotton unsprayed	944 c[1/]	296 a	1239	76.0 b
Bollgard cotton sprayed at 2% damaged squares	1020 bc	295 a	1313	77.6 b
Conventional cotton unsprayed	1074 ab	218 b	1292	83.0 a
Conventional cotton sprayed at 5% damaged squares	1137 a	204 b	1340	84.8 a
P > F	0.02	< 0.01	0.15	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

detected. These data suggest that Bollgard cotton matures later than the conventional cotton, or Bollgard was protected against damage from Heliothine complex emerging later in the season. Also, though sprayed conventional cotton had significantly greater plant densities and received two insecticide treatments, no differences were detected among total yields.

In 1996, no significant differences in plant heights, number of nodes or plant densities (Table 19) were found among treatments. Seasonal mean numbers of eggs (Table 20) and larvae (Table 21) were not significantly different. The seasonal mean number of damaged squares (Table 22) and damaged bolls (Table 23) were not significantly different among treatments. Damage was low due to the extremely low numbers of Heliothine larvae at Milan in 1996.

No significant differences were observed among first-harvest or percent first-harvest lint yields (Table 24). Second-harvest lint yields were significantly greater in unsprayed Bollgard cotton than either conventional treatment. Total harvest yields of Bollgard cottons were significantly greater than those of conventional cottons. Because no

Table 19. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean plant height (cm) June 12	Mean no. nodes June 12	Mean no. plants/3.1 m June 12
Bollgard cotton unsprayed	6.4	4.4	39.4
Bollgard cotton sprayed when conventional sprayed	6.4	4.6	36.6
Conventional cotton unsprayed	6.8	4.7	34.8
Conventional cotton sprayed at 5% damaged squares	6.6	4.6	30.1
P > F	0.13	0.02	0.11

Table 20. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean no. eggs/20 terminals								Seasonal
	Jul 1	Jul 9	Jul 15	Jul 22	Jul 29	Aug 5	Aug 12	Aug 17	Mean
Bollgard cotton unsprayed	0.3	0.0	0.0	0.3	1.0	0.0	1.0	0.3	0.3
Bollgard cotton sprayed when conventional sprayed	0.3	0.0	0.0	0.0	0.0	0.8	1.5	0.3	0.3
Conventional cotton unsprayed	0.5	0.0	0.0	0.3	0.0	0.3	0.8	0.0	0.2
Conventional cotton sprayed at 5% damaged squares	0.3	0.0	0.0	0.0	0.3	0.8	1.3	0.3	0.3
P > F	0.23	1.00	1.00	0.73	0.15	0.48	0.64	0.94	0.50

Table 21. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean no. larvae/20 terminals								Seasonal
	Jul 1	Jul 9	Jul 15	Jul 22	Jul 29	Aug 5	Aug 12	Aug 17	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Bollgard cotton sprayed when conventional sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P > F	1.00	1.00	1.00	1.00	1.00	1.00	0.48	1.00	0.48

Table 22. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal
	Jul 1	Jul 9	Jul 15	Jul 22	Jul 29	Aug 5	Aug 12	Aug 17	Mean
Bollgard cotton unsprayed	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bollgard cotton sprayed when conventional sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional cotton sprayed at 5% damaged squares	0.0	0.5	0.0	0.0	0.0	0.0	0.3	0.0	0.1
P > F	1.00	0.18	1.00	1.00	1.00	1.00	0.48	1.00	0.07

Table 23. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal
	Jul 1	Jul 9	Jul 15	Jul 22	Jul 29	Aug 5	Aug 12	Aug 17	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Bollgard cotton sprayed when conventional sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P > F	1.00	1.00	1.00	1.00	1.00	1.00	0.48	1.00	0.48

Table 24. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Bollgard cotton unsprayed	1065	295 a[1/]	1360 a	77.8
Bollgard cotton sprayed when conventional sprayed	1049	281 ab	1330 a	78.7
Conventional cotton unsprayed	982	230 b	1213 b	80.5
Conventional cotton sprayed at 5% damaged squares	963	229 b	1192 b	80.1
P > F	0.17	0.04	0.02	0.45

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

treatments received insecticide application due to low Heliothine numbers, the higher yield in Bollgard cotton may not be due to reduction of Heliothine complex damage.

AMES LOCATION

In 1995, no significant differences were detected in plant heights and number of nodes (Table 25) among treatments. Plant densities were significantly greater in unsprayed conventional cotton than in other treatments. Seasonal mean densities of Heliothine eggs (Table 26) were significantly less on unsprayed conventional cotton than in the other treatments. The seasonal mean number of larvae (Table 27), damaged squares (Table 28) and damaged bolls (Table 29) were significantly greater in conventional cottons than Bollgard cottons. Heliothine pressure was greatest at this location, therefore, sprayed Bollgard received three treatments and sprayed conventional cotton received four insecticide treatments.

The first, second and total harvest lint yields (Table 30) were significantly greater in both Bollgard cottons compared to the unsprayed conventional cotton. However, no significant

Table 25. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Mean plant height (cm) June 13	Mean no. nodes June 13	Mean no. plants/3.1 m June 15
Bollgard cotton unsprayed	9.6	2.1	30.6 b[1/]
Bollgard cotton sprayed at 2% damaged squares	10.7	2.2	31.3 b
Conventional cotton unsprayed	11.2	2.4	41.3 a
Conventional cotton sprayed at 5% damaged squares	10.4	2.4	32.3 b
P > F	0.23	0.39	0.03

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 26. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. Ames Plantation, Grand Junction, Tenn. 1995.

	Mean no. eggs/20 terminals									Seasonal
Cultivar/Treatment	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.5	2.0	1.5	1.0 ab[1/]	0.0	10.0 ab	1.67 a
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0	0.5	2.5	1.0	1.3 ab	0.5	16.0 a	2.42 a
Conventional cotton unsprayed	0.0	0.0	0.0	0.3	1.3	1.3	0.3 b	0.0	5.0 b	0.91 b
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	2.0	1.0	1.5 a	0.0	12.5 a	1.89 a
P > F	1.00	1.00	1.00	0.21	0.63	0.41	0.03	0.48	0.01	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 27. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. Ames Plantation, Grand Junction, Tenn. 1995.

	Mean no. larvae/20 terminals									Seasonal
Cultivar/Treatment	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.5	0.0	0.0 b[1/]	0.0 b	5.0	0.61 b
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0	0.0	1.0	0.0	0.3 b	0.0 b	0.5	0.20 b
Conventional cotton unsprayed	0.5	0.3	0.0	0.0	1.8	0.3	1.3 a	2.0 a	2.0	0.91 a
Conventional cotton sprayed at 5% damaged squares	0.3	0.3	0.3	0.0	2.0	0.5	1.5 a	2.0 a	2.5	1.04 a
P > F	0.57	0.73	0.48	1.00	0.17	0.69	0.04	0.01	0.18	0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 28. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged squares/20 squares									Seasonal
	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.5	0.3 c[1/]	0.0	0.0 c	0.0 b	0.0	0.09 b
Bollgard cotton sprayed at 2% damaged squares	0.0	0.3	0.0	0.0	0.8 bc	0.0	0.0 c	0.0 b	0.0	0.12 b
Conventional cotton unsprayed	0.5	0.8	0.0	0.0	2.5 ab	1.0	3.3 a	2.8 a	0.0	1.21 a
Conventional cotton sprayed at 5% damaged squares	0.0	0.8	1.3	0.8	3.5 a	0.5	2.0 b	2.5 a	0.0	1.27 a
P > F	0.48	0.48	0.27	0.18	0.01	0.33	< 0.01	< 0.01	1.00	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 29. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls									Seasonal
	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1/]	0.0	0.00 b
Bollgard cotton sprayed at 2% damaged squares	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b	0.0	0.00 b
Conventional cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.5 a	2.0	0.56 a
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.8 a	2.0	0.51 a
P > F	1.00	1.00	1.00	1.00	1.00	1.00	0.32	0.01	0.15	0.02

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 30. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Bollgard cotton unsprayed	856 ab[1/]	119 a	974 ab	87.9 ab
Bollgard cotton sprayed at 2% damaged squares	874 a	118 a	991 a	88.3 a
Conventional cotton unsprayed	634 c	95 b	719 c	86.8 b
Conventional cotton sprayed at 5% damaged squares	792 b	106 ab	898 b	88.1 ab
P > F	< 0.01	< 0.01	< 0.01	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

differences in first, second and total yields were detected between conventional cotton treated with insecticides and unsprayed Bollgard cotton. The yield of sprayed Bollgard cotton was significantly greater than either conventional cotton at both first and total harvest. The first- and second-harvest data indicate significantly less lint yield in conventional unsprayed cotton than Bollgard treatments. Sprayed Bollgard cotton had a significantly higher percent first harvest than unsprayed conventional cotton.

In 1996, no significant differences were detected in plant (Table 31) or Heliothine egg densities (Table 32). Seasonal mean larval densities (Table 33) were significantly greater in the conventional cottons than in the Bollgard cottons. Most larvae observed in conventional cottons were developed beyond the neonate stage, while the few larvae found in Bollgard cotton were neonates. The seasonal mean number of damaged squares (Table 34) and damaged bolls (Table 35) were significantly greater in unsprayed conventional cotton than either Bollgard cotton treatment.

