STRATEGIES FOR FOLIAR APPLICATIONS OF *BACILLUS THURINGIENSIS* IN COTTON

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Abstract

In 1995 and 1996, field studies were conducted in 0.5 acre plots on the Plant Science Research Farm at Mississippi State University to determine if foliar applications of *Bacillus thuringiensis* (Bt), alone or in combination with traditional insecticides, were efficacious for control of tobacco budworm (*Heliothis virescens*) on cotton at different phenological stages of development. This research was stimulated by the increased use of commercial Bt products on cotton over the past 5 years. A general consensus among consultants that participated in a previous Bt-use-strategy survey was that the addition of Bt to insecticide treatments in June would aid in suppressing tobacco budworm populations below economically damaging levels in July and August. The strategies tested in our experiments included comparisons between automatic spray approaches and a spray-when-needed approach, comparisons between Bt use before and after first bloom, and comparisons of Bt treatments made alone and in combination with traditional insecticides. Results indicated that a few Bt-use-strategies were as efficacious as current recommendations based on traditional insecticides, but were less efficacious or more expensive than current practices.

Introduction

Previous research (Tanada 1956, Hall and Andres 1958, McEwan et al. 1960, Hall et al. 1961) has shown that *Bacillus thuringiensis* (Bt) is an efficacious microbial insecticide for controlling lepidopteran pests on several crops. However, the ability to measure benefits from Bt insecticides is difficult because of the low insecticidal mortality typically observed (ca. 50% or less (Bell and Romine 1980, Luttrell et al. 1982, Starnes et al. 1993)). Advantages for the use of Bt may be closely linked to preservation of natural control agents, another control factor that is difficult to quantify. The difficulties associated with determining benefits from foliar-applied Bt insecticides complicates efforts to develop use strategies that can be recommended for the control of lepidopteran pests in cotton.

During the 1980's, Bt was regarded as having little or no value for cotton insect control because of the availability of the highly efficacious pyrethroid insecticides. Over the past few years, cotton growers have observed increased problems controlling pest populations, particularly the tobacco budworm (*Heliothis virescens*), because of resistance to most chemical insecticides (Martin et al. 1995). As a result, interest in alternative control methods, particularly the use of Bt, has dramatically increased. This interest created a measurable commercial market for Bt insecticides on cotton during the early to mid 1990's. Several industry groups including established and new biotechnology firms targeted this cotton market as a visible use-niche for new Bt insecticides. Although the high efficacy and commercialization of transgenic Bt cotton (Kennedy and Whalon 1995) threatens the size of the commercial market for foliar applied Bt on cotton, there is still significant interest in developing microbial insecticides for use on fields planted to non-Bt cotton.

Extensive field studies conducted in the U.S. have shown Bt cotton to be extremely efficacious against tobacco budworm (Benedict et al. 1992a, 1992b, 1993a, 1993b, Jenkins et al. 1992, 1993). With the introduction of Bt cotton into current IPM programs, unique advantages of foliar-applied Bt insecticides may be overlooked. The use of Bt to aid in suppression of insecticide-resistant tobacco budworms is supported by some data (Plapp 1991). Others (Green and Hutchins 1993 and Plapp 1993) have suggested that early-season applications of Bt applied at low, economical doses suppresses pest population growth. Unfortunately, empirical data supporting both uses are limited.

Prior to initiation of the study, we solicited the opinions of crop consultants regarding the best use-strategies for Bt. Their ideas were the foundation for our test design. A survey was sent to 20 professional consultants in several southeastern states in 1995. The survey included questions about Bt insecticides and how they were typically used. Of the consultants who responded to the survey: 57% reported that they recommend that Bt insecticides be tank-mixed with traditional insecticides throughout the growing season for control of insecticide-resistant tobacco budworms, 71% recommend tank-mixing traditional insecticides with early-season (June/pre-bloom) applications of Bt, 21% believed that they obtained long term (across tobacco budworm generations - July to harvest) benefits from early-season (June/pre-bloom) applications of Bt, and 50% believed that a spray-when-needed program with Bt was more profitable than an automatic spray program. Most of the consultants agreed that more information was needed to efficiently incorporate Bt insecticides into management systems and value their use, although commercial products have been available for more than three decades.