The first-harvest and percent first-harvest yields (Table 36) were significantly greater in both Bollgard cottons

Table 31. Effect of cotton cultivar and insecticide treatment on plant density. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Mean no. plants/3.1 m June 11
Bollgard cotton unsprayed	52.8
Bollgard cotton sprayed at 5% damaged squares	52.5
Conventional cotton unsprayed	62.8
Conventional cotton sprayed at 5% damaged squares	57.8
P > F	0.14

Table 32. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Mean no. eggs/20 terminals								Seasonal Mean
	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	
Bollgard cotton unsprayed	5.3	0.3	0.3	1.8	3.0	0.5	0.0	0.0	1.4
Bollgard cotton sprayed at 5% damaged squares	6.5	0.0	0.8	1.0	1.5	0.8	0.3	0.3	1.4
Conventional cotton unsprayed	6.3	0.0	0.3	0.8	1.5	0.5	0.5	0.3	1.3
Conventional cotton sprayed at 5% damaged squares	3.3	0.3	0.0	0.8	2.5	0.5	0.8	0.5	1.1
P > F	0.03	0.73	0.61	0.11	0.45	0.98	0.64	0.50	0.03

Table 33. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Mean no. larvae/20 terminals								Seasonal Mean
	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	
Bollgard cotton unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1]
Bollgard cotton sprayed at 5% damaged squares	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b
Conventional cotton unsprayed	0.3	1.8	0.8	0.0	0.3	0.3	0.3	0.0	0.4 a
Conventional cotton sprayed at 5% damaged squares	0.5	1.3	0.3	0.0	0.3	0.3	0.0	0.3	0.3 a
P > F	0.62	0.24	0.13	1.00	0.73	0.73	0.48	0.48	0.01

[1] Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 34. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal
	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Bollgard cotton unsprayed	0.8	0.0 b[1]	0.0 b	0.0	0.0 b	0.0 b	0.0	0.0	0.09 b
Bollgard cotton sprayed at 5% damaged squares	0.3	0.0 b	0.0 b	0.3	0.0 b	0.0 b	0.0	0.0	0.06 b
Conventional cotton unsprayed	2.5	4.3 a	2.3 a	0.3	1.8 a	0.5 b	0.5	0.0	1.50 a
Conventional cotton sprayed at 5% damaged squares	2.8	4.3 a	2.3 a	0.3	0.5 b	1.8 a	0.5	0.0	1.50 a
P > F	0.33	0.01	< 0.01	0.57	0.02	0.01	0.68	1.00	< 0.01

[1]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 35. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal
	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Bollgard cotton unsprayed	0.0	0.0	0.0 b[1]	0.0	0.0	0.0	0.0	0.0	0.00 b
Bollgard cotton sprayed at 5% damaged squares	0.0	0.0	0.0 b	0.0	0.0	0.0	0.0	0.0	0.00 b
Conventional cotton unsprayed	0.0	0.0	1.5 a	0.0	0.0	0.3	0.5	0.5	0.34 a
Conventional cotton sprayed at 5% damaged squares	0.0	0.0	0.5 ab	0.0	0.0	0.0	0.3	0.3	0.13 b
P > F	1.00	1.00	0.11	1.00	1.00	0.48	0.18	0.69	0.01

[1]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 36. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Lint yield (kg/ha) First	Lint yield (kg/ha) Second	Lint yield (kg/ha) Total	Percent first harvest
Bollgard cotton unsprayed	1260 a[1/]	201 c	1461 bc	86.2 a
Bollgard cotton sprayed at 5% damaged squares	1333 a	263 bc	1596 ab	83.6 a
Conventional cotton unsprayed	560 c	452 a	1012 d	55.0 c
Conventional cotton sprayed at 5% damaged squares	918 b	461 a	1379 c	66.1 b
P > F	< 0.01	< 0.01	< 0.01	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

than conventional cottons. The second-harvest yields were significantly greater in conventional cottons than Bollgard cottons. These data indicate an earlier maturity for Bollgard cotton, and a later maturity for conventional cottons. Similar to 1995 data, the yield of sprayed Bollgard cotton was significantly greater than either conventional cotton at both first and total harvest. No significant differences were observed between conventional cotton treated with insecticides (which received three treatments) and unsprayed Bollgard cotton in total yields. The first, total, and percent first harvest data indicate significantly less lint yield in conventional unsprayed cotton than Bollgard treatments. No significant differences were found among Bollgard treatments; however, the first, total and percent first yield of sprayed conventional cotton was significantly greater than unsprayed conventional cotton.

iv. SUMMARY

The number of damaged squares and bolls were generally lower for Bollgard cotton than conventional cotton throughout the season. Cotton at Ames experienced the greatest Heliothine complex numbers in 1995 and 1996 of any experiment location, and Bollgard cotton demonstrated protection from Heliothine complex damage throughout the season. These data suggest that Bollgard cotton may not require insecticide treatments to protect it from Heliothine complex damage. Data from all locations indicate that yields were not significantly different between Bollgard cotton not treated with insecticides and conventional cotton treated with insecticides which suggests that Bollgard cotton may not require insecticide treatments to preserve yield in West Tennessee, even in areas with higher Heliothine numbers like Ames.

The benefits of Bt cotton in low pressure areas such as WTES and Milan, however, need further exploration, due to factors such as cost of the technology. Data in 1995 and 1996 indicate that, under Heliothine complex pressures, Bollgard is comparable in yield performance with the conventional line and may be grown without application of insecticides for control of the Heliothine complex.

CHAPTER III

EVALUATION OF Bt/BXN COTTON FOR HELIOTHINE COMPLEX CONTROL AND YIELD POTENTIAL

i. INTRODUCTION

The main objectives of plant genetic engineering are currently insect resistance and herbicide resistance (Meredith 1995). BXN cotton, developed and patented by Calgene, is resistant to Buctril (bromoxynil), a nonresidual, postemergence herbicide with a short soil half-life which controls several annual broadleaf weed species. These weeds include morningglories, common cocklebur, bristly starbur, coffee senna, prickly sida, common lambsquarter, spurred anoda, velvetleaf, wild poinsettia, and some other species. Buctril is also economically cost effective (Ward et al. 1993, Wilcut 1995). Application of herbicides on herbicide-resistant cotton would allow much more flexibility in crop management, such as post emergence spraying as needed (Meredith 1993).

Stoneville Pedigreed Seed Company in conjunction with the Calgene company has combined BXN cotton with Bt cotton

(Bt/BXN) to provide the farmer two beneficial traits: 1) weed control with Buctril and 2) tobacco budworm and bollworm (Heliothine complex) control with Bt insecticidal protein. Plants with these combined gene constructions are resistant to Buctril herbicide and produce the Bt protein, which may help to control the Heliothine complex without chemical insecticides. The Stoneville and Calgene Research and Product Development teams have field tested the Bt/BXN combination in cotton plants for several years (Panter et al. 1993, Kiser 1995), though varieties will probably not be available to producers before 1998. More research needs to be conducted to establish the efficacy of Bt/BXN cotton in multiple locations. This study was conducted at three locations in West Tennessee to determine the ability of Bt/BXN cotton to control the Heliothine complex and to determine its yield potential under natural infestations.

The objectives of this study were to:

1. evaluate the performance of Bt/BXN cotton in managing the Heliothine complex,
2. determine if Bt/BXN cotton may need insecticide treatments to protect it from Heliothine complex damage, and

3. determine yield potential of Bt/BXN cotton under natural infestations and standard insecticide treatments.

ii. MATERIALS AND METHODS

In 1995, research was conducted at three locations in West Tennessee: Ames Plantation near Grand Junction, Milan Experiment Station in Milan, and the West Tennessee Experiment Station (WTES) in Jackson. Four treatments were evaluated at each location: 1) Bt/BXN cotton unsprayed (background not revealed by Calgene), 2) Bt/BXN cotton sprayed with insecticides for Heliothine complex control when treatment #4 is treated, 3) non-Bt cotton unsprayed (Coker 130), and 4) non-Bt cotton sprayed at 5% damaged square threshold. When Heliothine populations reached threshold levels in treatment #4, insecticides were applied to treatments #2 and #4. Insecticides used were cyfluthrin (Baythroid) and cyhalothrin (Karate), which are pyrethroids toxic to the Heliothine complex. Treatments were replicated four times (three at Milan) in a randomized complete block design, with four-row plots (rows were 1.02 m apart and 9.15 m long). Cotton varieties were planted on May 9 at WTES, May 11 at Milan (no-till), and May 23 at Ames according to the University of Tennessee Extension cotton production recommendations. Cotton was planted with aldicarb (Temik) (3.92 kg/ha) for thrips control.

Plant height, nodal development and plant density were determined in mid June as described in Chapter II. Cotton was monitored weekly for Heliothine complex from pinhead square stage at the beginning of July until late August to characterize insect pressure and determine plant damage. Insect pressure and plant damage in each plot were evaluated by examining the top 15.2 cm of 20 plants per plot and recording the number of Heliothine eggs, larvae, damaged squares and damaged bolls on each treatment. One square and one boll from each of these 20 plants were then examined for Heliothine damage and the presence of large (greater than 0.32 cm) Heliothine larvae. A square was considered damaged if a Heliothine larva had eaten a hole large enough to cause the bracts to flare open and the plant to abort the square. A boll was considered damaged if a Heliothine larva had eaten through the carpel wall. All experiments were oversprayed for boll weevil and plant bugs as needed. Experiments had 12 border rows of non-Bt/BXN cotton, as in the Bollgard 1995 experiment (Chapter II), for pollen and seed containment to prevent accidental release.

At WTES, sprayed plots were treated with cyfluthrin (0.18 L/ha) on July 14, 18 and 31. Cyhalothrin (0.29 L/ha) was applied on August 8 and 15. At Milan, sprayed plots were treated with cyfluthrin on July 14 and 19. At Ames, sprayed plots were treated with cyfluthrin on July 18 and August 21, and cyhalothrin on July 27 and August 15 and 16. The unsprayed Coker plot was treated in error on August 15.

To determine cotton yields, the center two rows of each plot were machine harvested twice. The harvest dates at WTES were on October 5 and 23, at Milan on October 9 and 30, and at Ames on October 13 and 30. The cotton lint yield from each harvest was ascertained and then combined to determine the total yield.

All data analyses were conducted using ANOVA and Fisher's Least Significant Difference test to determine significant differences among treatments. Data collected on eggs, larvae, damaged squares and damaged bolls were square root transformed for this test.

In 1996, Calgene Bt/BXN experiments were conducted at the same three locations with only a few modifications. The conventional non-Bt/BXN cotton used was ST 474, and a Bt/BXN cotton contained the ST 474 background. Cotton was planted on May 16 at WTES, May 9 at Milan (no-till), and May 6 at Ames according to the University of Tennessee Extension cotton production recommendations. Cotton was planted with aldicarb (Temik) (3.92 kg/ha) for thrips control. Experiments had 12 border rows of non-Bt/BXN cotton for pollen and seed containment to prevent accidental release. Plots were evaluated, and cotton was monitored for the same data (such as plant density, yield, and number of eggs, larvae, damaged squares and damaged bolls) using similar methods to those described for 1995. During 1996, however, larval size was classified as neonate or larger (greater than 0.32 cm) for more accuracy. Neonate larvae would be expected on both conventional and Bollgard cotton because larvae must digest some Bt toxin to cause midgut paralysis and death. Also, cotton at Ames Plantation had irregular heights within each row possibly due to soil compaction before planting, therefore height and node data were not taken. At Ames, all plots treated with insecticides had cyhalothrin (0.29 L/ha) applied on July 5, 12, 19, and August 2. No other locations received treatment.

To determine cotton yields, the center two rows of each plot were machine harvested twice. The harvest dates at WTES were on October 24 and November 4, at Milan on October 7 and November 5, and at Ames on October 17 and November 4. The cotton lint yield from each harvest was ascertained and then combined to determine the total yield.

iii. RESULTS AND DISCUSSION

WTES LOCATION

In 1995, plant height, mean number of nodes, and plant densities were not significantly different among treatments (Table 37). Seasonal mean numbers of eggs (Table 38) and larvae (Table 39) were not significantly different among treatments. The seasonal mean number of damaged squares (Table 40) was significantly greater in Coker 130 cotton than in Bt/BXN cotton. Also, significantly more damaged squares, based on the seasonal mean, were found in sprayed Coker 130 than in unsprayed Coker 130. Seasonal mean numbers of damaged bolls (Table 41) were significantly greater in unsprayed Coker 130 than in either Bt/BXN cotton treatment. These data indicate that Bt/BXN provides protection from Heliothine complex damage throughout the season. No significant differences were found in lint yields (Table 42) among

Table 37. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. West Tennessee Experiment Station, Jackson, Tenn. 1995.