Considering the potential value of foliar applications of Bt for tobacco budworm control and the variation in opinions among consultants, producers, and extension agents concerning Bt- use-strategies, we conducted an experiment in 1995 and 1996 to determine if foliar-applied Bt, alone or in combination with traditional insecticides, were

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efficacious for controlling tobacco budworm on cotton. The spatial scale of the study was appropriate for studying direct insecticidal effects of treatments on target pests, but it was probably too small to measure population suppression effects typically associated with large geographic areas.

Materials and Methods

To study the value of Bt treatment strategies, field studies were conducted in 0.5 acre plots on the Plant Science Research Farm at Mississippi State University in 1995 and 1996. The cotton variety used was 'DPL 119'. Dipel ES® (Abbott Laboratories, North Chicago, IL) was chosen as the Bt product because of previous experience with the formulation and the fact that many consultants, according to the survey previously mentioned, recommend the use of Dipel ES® for tobacco budworm control. A high rate of Dipel ES® (2 pt/acre) was used throughout the experiment. We assumed that results obtained with a high rate would be as efficacious as those with lower use rates. All treatments were applied using a John Deere 6000 high-cycle tractor equipped with 2 TX-8 nozzles per row. A total spray volume of 10 gallons per acre was used, and 50-mesh screens were included in the nozzle housing. All treatments were replicated four times, and the experiment was arranged in a randomized complete block design.

The strategies that were tested included using Bt alone and tank-mixed with traditional insecticides (ovicides and larvicides) at different stages of crop phenological development. The specific treatments tested both years were based on "automatic" and "treat-as-needed" approaches. They were:

1) Untreated all season
2) Untreated early-season -- CIC mid- and late-season
3) CIC all season
4) CIC + Bt all season
5) CIC early-season -- CIC + Bt mid- and late-season
6) CIC + Bt early-season -- CIC mid- and late-season
7) Bt early-season -- CIC mid- and late-season
8) Bt every Monday, Wednesday, and Friday early-season -- CIC mid- and late-season

In order to fully understand and explore other possible benefits of Bt insecticide use on cotton, three additional strategies were added to the experiment in 1996. They were:

9) CIC early-season -- Bt every Monday, Wednesday, and Friday mid- and late-season
10) Bt all season
11) Transgenic cotton expressing endotoxin protein of Bt (NuCOTN 33)

Early-season refers to insecticide applications made to pre-bloom cotton (June), and mid- and late-season refer to post-bloom cotton (July to harvest). CIC refers to the traditional insecticide recommendations (pyrethroids, carbamates, and organophosphates) listed in the Mississippi Cotton Insect Control Guide (Layton 1995 and 1996). Treatments 1-7 and 10 were designed to test a spray-when-needed program, and treatments 8 and 9 were designed to test an automatic spray program with applications made 3 times each week. All treatments were divided into pre- and post-bloom applications. Prior to the first bloom stage of crop development, pre-bloom treatments were applied. When the majority of the entire field that contained the test plots reached first bloom, the treatment scenarios were switched to post-bloom strategies. Data collection and treatment applications were terminated when plots within most treatments reached crop "cut out" defined as 5 nodes above white flower (5 NAWF) (Harris et al. 1996). Following the 5 NAWF stage, traditional insecticides were applied over the test plots on a routine, weekly basis to preserve any treatment differences that had been observed.

Observations were made once a week to determine if infestation levels reached the thresholds specified in the Mississippi Cotton Insect Control Guide (CIC). On each observation date, 25 terminals and 25 squares from each plot were observed for insects and insect damage. The Plant Science Research Farm at Mississippi State University was within the geographic boundary of the Boll Weevil Eradication Program, and weekly applications of malathion were made to eliminate the boll weevil from the area. This essentially eliminated all natural enemies, and initial sampling of natural enemies was abandoned because of low numbers. Data were recorded on the number of terminals and fruiting forms damaged and those with larvae. Data were studied by analysis of variance and means were separated by Student Newman Keul's (SNK) test at an error rate of P=0.05.