Cultivar/Treatment	Mean plant height (cm) June 12	Mean no. nodes June 12	Mean no. plants/3.1 m June 14
Stoneville Bt/BXN unsprayed	12.2	3.7	31.1
Stoneville Bt/BXN sprayed	12.2	3.9	33.6
Stoneville Coker 130 unsprayed	15.5	4.9	31.4
Stoneville Coker 130 sprayed	15.7	4.5	29.6
P > F	0.06	0.17	0.17

Table 38. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar/Treatment	Mean no. eggs/20 terminals								Seasonal Mean
	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	1.5a[1/]	0.8 a	0.5	0.0	0.4
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	3.3 b	0.3 b	0.3	0.0	0.5
Stoneville Coker 130 unsprayed	0.0	0.0	0.0	0.0	2.3 b	0.5 b	0.3	0.0	0.4
Stoneville Coker 130 sprayed	0.0	0.0	0.8	0.0	2.0 ab	0.8 ab	0.0	0.0	0.5
P > F	1.00	1.00	0.48	1.00	< 0.01	< 0.01	0.50	1.00	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 39. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar/Treatment	Mean no. larvae/20 terminals								Seasonal Mean
	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0 b[1/]	0.0
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3 ab	0.0
Stoneville Coker 130 unsprayed	0.0	0.0	0.0	0.0	0.0	1.3	2.3	0.8 a	0.6
Stoneville Coker 130 sprayed	0.5	0.0	0.3	0.0	0.3	0.5	0.8	0.3 ab	0.3
P > F	0.17	1.00	0.48	1.00	0.48	0.14	0.23	0.05	0.09

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 40. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal Mean
	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	
Stoneville Bt/BXN unsprayed	0.0	0.3	0.0 b[1/]	0.0	0.0 b	0.0 b	0.5 b	0.0	0.1 c
Stoneville Bt/BXN sprayed	0.0	0.3	0.0 b	0.0	0.3 b	0.0 b	0.3 b	0.5	0.2 c
Stoneville Coker 130 unsprayed	0.0	0.8	0.0 b	0.0	0.3 b	1.3 a	3.0 a	1.0	0.8 b
Stoneville Coker 130 sprayed	0.5	1.3	1.8 a	0.5	2.8 a	1.3 a	3.0 a	1.0	1.5 a
P > F	0.09	0.01	0.05	0.48	0.01	0.01	0.01	0.20	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 41. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal Mean
	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.3	0.0	0.0 b[1/]	0.0	0.0 bc
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b	0.0	0.0 c
Stoneville Coker 130 unsprayed	0.0	0.0	0.0	0.0	0.3	0.0	1.3 a	1.5	0.4 a
Stoneville Coker 130 sprayed	0.0	0.0	0.0	0.0	0.0	0.0	1.0 ab	0.8	0.2 ab
P > F	1.00	1.00	1.00	1.00	0.17	1.00	0.04	0.09	0.03

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 42. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Stoneville Bt/BXN unsprayed	734	351	1084	67.1
Stoneville Bt/BXN sprayed	775	384	1159	66.9
Stoneville Coker 130 unsprayed	968	297	1264	75.6
Stoneville Coker 130 sprayed	1156	224	1380	83.9
P > F	0.08	0.18	0.09	0.09

treatments. Therefore, unsprayed Bt/BXN cotton yielded similarly to conventional cotton sprayed with insecticides five times.

In 1996, plant height and the number of nodes (Table 43) in Bt/BXN cotton were significantly lower than in ST 474 (conventional) cotton. These differences may be attributed to less vigor, lower germination rate, or other factors in Bt/BXN cotton. Although treatments had not been applied when density data were collected, densities of plants in unsprayed ST 474 cotton were significantly greater than those in unsprayed Bt/BXN cotton.

Seasonal mean densities of eggs (Table 44), larvae (Table 45), or numbers of damaged squares (Table 46) were not significantly different among treatments. The seasonal mean number of Heliothine damaged bolls (Table 47) was significantly less in Bt/BXN cotton than in ST 474 cotton. Heliothine complex populations were low at WTES in 1996, therefore, no treatments received insecticide applications.

First-harvest lint yields (Table 48) were significantly greater in ST 474 cottons than unsprayed Bt/BXN cottons. These data may indicate an earlier yield for ST 474 cottons. No significant differences were found among second, total or percent first harvests, similar to 1995 data.

Table 43. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean plant height (cm) June 12	Mean no. nodes June 12	Mean no. plants/3.1 m June 12
Stoneville Bt/BXN unsprayed	2.8 b[1/]	1.9 b	27.0 b
Stoneville Bt/BXN sprayed	3.2 b	2.0 b	30.4 ab
Stoneville ST 474 unsprayed	4.4 a	3.0 a	34.8 a
Stoneville ST 474 sprayed	4.1 a	2.7 a	31.1 ab
P > F	< 0.01	< 0.01	0.06

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 44. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean no. eggs/20 terminals								Seasonal
	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Stoneville Bt/BXN unsprayed	0.8	0.0	0.0	0.3	0.5	0.5	1.0	0.3	0.4
Stoneville Bt/BXN sprayed	0.5	0.0	0.0	0.5	1.5	0.5	0.5	0.0	0.4
Stoneville ST 474 unsprayed	0.0	0.0	0.0	0.3	0.8	0.3	0.8	0.3	0.3
Stoneville ST 474 sprayed	1.0	0.0	0.0	0.0	0.3	0.8	1.5	0.0	0.4
P > F	0.15	1.00	1.00	0.62	0.67	0.99	0.78	0.73	0.71

Table 45. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean no. larvae/20 terminals								Seasonal
	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stoneville ST 474 unsprayed	0.0	0.3	0.0	0.0	0.0	0.0	0.8	0.3	0.2
Stoneville ST 474 sprayed	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5	0.1
P > F	1.00	0.48	1.00	1.00	1.00	0.17	0.20	0.18	0.21

Table 46. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal Mean
	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Stoneville ST 474 unsprayed	0.0	0.0	0.0	0.0	0.0	0.5	0.8	0.3	0.2
Stoneville ST 474 sprayed	0.0	0.5	0.0	0.0	0.0	0.8	0.5	0.5	0.3
P > F	1.00	0.48	1.00	1.00	1.00	0.18	0.62	0.57	0.26

Table 47. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal Mean
	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0b[1/]	0.0	0.0	0.0 c
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0 b	0.0	0.0	0.0 c
Stoneville ST 474 unsprayed	0.0	0.0	0.0	0.0	0.0	0.3 b	0.5	0.5	0.2 b
Stoneville ST 474 sprayed	0.0	0.0	0.0	0.0	0.0	1.3 a	1.0	0.8	0.4 a
P > F	1.00	1.00	1.00	1.00	1.00	0.01	0.23	0.37	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 48. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Stoneville Bt/BXN unsprayed	828 b[1/]	100	928	89.4
Stoneville Bt/BXN sprayed	981 ab	92	1073	91.4
Stoneville ST 474 unsprayed	1098 a	85	1183	92.8
Stoneville ST 474 sprayed	1038 a	79	1117	93.1
P > F	0.04	0.69	0.10	0.06

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

MILAN LOCATION

In 1995, plant height and number of nodes (Table 49) in Bt/BXN cotton were significantly lower than in Coker 130 (conventional) cotton, similar to data for 1996 WTES. Plant densities were not significantly different among treatments (Table 49). Egg (Table 50) or larval densities (Table 51) were not significantly different averaged throughout the season. Seasonal mean number of damaged squares (Table 52) was significantly greater for Coker 130 cotton than Bt/BXN cotton. Also, sprayed Coker 130 had significantly more damaged squares than unsprayed Coker 130, similar to 1995 WTES. Low numbers of damaged bolls (Table 53) were observed throughout the season, and no significant differences were documented. Heliothine pressure was low at Milan in 1995; therefore, only two insecticide applications were necessary.

First-harvest lint yields and percent first harvest (Table 54) were significantly greater in Coker 130 than in Bt/BXN cottons, similar to data for WTES and Ames during 1995. However, second-harvest yields were significantly greater for Bt/BXN cottons, which may indicate later maturity. Total yield was significantly greater for sprayed Coker 130 plots than either Bt/BXN treatment. Also, total yield of unsprayed Coker 130 was significantly greater than unsprayed Bt/BXN

Table 49. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Mean plant height (cm) June 9	Mean no. nodes June 9	Mean no. plants/3.1 m June 14
Stoneville Bt/BXN unsprayed	11.7 b[1/]	3.5 b	29.8
Stoneville Bt/BXN sprayed	11.7 b	3.3 b	31.8
Stoneville Coker 130 unsprayed	19.5 a	4.2 a	37.5
Stoneville Coker 130 sprayed	21.1 a	4.3 a	40.3
P > F	< 0.01	0.02	0.13

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 50. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Mean no. eggs/20 terminals								Seasonal
	Jul 6	Jul 12	Jul 18	Jul 25	Aug 2	Aug 9	Aug 16	Aug 23	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.3	2.7 a[1/]	0.0	0.0	0.4
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	1.0	1.3 ab	0.0	0.0	0.3
Stoneville Coker 130 unsprayed	0.0	0.0	0.0	0.0	1.0	0.0 b	0.3	0.0	0.2
Stoneville Coker 130 sprayed	0.0	0.0	0.0	0.0	0.3	0.3 b	0.0	0.0	0.1
P > F	1.00	1.00	1.00	1.00	0.56	0.02	0.49	1.00	0.28

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 51. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Mean no. larvae/20 terminals								Seasonal
	Jul 6	Jul 12	Jul 18	Jul 25	Aug 2	Aug 9	Aug 16	Aug 23	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.1
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Stoneville Coker 130 unsprayed	0.0	0.0	0.3	0.0	0.0	0.0	0.7	0.7	0.2
Stoneville Coker 130 sprayed	0.0	0.7	0.3	0.0	0.7	2.3	0.7	0.7	0.7
P > F	1.00	0.49	0.25	1.00	0.49	0.46	0.64	0.31	0.23

Table 52. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal Mean
	Jul 6	Jul 12	Jul 18	Jul 25	Aug 2	Aug 9	Aug 16	Aug 23	
Stoneville Bt/BXN unsprayed	0.3	0.0 b[1/]	0.0	0.0	0.0	0.0	0.0 b[1/]	0.0	0.0 c
Stoneville Bt/BXN sprayed	0.0	0.0 b	0.0	0.0	0.0	0.0	0.0 b	0.0	0.0 c
Stoneville Coker 130 unsprayed	0.7	0.3 b	1.7	0.0	0.0	0.3	1.3 a	0.0	0.5 b
Stoneville Coker 130 sprayed	0.3	3.3 a	2.7	0.0	1.0	0.7	0.7 ab	0.7	1.2 a
P > F	0.41	< 0.01	0.19	1.00	0.16	0.57	0.02	0.12	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 53. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal Mean
	Jul 6	Jul 12	Jul 18	Jul 25	Aug 2	Aug 9	Aug 16	Aug 23	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.1
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Stoneville Coker 130 unsprayed	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.7	0.4
Stoneville Coker 130 sprayed	0.0	0.0	0.0	0.0	0.0	1.0	0.3	2.7	0.5
P > F	1.00	1.00	1.00	1.00	1.00	0.18	0.49	0.31	0.23

Table 54. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. Milan Experiment Station, Milan, Tenn. 1995.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Stoneville Bt/BXN unsprayed	698 b[1/]	307 a	1004 c	69.2 b
Stoneville Bt/BXN sprayed	755 b	309 a	1065 bc	70.7 b
Stoneville Coker 130 unsprayed	982 a	218 b	1201 ab	81.8 a
Stoneville Coker 130 sprayed	1024 a	211 b	1235 a	82.8 a
P > F	< 0.01	< 0.01	0.02	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

cotton. The higher lint yield in Coker 130 than Bt/BXN occurred even though the damaged square count was significantly greater for Coker 130. This trend also occurred at the Ames location during 1995. These data indicate that Coker 130 may be a higher yielding variety than the Bt/BXN variety (the background of Bt/BXN was not revealed by Calgene), the significant decrease in Bt/BXN cotton height and number of nodes compared to Coker 130 may have led to a reduced yield, or Coker 130 may be better able to compensate for damage.

In 1996, plant height (Table 55) of Bt/BXN cottons was significantly lower than in the ST 474 (conventional) cottons, similar to data for 1995, 1996 WTES and 1995 Milan. No significant differences in number of nodes or plant densities were observed among treatments.

Seasonal mean densities of eggs (Table 56), larvae (Table 57), or numbers of damaged squares (Table 58) and damaged bolls (Table 59) were not significantly different among treatments. Data revealing no differences among treatments are probably due to the presence of few Heliothine during 1996; thus, no damage occurred to treatments. No insecticide treatments were necessary at Milan in 1996.

Table 55. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean plant height (cm) June 12	Mean no. nodes June 12	Mean no. plants/3.1 m June 12
Stoneville Bt/BXN unsprayed	5.5 c[1/]	4.2	31.0
Stoneville Bt/BXN sprayed	5.4 c	4.2	30.0
Stoneville ST 474 unsprayed	6.6 b	4.7	37.3
Stoneville ST 474 sprayed	6.8 a	4.7	34.8
P > F	< 0.01	0.13	0.19

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 56. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean no. eggs/20 terminals								Seasonal
	Jul 1	Jul 9	Jul 15	Jul 22	Jul 29	Aug 5	Aug 12	Aug 17	Mean
Stoneville Bt/BXN unsprayed	0.7	0.3	0.0	0.0	0.7	0.0	0.0	0.0	0.2
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.3	1.0	0.0	0.2
Stoneville ST 474 unsprayed	0.0	0.0	0.0	0.7	0.0	0.3	0.3	0.3	0.2
Stoneville ST 474 sprayed	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.1
P > F	0.21	0.76	1.00	0.12	0.49	0.76	0.26	0.25	0.97

Table 57. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean no. larvae/20 terminals								Seasonal
	Jul 1	Jul 9	Jul 15	Jul 22	Jul 29	Aug 5	Aug 12	Aug 17	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Stoneville ST 474 unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Stoneville ST 474 sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P > F	1.00	1.00	1.00	1.00	1.00	1.00	0.49	0.76	0.70

Table 58. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged squares/20 squares								Seasonal
	Jul 1	Jul 9	Jul 15	Jul 22	Jul 29	Aug 5	Aug 12	Aug 17	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stoneville Bt/BXN sprayed	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.1
Stoneville ST 474 unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stoneville ST 474 sprayed	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.1
P > F	1.00	0.76	1.00	1.00	1.00	0.49	1.00	0.49	0.72

Table 59. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal
	Jul 1	Jul 9	Jul 15	Jul 22	Jul 29	Aug 5	Aug 12	Aug 17	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stoneville ST 474 unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Stoneville ST 474 sprayed	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
P > F	1.00	1.00	1.00	1.00	1.00	0.49	1.00	0.49	0.25

First, total, and percent first-harvest yields (Table 60) were significantly greater in unsprayed Bt/BXN and unsprayed ST 474 than sprayed cotton treatments. However, second-harvest yields were significantly higher in sprayed cotton treatments. Although unsprayed Bt/BXN was significantly shorter than unsprayed ST 474 and sprayed Bt/BXN was significantly shorter than sprayed ST 474, total yields were not significantly different within the sprayed or unsprayed treatments. Also, unsprayed Bt/BXN had significantly higher yield than sprayed ST 474 (though no sprays were applied). However, unsprayed cottons had significantly higher yields than sprayed cottons, which may indicate beneficial insects were reduced in sprayed plots, or other factors were involved.

AMES LOCATION

In 1995, plant height, plant density (Table 61), and seasonal mean densities of eggs (Table 62) and larvae (Table 63) were not significantly different among treatments. However, the number of nodes in Bt/BXN cotton were significantly lower than in Coker 130 cotton (Table 61), similar to data for 1995, 1996 WTES and Milan. The seasonal mean number of damaged squares (Table 64) and bolls (Table 65)

Table 60. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. Milan Experiment Station, Milan, Tenn. 1996.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Stoneville Bt/BXN unsprayed	1265 a[1/]	324 b	1588 a	79.5 a
Stoneville Bt/BXN sprayed	773 b	449 a	1223 b	63.2 b
Stoneville ST 474 unsprayed	1265 a	287 b	1551 a	81.5 a
Stoneville ST 474 sprayed	842 b	499 a	1342 b	62.7 b
P > F	< 0.01	< 0.01	< 0.01	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 61. Effect of cotton cultivar and insecticide treatment on plant height, number of nodes and plant density. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Mean plant height (cm) June 13	Mean no. nodes June 13	Mean no. plants/3.1 m June 15
Stoneville Bt/BXN unsprayed	8.9	1.6 b[1/]	33.8
Stoneville Bt/BXN sprayed	8.4	1.6 b	32.0
Stoneville Coker 130 unsprayed	9.9	2.1 a	40.3
Stoneville Coker 130 sprayed	10.2	2.1 a	41.9
P > F	0.48	0.03	0.08

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 62. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Mean no. eggs/20 terminals									Seasonal
	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	1.0	2.5	1.8	0.0	1.5	9.5	1.8
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.3	4.8	1.8	0.5	0.0	16.0	2.6
Stoneville Coker 130 unsprayed	0.0	0.0	0.0	0.5	1.8	0.8	0.5	0.0	26.0	3.3
Stoneville Coker 130 sprayed	0.0	0.0	0.0	0.5	3.5	0.8	0.3	2.5	8.5	1.8
P > F	1.00	1.00	1.00	0.06	0.07	0.80	0.63	0.16	0.08	0.13

Table 63. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Mean no. larvae/20 terminals									Seasonal
	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1]	0.5	2.5	0.3
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.3 b	0.5	2.0	0.3
Stoneville Coker 130 unsprayed	0.0	0.3	0.0	0.3	0.8	0.0	1.8 a	0.0	8.0	1.2
Stoneville Coker 130 sprayed	0.0	0.3	0.0	0.3	0.3	0.0	0.3 b	0.3	3.5	0.6
P > F	1.00	0.73	1.00	0.73	0.07	1.00	0.03	0.61	0.52	0.16

[1]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 64. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged squares/20 squares									Seasonal Mean
	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0 b[1/]	0.0	0.0 c	0.8	0.0	0.1 b
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0 b	0.0	0.3 c	0.8	0.0	0.1 b
Stoneville Coker 130 unsprayed	0.0	0.3	0.8	0.8	1.0 a	0.8	3.0 a	1.3	0.5	0.9 a
Stoneville Coker 130 sprayed	0.0	2.5	0.3	1.0	0.5 ab	0.8	1.5 b	1.0	0.0	0.8 a
P > F	1.00	0.28	0.66	0.07	0.04	0.36	< 0.01	0.88	0.48	0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 65. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls									Seasonal Mean
	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0 b[1/]
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1 b
Stoneville Coker 130 unsprayed	0.0	0.0	0.0	0.3	0.5	0.0	0.3	0.8	0.0	0.2 a
Stoneville Coker 130 sprayed	0.0	0.0	0.0	0.0	0.3	0.0	1.0	1.0	0.5	0.3 a
P > F	1.00	1.00	1.00	0.48	0.18	1.00	0.15	0.81	0.48	0.02

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

were significantly greater in Coker 130 cotton than in Bt/BXN cotton. Heliothine pressure was greatest at this location, with sprayed plots receiving five insecticide applications.

First-harvest lint yields (Table 66) were significantly greater in sprayed Coker 130 than unsprayed Coker 130 cotton. Also, first-harvest Bt/BXN yields did not significantly differ from Coker 130 yields. Percent first-harvest yields were significantly greater in Coker 130 cotton. Second-harvest lint yields were significantly greater in Bt/BXN cotton than Coker 130 cotton, similar to the 1995 Milan experiment, which enabled Bt/BXN to produce high total yields despite not having an early maturity. Total lint yields were significantly greater in Bt/BXN cotton than in unsprayed Coker 130 cotton, yet did not differ significantly from sprayed Coker 130 cotton. Although Bt/BXN cottons had a significantly lower number of nodes in early-season counts than Coker 130 cottons, unsprayed Bt/BXN still yielded competitively with sprayed Coker 130 (which received five insecticide treatments) at total harvest. These data suggest that in high pressure areas of West Tennessee, Bt/BXN may not require insecticide treatment to preserve its yield.

In 1996, plant densities (Table 67) and seasonal mean densities of eggs (Table 68) were not significantly different

Table 66. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Stoneville Bt/BXN unsprayed	657 ab[1/]	231 a	888 a	74.0 b
Stoneville Bt/BXN sprayed	662 ab	214 a	876 a	75.6 b
Stoneville Coker 130 unsprayed	642 b	131 b	774 b	83.0 a
Stoneville Coker 130 sprayed	698 a	128 b	825 ab	84.4 a
P > F	0.01	< 0.01	0.01	< 0.1

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 67. Effect of cotton cultivar and insecticide treatment on plant density. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Mean no. plants/3.1 m June 12
Stoneville Bt/BXN unsprayed	28.0
Stoneville Bt/BXN sprayed	22.8
Stoneville ST 474 unsprayed	22.8
Stoneville ST 474 sprayed	24.8
P > F	0.89

Table 68. Effect of cotton cultivar and insecticide treatment on Heliothine egg densities. Ames Plantation, Grand Junction, Tenn. 1996.