Results and Discussion

The experimental conditions varied in 1995 and 1996. During 1995, the test area was infested with historically-high densities of tobacco budworm after first bloom (Layton et al. 1996). These epidemic-level densities caused tremendous crop loss in eastern Mississippi. Almost all insecticide treatments failed to provide satisfactory control across a large area of the state. During 1996, the plots were infested with damaging levels of tobacco budworm prior to bloom. After bloom heliothine (tobacco budworm and bollworm) densities were high and mostly composed of bollworm (*Helicoverpa zea*).

During 1995 and 1996, there were no significant differences among treatments in numbers of eggs infesting the plots (Table 1). These data indicate that oviposition preferences among female moths for particular treatments were not observed. There were also no significant differences among treatments in the total number of heliothine larvae found in terminals in the plots in 1995, but there were several treatment differences in 1996 (Table 2). The number of larvae in terminals in the Bt cotton treatment prior to bloom and in the seasonal average across all dates in 1996 were significantly lower than all other treatments. After bloom, all Bt-use-strategy treatments were not significantly different in numbers of larvae in terminals. The untreated plots had more larvae than all foliar treatments and the Bt cotton. Differences between the Bt cotton treatment and all other treatments indicate that these genetically altered crops are highly efficacious and have the potential to become a vital component of IPM programs in the future.

Prior to bloom in 1995, all treatments reduced terminal damage over that observed in one of the untreated plots. Treatment differences after bloom were small, and those estimated across the entire year were not significant (Table 3). During 1996, all foliar treatments resulted in less terminal damage than that observed in the untreated plot, but more than that observed for Bt cotton. Differences in treatment effects between 1995 and 1996 may be attributed to the difference in heliothine species infesting the plots in each year. More cotton bollworm numbers were observed in 1996. Previous studies (Luttrell et al. 1982 and MacIntosh et al. 1990) have shown cotton bollworm to be 3- to 10-fold more tolerant of Bt endotoxins than tobacco budworm.

Although no significant differences were found in numbers of larvae in fruit among the treatments prior to bloom and season-long in 1995, a few significant differences were observed after bloom (Table 4). Treatments that included traditional insecticides had fewer larvae. During 1996, pre- and post-bloom data revealed a few treatment differences , but differences among Bt-use-strategies were small. The seasonal average data indicated that the Bt cotton treatment had significantly fewer larvae infesting squares and bolls than all other treatments (Table 4). Bt applied on an as-needed basis alone was less efficacious than other Bt treatments.

Despite the wide variation in characteristics of the different Bt-use-strategies examined, significant differences among Bt-use-strategies in damaged fruit were not detected (Table 5). This may indicate that larvae surviving on Bt may feed less and cause less damage that those surviving on cotton not treated. In general, all data collected in 1996 indicated that more fruit damage was observed in Bt treated plots than in the Bt cotton treatment. Foliar applications reduced damage over that observed in the untreated plots. The failure to detect differences among specific Bt-use-strategies in Tables 1-5 suggests that there were no long term (July to harvest) benefits, especially during post-bloom periods, associated with Bt applications made in June (pre-bloom) in these 0.5 acre plots. This may be due to the limited size of the plots and the over-sprays of malathion for boll weevil eradication which probably negated positive interactions with natural control. The data also failed to demonstrate beneficial effects from using Bt as a stand-alone insecticide or mixing Bt with traditional insecticides for improved control of tobacco budworm.

Combined data for the treatments tested both years showed no differences among treatments in number of eggs in the terminals (Table 6). All treatments reduced numbers of larvae as compared to the untreated plot, but differences in numbers of larvae in terminals were not detected for foliar treatments. The same trend was observed for the average number of heliothine damaged terminals and fruit. The data suggest that differences in use-strategies are small. Differences in efficacy between Bt and traditional insecticides are larger. It was encouraging that Bt alone treatments were generally as efficacious as CIC treatments prior to bloom. However, damage in the untreated plots was often equal to that of treated plots.

Although the addition of Bt to treatments increased the total number of insecticide applications (Table 7) and the total cost for heliothine control within a treatment (Table 9), the different Bt-use-strategies did not appear to increase the amount of seed cotton harvested over that obtained with current CIC strategies (Table 8). Treatment strategies that included Bt inflated the total number of insecticide treatments (Table 7). In 1995 and 1996, the total cost per acre for heliothine control in untreated plots ranged from $0.00 and $12.81 (Table 9). Dramatic yield reductions were observed in these plots (Table 8). The most expensive strategies had heliothine control costs of $157.88 and $164.24 per acre (Table 9). Both were the CIC spray strategies with Bt applied in combination with traditional insecticides. This is a wide range in insecticide inputs and reflects the intense insect pressure in these studies.

Net profits above the cost of heliothine control ranged from $112.70 to $299.88 per acre in 1995, $74.81 to $485.86 per acre in 1996, and $93.76 to $382.52 per acre for the average of both years (Table 10). These data indicate that some Bt-use-strategies were as efficacious as CIC practices in 1995. The addition of Bt to late-season applications increased profits ca. $20.00 per acre. Interestingly, the use of Bt alone during the early-season was as profitable as CIC in 1995. In 1996, the CIC strategy was the most profitable strategy tested.

The relationship between the total cost for heliothine control per pound of lint produced and pounds of lint produced per dollar spent on heliothine control in 1995 and 1996 are summarized Table 11. In general, higher production costs translated into fewer pounds of lint per dollar invested. Although some treatments may appear to be economical approaches in terms of dollars invested, the ultimate goal in cotton production is to maximize output while minimizing the amount of input. Resulting yield is an important component. Table 12 provides a comparison of costs, net profit above heliothine control, and yield.

Data describing the Bt-use-strategies tested in this experiment were consistent in that higher numbers of insecticide applications, increased costs per pound of lint produced, and increased heliothine control costs were observed, while net profits above heliothine control costs were decreased. When compared to those for Bt cotton, which had very few insecticide applications, costs per pound of lint produced and heliothine control costs were higher for the Bt-use-strategies. Net profits above heliothine control costs and pounds of seed cotton produced were higher for CIC strategies and Bt cotton.

Although some Bt-use-strategies examined in this experiment were as economical as current practices, most failed to show that foliar applications of Bt applied alone or in combination with traditional insecticides increased efficacy of control over that observed for current CIC recommendations. Advantages of scheduled, automatic applications during the early-season (pre-bloom) also were not observed. It is important to view these results within the scope of the experiment conducted. The value of Bt in regulating pest populations over large areas was not tested in these experiments. Larger plots, probably on the scale of 100 acres or more, would be necessary to investigate these relationships. Also the costs of Bt were inflated with the high dose of Dipel ES® tested. If comparable efficacy can be obtained with lower rates, economic returns would be higher. If Bt is to be used as a selective IPM management tool, cotton consultants and producers must understand how to incorporate them into management systems and value their use. Additional research is needed to determine exactly how foliar applications of Bt can be used in IPM programs to regulate population growth of tobacco budworm over large areas. The direct insecticidal control obtained with foliar Bt does not appear to be sufficient to replace traditional insecticides. However, it provides enough efficacy against tobacco budworm to have possible use-niches during the early-season, particularly in situations where it is advisable to preserve natural enemies.

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Table 1. Total number of heliothine eggs per 25 terminals in large cotton plots (ca. 0.5 acre) in 1995 and 1996.