	Mean no. eggs/20 terminals								Seasonal
Cultivar/Treatment	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Stoneville Bt/BXN unsprayed	9.8	0.0	0.3	1.0	0.5	0.3 c[1/]	0.8	0.0	1.6
Stoneville Bt/BXN sprayed	10.8	0.3	0.0	1.3	0.8	1.0 ab	0.3	0.0	1.8
Stoneville ST 474 unsprayed	6.5	0.5	0.0	1.8	0.8	0.8 bc	0.5	0.0	1.3
Stoneville ST 474 sprayed	5.8	0.3	0.0	1.3	1.0	1.8 a	0.5	0.3	1.3
P > F	0.45	0.86	0.53	0.98	1.0	0.02	0.38	0.53	0.51

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

among treatments. Seasonal mean number of larvae (Table 69) and damaged squares (Table 70) were significantly greater in ST 474 cotton than in Bt/BXN cotton. Also, significantly more larvae and square damage were found in unsprayed ST 474 cotton than in sprayed ST 474 cotton. Most larvae observed in conventional cottons were beyond neonate stage, while only a few neonate larvae were found in Bt/BXN cotton. Seasonal mean numbers of damaged bolls (Table 71) were not significantly different among treatments.

First-harvest yields (Table 72) were significantly lower in unsprayed ST 474 than other treatments. No significant differences were observed in second or percent first harvests, or between Bt/BXN treatments in total harvest. Yield of sprayed ST 474 was significantly higher than unsprayed ST 474, though ST 474 treatments had significantly more damage to squares. These data indicate that ST 474 may be higher yielding than Bt/BXN, or there may have been differences in height and nodes, similar to 1995 data. Because cotton at Ames had irregular heights within each row, possibly due to soil compaction before planting, these data were not collected.

Table 69. Effect of cotton cultivar and insecticide treatment on Heliothine larval densities. Ames Plantation, Grand Junction, Tenn. 1996.

	Mean no. larvae/20 terminals								Seasonal
Cultivar/Treatment	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0 b[1/]	0.0	0.0	0.0	0.0 c
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0 b	0.0	0.0	0.0	0.0 c
Stoneville ST 474 unsprayed	1.5	1.8	0.0	1.0	1.5 a	0.3	0.5	2.0	1.1 a
Stoneville ST 474 sprayed	0.8	2.3	0.3	0.5	0.3 b	0.3	0.3	0.5	0.6 b
P > F	0.30	0.13	0.53	0.27	0.02	0.73	0.53	0.40	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 70. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged squares. Ames Plantation, Grand Junction, Tenn. 1996.

	Mean no. damaged squares/20 squares								Seasonal
Cultivar/Treatment	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Stoneville Bt/BXN unsprayed	0.3	0.8 b[1/]	0.0	0.0	0.0 c	0.0	0.0	0.0	0.1 c
Stoneville Bt/BXN sprayed	0.0	0.0 b	0.0	0.0	0.0 c	0.0	0.3	0.0	0.0 d
Stoneville ST 474 unsprayed	5.0	10.0 a	2.5	1.8	2.8 a	1.3	0.8	0.8	3.1 a
Stoneville ST 474 sprayed	3.5	8.5 a	1.5	0.8	1.0 b	0.5	0.5	0.8	2.1 b
P > F	0.12	0.02	0.32	0.33	0.01	0.45	0.83	0.56	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 71. Effect of cotton cultivar and insecticide treatment on the number of Heliothine damaged bolls. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Mean no. damaged bolls/20 bolls								Seasonal Mean
	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	
Stoneville Bt/BXN unsprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1/]	0.0
Stoneville Bt/BXN sprayed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b	0.0
Stoneville ST 474 unsprayed	0.0	0.0	0.0	0.0	0.5	0.0	0.8	2.3 a	0.4
Stoneville ST 474 sprayed	0.0	0.0	0.0	0.0	0.8	0.0	0.5	0.0 b	0.2
P > F	1.00	1.00	1.00	1.00	0.31	1.00	0.31	< 0.01	0.09

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 72. Effect of cotton cultivar and insecticide treatment on lint yield and maturity. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar/Treatment	Lint yield (kg/ha)			Percent first harvest
	First	Second	Total	
Stoneville Bt/BXN unsprayed	729 a[1/]	191	920 bc	79.1
Stoneville Bt/BXN sprayed	814 a	143	957 ab	85.1
Stoneville ST 474 unsprayed	485 b	233	718 c	66.5
Stoneville ST 474 sprayed	915 a	239	1155 a	79.5
P > F	0.03	0.33	0.02	0.12

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

iv. SUMMARY

The seasonal mean number of damaged squares and bolls were generally lower for Bt/BXN cotton than conventional cottons. Cotton at Ames experienced the greatest Heliothine complex pressure in 1995 and 1996 of any experiment location, and Bt/BXN cotton demonstrated protection against Heliothine complex damage throughout the season. These data suggest that Bt/BXN cotton may not require insecticide treatments to protect it from Heliothine complex damage in West Tennessee.

Total harvest yields at WTES and Milan were significantly lower for unsprayed Bt/BXN cotton than sprayed Coker 130 conventional cotton, yet Coker 130 had significantly greater numbers of damaged squares. These data suggest that: 1) Bt/BXN cotton is lower yielding, possibly due to its decreased height and node numbers, or 2) Coker 130 recovers from damage faster. Insect pressure was greatest at Ames Plantation, where in 1995, total harvest was not significantly different between unsprayed Bt/BXN cotton and sprayed Coker 130 conventional cotton which was treated five times. However, in 1996, sprayed ST 474 had a higher total yield than unsprayed Bt/BXN. More research needs to be conducted on the benefits of Bt/BXN cotton use in West Tennessee.

CHAPTER IV

IMPACT OF PLANTING DATE AND Bt COTTON (NuCOTN 33B and HARTZ Bt1215) ON HELIOTHINE COMPLEX CONTROL AND YIELD POTENTIAL

i. INTRODUCTION

While it is difficult to predict which cotton insect pests will cause the most problems in a given year, certain management techniques can help a grower to deal more effectively with the major pests which emerge during the season. Early planting and harvesting are considered important management tools for traditional cotton production because populations of tobacco budworm and bollworm (Heliothine complex) which are typically the highest and most insecticide resistant during the late season can be avoided. Early-planted cotton matures before the late-season emergence of the Heliothine complex. Manipulation of planting date is a useful management tactic which can minimize cotton yield losses to late-season insect pests and decrease the cost and need for their control with synthetic insecticides (Ihrig et al. 1995). Suitable early-planting dates for traditional cotton in Tennessee are April 20 to May 10, with cotton planted after May 20 yielding less and requiring more insecticide applications (Shelby 1996).

Because the target pests of Bt cotton are the Heliothine complex, late-season populations of these pests may not need additional insecticide applications or reduce yields. A late-planting date for transgenic Bt cotton will offer the grower more flexibility than with traditional cotton. Only after thorough evaluation under varying planting dates can the proper use of Bt cottons be determined (Meredith 1995).

NuCOTN 33B was developed by Delta and Pine Land Company using the Monsanto Bollgard gene and was used for this experiment in 1995. Hartz Bt1215 produced by Jacob Hartz Co. was used in 1996. NuCOTN 33B had a DPL 5415 background, while Hartz Bt1215 had a Hartz 1215 background.

The objectives of this study were to:

1. determine Heliothine complex damage on two Bt cottons (NuCOTN 33B and Hartz Bt1215),
2. determine if NuCOTN 33B and/or Hartz Bt1215 may need insecticide treatments to protect them from damage, and
3. determine impact of planting dates on yield of NuCOTN 33B and Hartz Bt1215.

ii. MATERIALS AND METHODS

In 1995, research was conducted at two locations in West Tennessee: Ames Plantation in Grand Junction and the West Tennessee Experiment Station (WTES) in Jackson to evaluate the performance of NuCOTN 33B (Bt) and DPL 5415 (conventional recurrent parent) planted at three planting dates (early, mid and late). Satisfactory planting dates in Tennessee are April 20 to May 10, with planting dates after May 20 tending to reduce yields and requiring more insecticide applications (Shelby 1996). For this experiment, early planting was April 26 at WTES and April 27 at Ames, mid planting was May 9 at WTES and May 11 at Ames, and late planting was May 22 at WTES and May 23 at Ames. Six treatments were evaluated at each location: 1) NuCOTN 33B early, 2) NuCOTN 33B mid, 3) NuCOTN 33B late, 4) DPL 5415 early, 5) DPL 5415 mid, and 6) DPL 5415 late. When Heliothine square damage reached recommended threshold levels (5%) in treatments #4-6, insecticides were applied to those treatments. Insecticides used were cyfluthrin (Baythroid) and cyhalothrin (Karate), which are pyrethroids toxic to the Heliothine complex. NuCOTN 33B plots were not treated with insecticides throughout the season. Treatments were replicated four times in a randomized complete block design, with four row plots (rows were 1.02 m apart and 9.15 m long). Cotton was planted with aldicarb (Temik) (3.92 kg/ha) applied in-furrow for control of thrips.

Plant density was determined in mid June as described in Chapter II. Cotton was monitored weekly for Heliothine complex from pinhead square stage at the beginning of July until late August to characterize insect pressure and determine plant damage. Insect pressure and plant damage was evaluated as described in Chapters II and III.

All plots initially received the same amount of fertilizer. Additional nitrogen (22.68 kg) was applied to the late-planted cotton at the pinhead square stage (July 6 at WTES and July 27 at Ames) to compensate for possible nitrogen losses which may have occurred in the time interval between the preplant application and the late planting. PIX plant growth regulator was applied to all early-planted treatments on July 18 at WTES and July 28 at Ames to control excessive vegetative growth. All experiments were oversprayed for boll weevils and plant bugs as needed.

At WTES, all DPL 5415 plots were treated with cyfluthrin (0.18 L/ha) on July 14, and the mid-planting DPL 5415 also was treated with cyhalothrin (0.29 L/ha) on August 15. At Ames, all DPL 5415 plots were treated with cyhalothrin on August 1, 8 and 15 and with cyfluthrin on August 21. The mid-planting of DPL 5415 also was treated with cyfluthrin on August 29.

To determine cotton yields, the middle two rows of each plot were machine harvested twice. Cotton at WTES was harvested on October 5 and 23 and at Ames on October 16 and 30. The cotton lint yield from each harvest was ascertained and then combined to determine the total yield.

All data analyses were conducted using ANOVA and Fisher's Least Significant Difference test to determine differences among treatments. Data collected on eggs, larvae, damaged squares and damaged bolls were square root transformed for this test.