	1995			1996		
Treatment	Pre Bloom	Post Bloom	All Year	Pre Bloom	Post Bloom	All Year
Untrt -- Untrt	1.5 a	2.6 a	2.1 a	3.2 a	5.2 a	4.5 a
Untrt -- CIC	1.4 a	2.1 a	1.7 a	3.2 a	5.0 a	4.4 a
CIC -- CIC	1.5 a	2.2 a	1.9 a	3.7 a	5.7 a	5.0 a
CIC+Bt -- CIC+Bt	1.5 a	2.1 a	1.8 a	3.1 a	5.7 a	4.8 a
CIC -- CIC+Bt	1.0 a	2.2 a	1.6 a	4.0 a	5.8 a	5.2 a
CIC+Bt -- CIC	1.7 a	1.9 a	1.8 a	3.2 a	5.6 a	4.8 a
CIC -- Bt M,W,F	---	---	---	3.1 a	5.1 a	4.4 a
Bt M,W,F -- CIC	1.6 a	1.8 a	1.7 a	3.3 a	5.5 a	4.8 a
Bt -- CIC	1.6 a	2.5 a	2.0 a	4.4 a	5.6 a	5.2 a
Bt -- Bt	---	---	---	3.7 a	7.0 a	5.9 a
Bt cotton	---	---	---	4.8 a	5.0 a	4.9 a

* Means within a column not followed by a common letter differ significantly (P=0.05).

Table 2. Total number of heliothine larvae per 25 terminals in large cotton plots (ca. 0.5 acre) in 1995 and 1996.

	1995			1996		
Treatment	Pre Bloom	Post Bloom	All Year	Pre Bloom	Post Bloom	All Year
Untrt -- Untrt	1.6 a	3.6 a	2.6 a	5.3 a	3.7 a	4.2 a
Untrt -- CIC	1.2 a	2.4 a	1.8 a	4.6 ab	2.2 b	3.0 b
CIC -- CIC	1.6 a	2.6 a	2.1 a	3.0 ab	2.2 b	2.5 b
CIC+Bt -- CIC+Bt	1.4 a	2.6 a	2.0 a	3.0 ab	1.8 b	2.2 b
CIC -- CIC+Bt	1.4 a	2.8 a	2.1 a	3.3 ab	2.0 b	2.4 b
CIC+Bt -- CIC	1.1 a	2.3 a	1.7 a	3.1 ab	1.6 b	2.1 b
CIC -- Bt M,W,F	---	---	---	2.8 b	2.4 b	2.5 b
Bt M,W,F -- CIC	0.8 a	2.8 a	1.8 a	3.4 ab	1.8 b	2.3 b
Bt -- CIC	1.1 a	2.9 a	2.0 a	3.2 ab	2.0 b	2.4 b
Bt -- Bt	---	---	---	3.8 ab	2.7 b	3.1 b
Bt cotton	---	---	---	0.4 c	1.2 b	0.9 c

* Means within a column not followed by a common letter differ significantly (P=0.05).

Table 3. Total number of heliothine damage per 25 terminals in large cotton plots (ca. 0.5 acre) in 1995 and 1996.

	1995			1996		
Treatment	Pre Bloom	Post Bloom	All Year	Pre Bloom	Post Bloom	All Year
Untrt -- Untrt	2.3 b	4.7 a	3.5 a	10.4 a	9.3 a	9.7 a
Untrt -- CIC	3.3 a	3.3 ab	3.3 a	7.8 b	6.2 b	6.8 b
CIC -- CIC	1.9 b	3.5 ab	2.7 a	5.5 b	5.1 b	5.2 b
CIC+Bt-- CIC+Bt	2.2 b	2.9 b	2.5 a	6.2 b	4.6 b	5.1 b
CIC -- CIC+Bt	2.2 b	3.6 ab	2.9 a	5.8 b	5.6 b	5.7 b
CIC+Bt -- CIC	2.1 b	3.2 ab	2.6 a	6.8 b	4.5 b	5.2 b
CIC -- Bt M,W,F	---	---	---	6.1 b	4.6 b	5.1 b
Bt M,W,F -- CIC	1.7 b	3.2 ab	2.4 a	6.4 b	4.9 b	5.4 b
Bt -- CIC	1.8 b	3.4 ab	2.6 a	6.9 b	4.8 b	5.5 b
Bt -- Bt	---	---	---	7.3 b	5.5 b	6.1 b
Bt cotton	---	---	---	0.4 c	1.4 c	1.1 c

* Means within a column not followed by a common letter differ significantly (P=0.05).

Table 4. Total number of heliothine larvae per 25 squares/bolls in large cotton plots (ca. 0.5 acre) in 1995 and 1996.

	1995			1996		
Treatment	Pre Bloom	Post Bloom	All Year	Pre Bloom	Post Bloom	All Year
Untrt -- Untrt	1.1 a	5.5 a	3.3 a	3.0 a	3.8 a	3.5 a
Untrt -- CIC	1.8 a	3.4 b	2.6 a	3.3 a	1.8 bc	2.3 bc
CIC -- CIC	1.6 a	3.5 b	2.5 a	2.1 a-c	1.7 bc	1.8 bc
CIC+Bt-- CIC+Bt	1.3 a	3.6 b	2.4 a	2.9 ab	1.2 c	1.8 bc
CIC -- CIC+Bt	1.3 a	3.5 b	2.4 a	1.3 c	1.4 bc	1.4 c
CIC+Bt -- CIC	0.9 a	3.7 b	2.3 a	0.9 cd	1.8 bc	1.5 c
CIC -- Bt M,W,F	---	---	---	2.0 a-c	1.6 bc	1.8 bc
Bt M,W,F -- CIC	0.6 a	4.3 ab	2.4 a	1.4 bc	1.6 bc	1.5 c
Bt -- CIC	1.4 a	3.8 b	2.6 a	2.1 a-c	1.1 c	1.4 c
Bt -- Bt	---	---	---	2.4 a-c	2.6 b	2.6 b
Bt cotton	---	---	---	0.0 d	0.4 c	0.3 d

* Means within a column not followed by a common letter differ significantly (P=0.05).

Table 5. Total number of heliothine damage per 25 squares/bolls in large cotton plots (ca. 0.5 acre) in 1995 and 1996.

	1995			1996		
Treatment	Pre Bloom	Post Bloom	All Year	Pre Bloom	Post Bloom	All Year
Untrt -- Untrt	2.7 b	6.8 a	4.8 a	9.7 a	10.6 a	10.3 a
Untrt -- CIC	4.5 a	4.9 b	4.7 ab	7.8 ab	6.6 b	7.0 b
CIC -- CIC	2.3 b	5.0 b	3.6 ab	4.8 b	4.6 b	4.7 c
CIC+Bt-- CIC+Bt	2.0 b	4.3 b	3.2 b	5.8 b	4.6 b	5.0 c
CIC -- CIC+Bt	2.3 b	5.7 ab	4.0 ab	5.2 b	5.3 b	5.3 c
CIC+Bt -- CIC	2.1 b	4.4 b	3.2 ab	4.7 b	4.6 b	4.6 c
CIC -- Bt M,W,F	---	---	---	5.3 b	4.8 b	5.0 c
Bt M,W,F -- CIC	2.2 b	5.6 ab	3.9 ab	5.3 b	4.9 b	5.0 c
Bt -- CIC	2.1 b	5.0 b	3.5 ab	5.2 b	5.0 b	5.1 c
Bt -- Bt	---	---	---	6.0 b	6.0 b	6.0 bc
Bt cotton	---	---	---	0.1 c	0.5 c	0.3 d

* Means within a column not followed by a common letter differ significantly (P=0.05).

Table 6. Total number of heliothine eggs, larvae, and damage interminals and heliothine larvae and damage in squares/bolls in large cotton plots (ca. 0.5 acre) in 1995 and 1996.