In 1996, experiments were conducted at the same two locations with only a few modifications. The Bt cotton used was Hartz Bt1215, which was compared to the conventional cotton Hartz 1215. Early planting was May 2 at both WTES and Ames, mid planting was May 15 at WTES and May 16 at Ames, and late planting was May 24 at both WTES and Ames. Aldicarb (3.92 kg/ha) was applied in-furrow at planting for control of thrips. Height of cotton within each row at Ames was irregular possibly due to soil compaction prior to planting, so height and node data were not collected at this location. Plots were evaluated, and cotton was monitored for the same data (such as plant density, yield, and number of eggs, larvae, damaged squares and damaged bolls) using similar methods to those described for 1995. During 1996, however, larval size was classified as neonate or larger (greater than 0.32 cm) for more accuracy.

At Ames, early- and mid-planted 1215 cotton was treated with insecticides on July 5. Early, mid and late- planted 1215 cotton was treated on July 12, early and late 1215 cotton was treated on July 19, and mid- and late-planted 1215 cotton was treated on August 2. WTES received no treatments.

To determine cotton yields, the middle two rows of each plot were machine harvested twice. Cotton at WTES was harvested on October 4 and 30 and at Ames on October 17 and November 4. The cotton lint yield from each harvest was ascertained and then combined to determine the total yield.

iii. RESULTS AND DISCUSSION

WTES LOCATION

In 1995, plant densities (Table 73) were significantly greater for NuCOTN 33B and DPL 5415 mid-planted varieties than any other date or variety except for NuCOTN 33B planted early. Seasonal mean densities of Heliothine eggs (Table 74) and

Table 73. Effect of cotton cultivar and planting date on plant density. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar	Planting date	Mean no. plants/3.1 m June 14
NuCOTN 33B	Early (Apr 26)	40.6 ab[1/]
NuCOTN 33B	Mid (May 9)	44.4 a
NuCOTN 33B	Late (May 22)	39.0 bc
DPL 5415	Early (Apr 26)	36.1 cd
DPL 5415	Mid (May 9)	43.6 a
DPL 5415	Late (May 22)	32.6 d
P > F		< 0.01

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 74. Effect of cotton cultivar and planting date on Heliothine egg densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

		Mean no. eggs/20 terminals								Seasonal
Cultivar	Planting Date	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	Mean
NuCOTN 33B	Early	0.0	0.0	0.0	0.0 b[1/]	0.3	1.8	0.3	0.3	0.3
NuCOTN 33B	Mid	0.0	0.0	0.0	1.0 a	2.0	1.5	0.0	0.0	0.6
NuCOTN 33B	Late	0.0	0.0	0.0	0.5 ab	1.5	1.8	0.0	0.5	0.5
DPL 5415	Early	0.0	0.0	0.0	0.5 ab	0.3	1.0	0.0	0.0	0.2
DPL 5415	Mid	0.0	0.0	0.0	0.0 b	0.3	1.0	0.0	0.3	0.2
DPL 5415	Late	0.0	0.0	0.0	0.3 ab	0.5	2.3	0.0	0.5	0.5
	P > F	1.00	1.00	1.00	0.01	0.19	0.58	0.47	0.01	0.30

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

larvae (Table 75) were not significantly different between varieties or among planting dates. The seasonal mean number of damaged squares (Table 76) were significantly greater in mid- and late-planted DPL 5415 than other treatments. Seasonal mean numbers of damaged bolls (Table 77) on early-planted DPL 5415 were higher than any NuCOTN 33B planting date. Also, numbers of damaged bolls were not significantly different between early- and late-planted NuCOTN 33B and mid- and late-planted DPL 5415. These data indicate that regardless of planting date, damage caused by Heliothine complex throughout the season was less on NuCOTN 33B than on DPL 5415.

First-harvest and percent first harvest yields (Table 78) in early- and mid-planted NuCOTN 33B were significantly greater than other treatments. The extra nitrogen added to late-planted cotton made the plants more vegetative and less productive, or NuCOTN 33B may have an earlier maturity. Second-harvest lint yields were significantly less for early- and mid-planted NuCOTN 33B than for early-planted DPL 5415. Total harvest lint yields were lowest for late-planted NuCOTN 33B and DPL 5415. However, late-planted NuCOTN 33B had significantly greater yields than late-planted DPL 5415. The best yielding treatment for total harvest was early-planted

Table 75. Effect of cotton cultivar and planting date on Heliothine larval densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar	Planting Date	Mean no. larvae/20 terminals								Seasonal
		Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	Mean
NuCOTN 33B	Early	0.0	0.0	0.0	0.0	0.0	0.3	0.3 bc[1]	0.5 bc	0.1
NuCOTN 33B	Mid	0.0	0.0	0.0	0.0	0.0	0.0	0.0 c	0.0 c	0.0
NuCOTN 33B	Late	0.0	0.0	0.0	0.0	0.0	0.8	0.0 c	0.3 c	0.1
DPL 5415	Early	0.5	0.0	0.0	0.3	0.0	0.3	0.8 ab	1.3 a	0.4
DPL 5415	Mid	0.3	0.0	0.0	0.0	0.0	0.5	1.3 a	0.3 c	0.3
DPL 5415	Late	0.0	0.0	0.0	0.0	0.0	0.5	0.0 c	1.0 ab	0.2
P > F		0.66	1.00	1.00	0.47	1.00	0.12	0.02	0.01	0.06

[1]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 76. Effect of cotton cultivar and planting date on the number of Heliothine damaged squares. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar	Planting Date	Mean no. damaged squares/20 squares								Seasonal
		Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	Mean
NuCOTN 33B	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1]	0.0 b
NuCOTN 33B	Mid	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0 b	0.0 b
NuCOTN 33B	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0 b	0.0 b
DPL 5415	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8 b	0.2 b
DPL 5415	Mid	0.0	0.5	0.0	0.0	0.3	1.0	1.8	0.0 b	0.5 a
DPL 5415	Late	0.0	0.0	0.0	0.0	0.0	0.8	0.8	2.3 a	0.5 a
P > F		1.00	0.08	1.00	1.00	0.69	0.14	0.26	< 0.01	< 0.01

[1]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 77. Effect of cotton cultivar and planting date on the number of Heliothine damaged bolls. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

		Mean no. damaged bolls/20 bolls								Seasonal
Cultivar	Planting Date	Jun 30	Jul 10	Jul 17	Jul 24	Jul 31	Aug 7	Aug 14	Aug 22	Mean
NuCOTN 33B	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5 bc[1]	0.1 bc
NuCOTN 33B	Mid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 c	0.0 c
NuCOTN 33B	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5 bc	0.1 bc
DPL 5415	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0 a	0.4 a
DPL 5415	Mid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8 ab	0.2 ab
DPL 5415	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5 abc	0.2 abc
	P > F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.02	0.02

[1] Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 78. Effect of cotton cultivar and planting date on lint yield and maturity. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1995.

Cultivar	Planting date	Lint yield (kg/ha) First	Second	Total	Percent first harvest
NuCOTN 33B	Early	1417 a[1/]	232 c	1649 a	85.9 a
NuCOTN 33B	Mid	1351 a	244 c	1595 ab	84.7 a
NuCOTN 33B	Late	355 c	444 a	799 d	45.1 c
DPL 5415	Early	1033 b	366 ab	1399 bc	74.3 b
DPL 5415	Mid	1075 b	320 bc	1396 c	77.1 b
DPL 5415	Late	159 d	273 bc	432 e	36.5 d
	P > F	< 0.01	< 0.01	< 0.01	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

NuCOTN 33B, though mid-planted NuCOTN 33B was not significantly different. These data suggest that in addition to protection provided to squares and bolls throughout the season, an early- or mid-planting date also benefits the yield of NuCOTN 33B.

In a related study, a large-scale field test compared NuCOTN to its recurrent parent DPL 5415. NuCOTN varieties had larger seeds (9%), increased seedling vigor (15%), higher yields (20.6%) and greater fiber value compared to their recurrent parent, which also may have influenced total yield data (Jones et al. 1996).

In 1996, plant densities (Table 79) were significantly greater in mid-planted Bt1215 than all other treatments or dates except mid-planted 1215. Seasonal mean densities of eggs (Table 80) and larvae (Table 81) were not significantly different among treatments. Seasonal mean numbers of damaged squares (Table 82) were significantly greater in early- and mid-planted 1215 than in any Bt1215 plot, suggesting that Heliothine populations were lower on Bt1215 at these planting dates. Seasonal densities of damaged bolls (Table 83) were not significantly different among treatments. Few Heliothine larvae were present at this location in 1996, which probably explains the lack of boll damage. Due to low Heliothine

Table 79. Effect of cotton cultivar and planting date on plant density. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar	Planting date	Mean no. plants/3.1 m June 14
Hartz Bt1215	Early	37.8 bc[1/]
Hartz Bt1215	Mid	45.0 a
Hartz Bt1215	Late	37.8 bc
Hartz 1215	Early	34.1 c
Hartz 1215	Mid	41.6 ab
Hartz 1215	Late	33.4 c
P > F		0.03

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 80. Effect of cotton cultivar and planting date on Heliothine egg densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

		Mean no. eggs/20 terminals								Seasonal
Cultivar	Planting Date	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Hartz Bt1215	Early	0.0	0.5	0.3	0.5	0.5	1.0	0.0	0.3	0.4
Hartz Bt1215	Mid	0.8	0.3	0.0	0.5	0.8	0.8	0.3	0.3	0.4
Hartz Bt1215	Late	0.5	0.0	0.0	0.3	0.8	1.5	1.3	0.3	0.6
Hartz 1215	Early	0.3	0.0	0.3	0.8	1.0	1.0	0.8	0.5	0.6
Hartz 1215	Mid	0.5	0.5	0.0	0.5	1.0	0.8	0.8	0.0	0.5
Hartz 1215	Late	0.3	0.3	0.0	0.5	0.5	1.5	0.5	0.5	0.5
	P > F	0.14	0.66	0.69	0.39	0.999	0.92	0.12	0.92	0.70

Table 81. Effect of cotton cultivar and planting date on Heliothine larval densities. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

		Mean no. larvae/20 terminals								Seasonal
Cultivar	Planting Date	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Hartz Bt1215	Early	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.1
Hartz Bt1215	Mid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hartz Bt1215	Late	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Hartz 1215	Early	0.0	0.0	0.0	0.0	0.0	0.8	0.3	0.0	0.1
Hartz 1215	Mid	0.0	0.0	0.0	0.0	0.0	0.8	0.3	0.3	0.2
Hartz 1215	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.1
	P > F	1.00	1.00	1.00	1.00	0.47	0.28	0.88	0.69	0.30

Table 82. Effect of cotton cultivar and planting date on the number of Heliothine damaged squares. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

		Mean no. damaged squares/20 squares								Seasonal
Cultivar	Planting Date	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Hartz Bt1215	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1/]
Hartz Bt1215	Mid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b
Hartz Bt1215	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b
Hartz 1215	Early	0.3	0.3	0.0	0.0	0.3	0.5	0.3	0.0	0.2 a
Hartz 1215	Mid	0.0	0.8	0.3	0.0	0.0	0.8	0.3	0.3	0.3 a
Hartz 1215	Late	0.0	0.0	0.0	0.0	0.0	0.8	0.3	0.5	0.2 ab
P > F		0.47	0.63	0.47	1.00	0.47	0.10	0.56	0.39	0.05

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 83. Effect of cotton cultivar and planting date on the number of Heliothine damaged bolls. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

		Mean no. damaged bolls/20 bolls								Seasonal
Cultivar	Planting Date	Jul 1	Jul 8	Jul 15	Jul 22	Jul 29	Aug 6	Aug 12	Aug 17	Mean
Hartz Bt1215	Early	0.0	0.0	0.0	0.0	0.0	0.5 ab[1]	0.0	0.0	0.1
Hartz Bt1215	Mid	0.0	0.0	0.0	0.0	0.0	0.0 b	0.0	0.0	0.0
Hartz Bt1215	Late	0.0	0.0	0.0	0.0	0.0	0.0 b	0.0	0.0	0.0
Hartz 1215	Early	0.0	0.0	0.0	0.0	0.0	1.0 a	0.5	0.0	0.2
Hartz 1215	Mid	0.0	0.0	0.0	0.0	0.3	1.0 a	0.3	0.3	0.2
Hartz 1215	Late	0.0	0.0	0.0	0.0	0.3	0.0 b	0.3	0.8	0.2
P > F		1.00	1.00	1.00	1.00	0.69	0.01	0.65	0.33	0.18

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

numbers, no 1215 plots received insecticide treatments this year.