	Terminals			Fruit	
Treatment	Eggs	Larvae	Damage	Larvae	Damage
Untrt -- Untrt	3.22 a	3.36 a	6.41 a	3.38 a	7.37 a
Untrt -- CIC	2.99 a	2.37 b	4.92 b	2.45 b	5.76 b
CIC -- CIC	3.34 a	2.25 b	3.88 b	2.18 b	4.11 c
CIC+Bt -- CIC+Bt	3.21 a	2.11 b	3.75 b	2.11 b	4.03 c
CIC -- CIC+Bt	3.30 a	2.24 b	4.20 b	1.89 b	4.59 b c
CIC+Bt -- CIC	3.21 a	1.88 b	3.84 b	1.89 b	3.89 c
CIC -- Bt M,W,F	---	---	---	---	---
Bt M,W,F -- CIC	3.13 a	2.04 b	3.84 b	2.00 b	4.41 c
Bt -- CIC	3.54 a	2.16 b	3.96 b	2.04 b	4.25 c
Bt -- Bt	---	---	---	---	---
Bt cotton	---	---	---	---	---

* Means within a column not followed by a common letter differ significantly (P=0.05).

Table 7. Total number of insecticide treatments in large cotton plots (ca. 0.5 acre) in 1995 and 1996.

	1995					1996				
Treatment	Bt	Pyr	Carb	OP	Total	Bt	Pyr	Carb	OP	Total
Untrt -- Untrt	0	0	0	0	0	0	0	0	1	1
Untrt -- CIC	1	3	5	2	11	0	5	1	1	7
CIC -- CIC	2	3	7	2	14	0	5	4	2	11
CIC+Bt-- CIC+Bt	10	3	7	2	22	10	5	4	2	21
CIC -- CIC+Bt	7	3	7	2	19	6	5	4	2	17
CIC+Bt -- CIC	5	3	7	2	17	4	5	4	2	15
CIC -- Bt M,W,F	--	--	--	--	--	10	0	3	2	15
Bt M,W,F -- CIC	11	3	5	2	21	6	5	1	1	13
Bt -- CIC	5	3	5	2	15	4	5	1	1	11
Bt -- Bt	--	--	--	--	--	10	0	0	1	11
Bt cotton	--	--	--	--	--	0	0	0	1	1

* Some treatments may have been applied together within a treatment.

** Pyr. refers to pyrethroids, Carb. to carbamates, and OP to organophosphate insecticides.

Table 8. Pounds of seed cotton per acre in large cotton plots (ca. 0.5 acre) in 1995 and 1996.

Treatment	1995	1996	Average
Untrt -- Untrt	494.6 b	373.1 d	433.9 b
Untrt -- CIC	1098.1 a	1323.9 bc	1211.0 a
CIC -- CIC	1219.4 a	2101.0 a	1660.2 a
CIC+Bt -- CIC+Bt	1091.2 a	2186.9 a	1639.1 a
CIC -- CIC+Bt	1316.8 a	2101.0 a	1708.9 a
CIC+Bt -- CIC	1224.0 a	1982.3 a	1603.2 a
CIC -- Bt M,W,F	---	1394.3 bc	---
Bt M,W,F -- CIC	1190.8 a	1772.6 ab	1481.7 a
Bt -- CIC	1242.3 a	1824.2 ab	1533.2 a
Bt -- Bt	---	1243.0 c	---
Bt cotton	---	2076.9 a	---

* Means within a column not followed by a common letter differ significantly (P=0.05).

Table 9. Total cost for heliothine control per acre in largecotton plots (ca. 0.5 acre) in 1995 and 1996.

Treatment	1995	1996	Average
Untrt -- Untrt	$0.00	$12.81	$12.81
Untrt -- CIC	$86.78	$58.68	$72.73
CIC -- CIC	$106.68	$103.30	$104.99
CIC+Bt -- CIC+Bt	$157.88	$164.24	$161.06
CIC -- CIC+Bt	$138.68	$141.70	$140.19
CIC+Bt -- CIC	$125.88	$128.90	$127.39
CIC -- Bt M,W,F	---	$121.43	---
Bt M,W,F -- CIC	$150.78	$97.08	$123.93
Bt -- CIC	$112.38	$84.28	$98.33
Bt -- Bt	---	$76.81	---
Bt cotton	---	$44.81	---

* Estimate costs do not include application costs, over-sprays of entire test area, or the per acre cost of Boll Weevil Eradication.
** Costs for heliothine control with Bt cotton included a $32.00 per acre license fee.

Table 10. Net profit above heliothine control per acre ($0.70 per pound of cotton) in large cotton plots (ca. 0.5 acre) in 1995 and 1996

Treatment	1995	1996	Average
Untrt -- Untrt	$112.70	$74.81	$93.76
Untrt -- CIC	$250.18	$334.31	$292.25
CIC -- CIC	$277.83	$483.10	$380.47
CIC+Bt -- CIC+Bt	$248.64	$485.86	$367.25
CIC -- CIC+Bt	$299.88	$465.16	$382.52
CIC+Bt -- CIC	$278.88	$444.91	$361.90
CIC -- Bt M,W,F	---	$309.55	---
Bt M,W,F -- CIC	$271.32	$381.23	$326.28
Bt -- CIC	$283.08	$425.10	$354.09
Bt -- Bt	---	$317.33	---
Bt cotton	---	$432.91	---

* Estimate costs do not include application costs, over-sprays of entire test area, or the per acre cost of Boll Weevil Eradication.
* Net profits are calculated above heliothine control costs.

Table 11. Total cost of heliothine control per pound of lintproduced and pounds of lint produced per dollar spent onheliothine control in large cotton plots (ca. 0.5 acre) in 1995and 1996.

	$ Spent/Lb. of Lint			Lbs. of Lint/$ Spent		
Treatment	1995	1996	Avg.	1995	1996	Avg
Untrt -- Untrt	$0.00	$0.12	$0.06	0	8.3	4.2
Untrt -- CIC	$0.24	$0.12	$0.18	4.1	8.1	6.1
CIC -- CIC	$0.27	$0.15	$0.21	3.7	6.7	5.2
CIC+Bt -- CIC+Bt	$0.44	$0.24	$0.34	2.3	4.2	3.2
CIC -- CIC+Bt	$0.32	$0.21	$0.27	3.1	4.7	3.9
CIC+Bt -- CIC	$0.32	$0.20	$0.26	3.2	4.9	4.1
CIC -- Bt M,W,F	--	$0.27	--	--	3.6	--
Bt M,W,F -- CIC	$0.39	$0.18	$0.29	2.6	5.6	4.1
Bt -- CIC	$0.28	$0.14	$0.21	3.6	7.2	5.4
Bt -- Bt	--	$0.17	--	--	5.9	--
Bt cotton	--	$0.07	--	--	14.8	--

* Estimate costs do not include application costs, over-spraysof entire test area, or the per acre cost of Boll WeevilEradication.

Table 12. Average number of insecticide applications, cost perpound of lint produced, net profit above heliothine control, total costfor heliothine control, and pounds of seed cotton per acre in cottonplots (ca. 0.5 acre) in 1995 and 1996.

Treatment	No. of Insect. Apps.	Cost/Lb . of Lint Prod.	Total Net Profit	Heliothine Control Cost/A	Lbs. of Seed Cotton
Untrt -- Untrt	0.5	$0.06	$93.76	$12.81	433.9 b
Untrt -- CIC	9	$0.18	$292.25	$72.73	1211.0 a
CIC -- CIC	12.5	$0.21	$380.47	$104.99	1660.2 a
CIC+Bt-- CIC+Bt	21.5	$0.34	$367.25	$161.06	1639.1 a
CIC -- CIC+Bt	18	$0.27	$382.52	$140.19	1708.9 a
CIC+Bt -- CIC	16	$0.26	$361.90	$127.39	1603.2 a
CIC -- Bt M,W,F	---	---	---	---	---
Bt M,W,F -- CIC	17	$0.29	$326.28	$123.93	1481.7 a
Bt -- CIC	13	$0.21	$354.09	$98.33	1533.2 a
Bt -- Bt	---	---	---	---	---
Bt cotton	---	---	---	---	---

* Estimate costs do not include application costs, over-sprays ofentire test area, or the per acre cost of Boll Weevil Eradication.
* Net profits are calculated above heliothine control costs.