First-harvest and percent first harvest yields (Table 84) in early- and mid-planted cotton were significantly greater than late-planted treatments. Second-harvest yields were significantly greater in late-planted cottons than other treatments, indicating a later maturity for late-planted cotton, as would be expected. Total harvest yields were significantly lower for late-planted Bt1215 and 1215 than other treatments, similar to 1995 WTES.

AMES LOCATION

In 1995, plant densities (Table 85) were significantly greater for mid-planted NuCOTN 33B than any other date or variety except for mid-planted DPL 5415. Seasonal mean densities of Heliothine eggs (Table 86) were not significantly different among treatments. Seasonal mean numbers of larvae (Table 87) and damaged squares (Table 88) were significantly greater in all planting dates of DPL 5415 cottons than any NuCOTN 33B planting date, indicating that Heliothine complex damage is lower on NuCOTN 33B. The seasonal mean number of damaged bolls (Table 89) was not significantly different among treatments.

Table 84. Effect of cotton cultivar and planting date on lint yield and maturity. West Tennessee Experiment Station (WTES), Jackson, Tenn. 1996.

Cultivar	Planting date	Lint yield (kg/ha) First	Second	Total	Percent first harvest
NuCOTN 33B	Early	1332 a[1/]	155 b	1488 a	89.4 a
NuCOTN 33B	Mid	1200 ab	172 b	1372 ab	87.5 a
NuCOTN 33B	Late	458 c	452 a	910 c	50.5 b
DPL 5415	Early	1292 a	139 b	1431 ab	90.4 a
DPL 5415	Mid	1082 b	151 b	1234 b	87.9 a
DPL 5415	Late	437 c	464 a	900 c	48.3 b
P > F		< 0.01	< 0.01	< 0.01	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = .05).

Table 85. Effect of cotton cultivar and planting date on plant density. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar	Planting date	Mean no. plants/3.1 m June 15
NuCOTN 33B	Early	36.1 bc[1/]
NuCOTN 33B	Mid	51.5 a
NuCOTN 33B	Late	37.6 b
DPL 5415	Early	19.8 d
DPL 5415	Mid	43.1 ab
DPL 5415	Late	27.0 cd
P > F		< 0.01

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 86. Effect of cotton cultivar and planting date on Heliothine egg densities. Ames Plantation, Grand Junction, Tenn. 1995.

		Mean no. eggs/20 terminals									Seasonal
Cultivar	Planting Date	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
NuCOTN 33B	Early	0.0	0.0	0.0	0.0	3.0	2.8 a[1/]	1.5	1.0 b	4.0	1.4
NuCOTN 33B	Mid	0.0	0.0	0.0	1.0	1.5	1.5 ab	1.3	1.5 b	3.0	1.1
NuCOTN 33B	Late	0.0	0.0	0.0	0.0	1.5	3.0 a	1.8	3.3 a	13.5	2.6
DPL 5415	Early	0.0	0.0	0.0	0.3	1.5	2.8 a	0.3	1.5 b	5.0	1.3
DPL 5415	Mid	0.0	0.0	0.0	0.0	1.5	0.5 b	1.3	2.0 ab	2.5	0.9
DPL 5415	Late	0.0	0.0	0.0	0.0	1.0	1.3 ab	0.8	2.3 ab	12.5	2.0
	P > F	1.00	1.00	1.00	0.61	0.75	0.04	0.49	0.03	0.18	0.06

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 87. Effect of cotton cultivar and planting date on Heliothine larval densities. Ames Plantation, Grand Junction, Tenn. 1995.

		Mean no. larvae/20 terminals									Seasonal
Cultivar	Planting Date	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
NuCOTN 33B	Early	0.0	0.3	0.0	0.0	0.3 b[1/]	0.0	0.0 b	0.0 b	1.5	0.2 b
NuCOTN 33B	Mid	0.0	0.3	0.0	0.0	0.8 ab	0.5	0.0 b	0.0 b	3.0	0.5 b
NuCOTN 33B	Late	0.0	0.0	0.3	0.0	0.3 b	0.3	0.0 b	0.0 b	3.0	0.4 b
DPL 5415	Early	0.0	0.3	0.0	0.0	0.3 b	1.0	1.0 a	1.3 ab	1.5	0.6 a
DPL 5415	Mid	0.0	0.0	0.0	0.0	0.8 ab	0.0	1.0 a	1.5 a	3.0	0.7 a
DPL 5415	Late	0.0	0.3	0.0	0.0	1.5 a	0.3	1.3 a	0.3 ab	7.5	1.2 a
	P > F	1.00	0.86	0.47	1.00	< 0.01	0.07	0.02	0.04	0.09	< 0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 88. Effect of cotton cultivar and planting date on the number of Heliothine damaged squares. Ames Plantation, Grand Junction, Tenn. 1995.

		Mean no. damaged squares/20 squares									Seasonal
Cultivar	Planting Date	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
NuCOTN 33B	Early	0.0	0.0	1.0	0.8	0.8	0.0 c[1]	0.0 c	0.0 b	0.0	0.3 b
NuCOTN 33B	Mid	0.0	1.0	0.0	0.0	1.0	0.0 c	0.0 c	0.0 b	0.0	0.2 b
NuCOTN 33B	Late	0.0	0.0	0.0	0.0	0.5	0.0 c	0.0 c	0.0 b	1.0	0.2 b
DPL 5415	Early	0.8	2.5	1.3	0.0	1.0	1.0 ab	1.3 ab	1.3 a	0.5	1.1 a
DPL 5415	Mid	0.5	0.8	0.0	0.8	1.0	0.5 bc	1.0 b	2.3 a	1.0	0.9 a
DPL 5415	Late	0.0	0.3	0.5	1.0	1.8	2.0 a	2.5 a	1.3 a	0.0	1.0 a
	P > F	0.35	0.08	0.09	0.53	0.53	< 0.01	< 0.01	0.01	0.85	< 0.01

[1] Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference of the square root transformed data (P = 0.05).

Table 89. Effect of cotton cultivar and planting date on the number of Heliothine damaged bolls. Ames Plantation, Grand Junction, Tenn. 1995.

		Mean no. damaged bolls/20 bolls									Seasonal
Cultivar	Planting Date	Jul 7	Jul 14	Jul 20	Jul 27	Aug 1	Aug 8	Aug 15	Aug 21	Aug 29	Mean
NuCOTN 33B	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
NuCOTN 33B	Mid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NuCOTN 33B	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DPL 5415	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.0	0.4
DPL 5415	Mid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
DPL 5415	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1
	P > F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.12	0.08	0.06

First-harvest yields (Table 90) were not significantly different between early-planted NuCOTN 33B and early-planted DPL 5415 or between mid-planted NuCOTN 33B or mid-planted DPL 5415. First-harvest and percent first harvest yields were significantly lower in late-planted DPL 5415 than other treatments. Early-planted NuCOTN 33B had significantly greater first-harvest yields than late-planted NuCOTN 33B. Second-harvest yields were not significantly different among treatments. Total yield was not significantly different among the different planting dates of NuCOTN 33B. With no significant differences in total yield among planting dates of NuCOTN 33B, farmers may have more flexibility on when to plant this variety. For the DPL 5415 planting dates, early-planted total yield was significantly greater than mid-planted, which was significantly greater than late-planted. Also, NuCOTN yields at all planting dates were not significantly different from early- and mid-planted conventional cottons which were sprayed with insecticides four and five times.

In 1996, plant densities (Table 91) were significantly greater in mid-planted Bt1215 than all other treatments, similar to 1996 WTES data. Both early-planted varieties had significantly fewer plants than other planting dates, due to planting problems. Seasonal mean densities of Heliothine eggs

Table 90. Effect of cotton cultivar and planting date on lint yield and maturity. Ames Plantation, Grand Junction, Tenn. 1995.

Cultivar	Planting date	Lint yield (kg/ha) First	Second	Total	Percent first harvest
NuCOTN 33B	Early	1273 a[1/]	130	1403 a	90.9 a
NuCOTN 33B	Mid	1110 ab	190	1300 ab	85.3 ab
NuCOTN 33B	Late	951 b	281	1232 ab	77.9 b
DPL 5415	Early	1178 a	221	1399 a	84.3 ab
DPL 5415	Mid	945 b	212	1157 b	81.7 ab
DPL 5415	Late	540 c	305	844 c	64.0 c
P > F		< 0.01	0.60	< 0.01	0.04

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = .05).

Table 91. Effect of cotton cultivar and planting date on plant density. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar	Planting date	Mean no. plants/3.1 m June 11
Hartz Bt1215	Early	11.1 c[1/]
Hartz Bt1215	Mid	31.1 a
Hartz Bt1215	Late	26.2 b
Hartz 1215	Early	9.3 c
Hartz 1215	Mid	25.0 b
Hartz 1215	Late	22.2 b
P > F		< 0.01

[1/]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

(Table 92) and larvae (Table 93) were not significantly different among treatments. Most larvae observed in conventional cotton were developed beyond the neonate stage, while the few larvae found in Bt1215 were neonates. Seasonal mean numbers of damaged squares (Table 94) were significantly lower in all planting dates of Bt1215 than all 1215. Seasonal mean numbers of damaged bolls (Table 95) were significantly greater in early- and mid-planted 1215 cottons than in any Bt1215 cotton. These data suggest that Bt1215 suppresses Heliothine complex damage throughout the season and, regardless of planting date, may not require insecticide treatment to prevent Heliothine complex damage.

First-harvest and total yields were not significantly different among treatments (Table 96), even though some stand loss occurred in early-planted cottons. Second-harvest yields were significantly greater in late-planted cotton treatments than in early-planted treatments, as would be expected. Percent first-harvest data were significantly higher for early- and mid-planted Bt1215 and early-planted 1215 than late-planted 1215. No significant differences were observed in total harvest although each 1215 treatment was sprayed with insecticides three times.

Table 92. Effect of cotton cultivar and planting date on Heliothine egg densities. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar	Planting Date	Mean no. eggs/20 terminals								Seasonal
		Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Hartz Bt1215	Early	3.5	0.3	0.0	2.3	2.8	1.3	0.5	0.8	1.4
Hartz Bt1215	Mid	4.8	0.0	0.0	1.3	3.0	2.0	0.5	0.0	1.4
Hartz Bt1215	Late	6.0	0.0	0.0	1.3	3.3	1.8	0.5	0.3	1.6
Hartz 1215	Early	2.0	0.3	0.0	1.8	2.3	0.8	1.0	0.5	1.1
Hartz 1215	Mid	0.8	0.0	0.0	3.0	3.3	1.0	0.3	0.0	1.0
Hartz 1215	Late	3.3	0.0	0.3	1.0	2.3	2.0	0.8	0.3	1.2
	P > F	0.31	0.22	0.47	0.11	0.62	0.22	0.95	0.64	0.34

Table 93. Effect of cotton cultivar and planting date on Heliothine larval densities. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar	Planting Date	Mean no. larvae/20 terminals								Seasonal
		Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Hartz Bt1215	Early	0.0	0.3 b[1]	0.0 b	0.0	0.3	0.0	0.0	0.0	0.1
Hartz Bt1215	Mid	0.3	0.3 b	0.0 b	0.0	0.0	0.0	0.0	0.0	0.1
Hartz Bt1215	Late	0.5	0.0 b	0.0 b	0.0	0.0	0.0	0.0	0.0	0.1
Hartz 1215	Early	0.3	0.5 b	0.0 b	0.0	0.3	0.0	0.3	0.3	0.2
Hartz 1215	Mid	0.3	2.0 a	0.0 b	0.3	0.3	0.3	0.0	0.0	0.4
Hartz 1215	Late	0.0	0.0 b	0.8 a	0.0	0.8	0.0	0.3	0.0	0.2
	P > F	0.62	< 0.01	< 0.01	0.47	0.48	0.47	0.69	0.47	0.06

[1]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 94. Effect of cotton cultivar and planting date on the number of Heliothine damaged squares. Ames Plantation, Grand Junction, Tenn. 1996.

		Mean no. damaged squares/20 squares								Seasonal
Cultivar	Planting Date	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Hartz Bt1215	Early	1.3 ab[1]	0.5 b	0.0 b	0.0	0.3	0.0	0.0	0.0	0.3 b
Hartz Bt1215	Mid	0.0 b	0.0 b	0.0 b	0.0	0.3	0.0	0.0	0.0	0.0 b
Hartz Bt1215	Late	0.0 b	0.0 b	0.0 b	0.0	0.0	0.0	0.0	0.0	0.0 b
Hartz 1215	Early	4.3 a	4.0 a	1.3 a	0.5	0.5	0.3	0.3	0.5	1.4 a
Hartz 1215	Mid	4.5 a	4.5 a	0.5 ab	0.0	1.3	0.3	0.0	0.0	1.4 a
Hartz 1215	Late	0.5 b	5.5 a	1.0 a	0.0	1.3	0.0	0.3	0.3	1.1 a
P > F		0.02	< 0.01	0.03	0.47	0.15	0.69	0.69	0.39	< 0.01

[1]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 95. Effect of cotton cultivar and planting date on the number of Heliothine damaged bolls. Ames Plantation, Grand Junction, Tenn. 1996.

		Mean no. damaged bolls/20 bolls								Seasonal
Cultivar	Planting Date	Jul 2	Jul 11	Jul 17	Jul 24	Jul 30	Aug 9	Aug 13	Aug 17	Mean
Hartz Bt1215	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b[1]
Hartz Bt1215	Mid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b
Hartz Bt1215	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 b
Hartz 1215	Early	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.1 a
Hartz 1215	Mid	0.0	0.0	0.0	0.3	0.3	0.0	0.8	0.0	0.1 a
Hartz 1215	Late	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1 ab
P > F		1.00	1.00	1.00	0.47	0.47	1.00	0.17	1.00	0.04

[1]Means followed by the same letter within this column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

Table 96. Effect of cotton cultivar and planting date on lint yield and maturity. Ames Plantation, Grand Junction, Tenn. 1996.

Cultivar	Planting date	Lint yield (kg/ha) First	Lint yield (kg/ha) Second	Lint yield (kg/ha) Total	Percent first harvest
NuCOTN 33B	Early	751	91 e[1/]	842	88.9 a
NuCOTN 33B	Mid	785	214 cd	999	76.1 b
NuCOTN 33B	Late	827	293 bc	1119	72.3 bc
DPL 5415	Early	684	167 de	853	78.6 ab
DPL 5415	Mid	595	308 b	903	65.7 bc
DPL 5415	Late	649	402 a	1051	61.2 c
	P > F	0.72	< 0.01	0.42	0.01

[1/]Means followed by the same letter within a column are not significantly different according to Fisher's Least Significant Difference (P = 0.05).

iv. SUMMARY

The number of damaged squares and bolls were generally lower for Bt cottons than conventional cottons. Bt cottons were protected from Heliothine complex damage throughout the season at each planting date. In 1995 and 1996 at WTES, early- and mid-planting dates benefited Bt cotton yield, with late-planted cotton having significantly lower yields. However, yields of early- and mid-planted Bt cottons were higher (1995) or not significantly different from (1996) those of early- and mid-planted conventional cottons which were treated with insecticides. These data suggest that, at WTES, Bt cotton may not need insecticide treatments to preserve its yield.

At Ames in 1995, no significant differences were observed between total yields of early-planted NuCOTN 33B and early-planted DPL 5415, or between mid-planted yields. Also, no significant differences were observed among NuCOTN 33B yields at each planting date. These data suggest that NuCOTN 33B is competitive in performance with DPL 5415 and may be grown without application of insecticides for control of Heliothine complex at each planting date, which would allow farmers more flexibility with their planting date. However, at Ames during 1996, no significant differences in total yield were detected among all treatments, though 1215 received three treatments. Because of planting problems experienced in 1996, more research needs to be conducted to determine benefits of planting dates for Hartz Bt1215 at this location.

CHAPTER V

CONCLUSIONS

In 1995, Williams (1995) estimated that bollworm, tobacco budworm, and other cotton insect pests cost cotton farmers $1.68 billion due to yield losses, insecticide, and insecticide application costs. If the use of Bt cotton can reduce these costs it will save farmers several million dollars annually. These potential savings do not include additional costs that may be avoided involving human health and safety, and the environmental pollution issues related to conventional synthetic insecticide use (Benedict et al. 1992b). Bollgard cotton has the potential to save farmers substantial money on insect control in high insect pressure areas.

The experiments discussed here indicated a high reduction in square and boll damage throughout the season from Heliothine complex with Bt cottons. Cotton at Ames experienced the greatest Heliothine complex pressure of any experiment location, and Bt cotton demonstrated protection against the Heliothine complex throughout the season.

Data for the three locations indicated that yields generally did not differ significantly between Bt cottons not treated with insecticides and conventional cottons treated with insecticides. These data suggest that Bt cottons may not need insecticide treatments to preserve their yield. Therefore, Bt cottons can potentially reduce the number of chemical pesticide applications for control of Heliothine complex. However, Bt cotton is only cost effective in high pressure Heliothine complex areas. Bt cotton may provide a sort of "insurance policy" against the possibility of a severe Heliothine complex problem in these areas.

Concerns about genetically engineered plants being safe to release into the environment and the anticipated development of resistance to transgenic Bt by the Heliothine complex trigger debate on genetically engineered crops (Luttrell and Herzog 1994). Biotechnology is enabling scientists to change and manipulate microorganisms in ways unimaginable only a few years ago. These microbes can kill pests, clean up oil spills and toxic chemicals, fertilize crops, and more. The release of these microbes into the environment begins debates within the scientific community, problems with government regulations, and anxiety in environmental groups (Witt 1990). Alarming analogies to transgenic plant release are stories of Kudzu plants, gypsy moths, and killer bees. These are not considered accurate comparisons to Bt cottons because in those cases the entire organism was introduced into a non-native environment. A one-gene change in a cotton plant does not make it fill a niche formerly filled by another plant (Witt 1990). Environmental regulatory agencies are concerned with these matters because Bt cotton is one of the first outcomes of genetic engineering to be commercialized for use in agricultural production.

A regulatory framework has been established by the United States Department of Agriculture (USDA) (Reding 1995) and the Food and Drug Administration (FDA) which transgenic plant products must meet before commercialization. The regulatory process involves public discussion of scientific issues and has provided assurance of the safety of transgenic plants. In 1994, FLAVRSAVR™ tomato was the first transgenic plant product placed on the market and had excellent consumer response (Malyj 1995). Delta and Pine Land Co. had NuCOTN Bt cotton seed for sale in 1996. The Jacob Hartz seed company may have three Bt varieties available to farmers in 1997. The Calgene company in conjunction with Stoneville may have Bt/BXN varieties available to producers by 1998.

Future projects involving insect-resistant cotton would include the establishment of new scouting methods and economic threshold limits for lepidopterans on Bt cotton, and the effect of Bt cotton on beneficial and non-target lepidopteran pest species (Fischhoff 1992). Some projects could involve Bt plants in pyramiding, a breeding program to transfer Bt genes to those plants exhibiting natural defenses. Many different Bt genes can be added to a plant simultaneously to delay resistance. A new gene which is resistant to boll weevil and the Heliothine complex is being evaluated, and may be available by the year 2005. The intensely debated issues involving the environmental safety of genetically engineered plants and the probable development of pest populations resistant to transgenic crops warrant further research and consideration by the scientific community (Luttrell and Herzog 1994).

The best use of Bt cotton for Tennessee will depend on the annual Heliothine pressure each grower has, the expense and availability of regionally adapted Bt cotton varieties, and any insecticide resistance the Heliothine complex may develop. Bt cotton is predicted to become a powerful new tool to enhance integrated pest management. Bt cotton itself is not the exclusive answer to Heliothine complex problems, but provides assistance to producers whose cotton yields have been intensely and recurrently reduced by them. Biotechnology is expected to help cotton to remain a major commodity in American agriculture far into the future (Stewart 1995). The use of biotechnology promises new techniques, knowledge, and products for the future (El-Zik and Thaxton 1995).

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