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PEST STATUS AND MANAGEMENT OF BEET ARMYWORM, *SPODOPTERA EXIGUA* (HÜBNER), ON COTTON IN LOUISIANA

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

Department of Entomology

by

Victor J. Mascarenhas
B. S., University of Florida, 1990
M. S., Mississippi State University, 1994
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ABSTRACT

Field cage studies were conducted to measure the effects of late season beet armyworm, *Spodoptera exigua* (Hübner), infestations (0, 1, 3, and 6 egg masses per 5.1 row m) on defoliation, fruit damage, and yield of cotton. Light penetration through the canopy was significantly higher in infested plots. Although a trend for increased numbers of damaged fruiting forms with increases in egg mass density was observed, there were no significant differences between infested and control plots. There were no significant differences in the cumulative number of shed fruiting forms or yield between infested and control plots.

Field tests were conducted to evaluate the effectiveness of selected insecticides against native populations of beet armyworms. The experimental insecticides, chlorfenapyr, spinosad, and tebufenozide, provided satisfactory control (83-91%). Chlorpyrifos provided adequate (70-80%) control, while thiodicarb and Spod-X did not provide adequate control (< 60%).

Susceptibility of field-collected beet armyworm larvae to registered and experimental insecticides was evaluated in a diet overlay bioassay using 2-d old larvae and third instars (30-45 mg). Larvae were collected from cotton fields throughout the U.S. and from Rio Bravo, Mexico. Susceptibility of field strains was compared with a laboratory strain. In chlorpyrifos bioassays of 2-d old larvae, 7 of 11 field strains had significantly higher LC$_{50}$s, while in third instar bioassays, all field strains had significantly higher LC$_{50}$s. In thiodicarb bioassays, 3 of 10 and 5 of 8 field strains had significantly higher LC$_{50}$s in 2-d old and third instar bioassays, respectively. In bioassays of 2-d old larvae and third instars with chlorfenapyr, 1 of 9 and 5 of 8 field...
strains had significantly higher LC₅₀s. With spinosad, 3 of 10 field strains tested as 2-d old larvae had significantly lower LC₅₀s, while 1 of 7 strains tested as third instars had significantly higher LC₅₀s. With tebufenozide, 1 of 10 and 2 of 7 field strains had significantly higher LC₅₀s in 2-d old and third instar bioassays, respectively. Emamectin benzoate and methoxyfenozide were evaluated only in third instar bioassays, where 5 of 7 strains had significantly lower LC₅₀s and 1 of 7 strains had significantly higher LC₅₀s, respectively.
INTRODUCTION

The beet armyworm, *Spodoptera exigua* (Hübner), is a polyphagous insect pest with world-wide distribution. A native of the tropical and temperate zones of the Orient (Pearson 1982, Kawana 1993), this pest was first documented in the continental United States in 1876, feeding on sugar beets in Oregon (Harvey 1876). Beet armyworm populations expanded their distribution eastward and were reported in most southeastern states by the 1920's (Wilson 1932). The present distribution of beet armyworms in the U.S. extends from California to the Carolinas, and from Wisconsin to southern Florida and Texas (Mitchell 1979, Pearson 1982).

This insect is a general feeder with a wide host range. Pearson (1982) compiled a list of over 90 host species, including many agronomic, fruit, ornamental, and vegetable crops as well as numerous wild plants. The ability of this pest to utilize a wide range of hosts is a key factor for its survival during the winter months, when perhaps a preferred host is not available. Although this insect lacks the ability to diapause (Fye and Carranza 1973, Pearson 1982), it is well adapted to cold climates, given that appropriate food sources are available throughout the winter months (Ruberson 1996).

The cold-hardiness of beet armyworms allows them to overwinter in southern Florida and Texas (Luginbill 1928). Overwintering beet armyworm populations have been recorded as far north as Montgomery, Alabama; Dooly County, Georgia; and Yazoo City, Mississippi (Smith 1994, Ruberson 1996). Overwintering beet armyworm populations have not been documented in Louisiana, although moth captures have been reported throughout the winter months (Sprenkel and Austin 1994). The absence of
commercial production of vegetables or ornamental crops to sustain larval populations is a major factor preventing successful overwintering of this pest in Louisiana (Burris et al. 1994). During the 1994 Cooperative Beet Armyworm Trapping Program, winter moth captures in Tensas, Franklin, and Bossier Parishes were 2.5 fold greater than the average moth captures from 5 counties in Florida (Sprenkel and Austin 1994), where beet armyworms have been documented to be present year-round (Luginbill 1928). This suggests that beet armyworms may survive moderate winter conditions in Louisiana and possibly infest crops earlier than previously reported.

The first recorded damage to cotton caused by beet armyworm occurred during 1904 in Texas (Sanderson 1905). By the 1920's, beet armyworms were observed throughout the cotton producing regions of the mid-south and southeastern U. S. (Wilson 1932). This insect has been historically viewed as an occasional pest of cotton, generally occurring during the late season and causing most of its damage as a defoliating pest. However, some researchers feel that the behavior of this pest has changed in recent years, and that cotton is becoming a preferred host (Smith 1989a, Ruberson 1996, Huffman 1996). The feeding pattern of this pest also may have changed. Feeding on fruiting forms (squares, blooms, and bolls) during the period of critical fruit set has greatly increased the economic damage associated with beet armyworm infestations (Smith 1989b, Layton 1994).

Researchers have agreed on several factors that are generally associated with beet armyworm population outbreaks on cotton. These factors have been reviewed by Smith (1989b, 1995), Layton (1994), Ruberson et al. (1994a), and others and include mild winters, delayed planting and crop maturity, early-season insecticide use.
(organophosphates and pyrethroids) that are detrimental to natural enemies, prolonged hot and dry weather, and presence of beet armyworms early in the season. Within fields, higher densities of beet armyworm also have been correlated with sandier soils as opposed to soils with high clay or loam content, dryland instead of irrigated cotton, fields with irregular plant stand, and plants that are stressed rather than healthy plants (Smith 1989b, Ruberson et al. 1994a).

The use of broad spectrum insecticides early in the growing season has been documented as a major factor associated with beet armyworm outbreaks (Eveleens et al. 1973, Gaylor and Graham 1991, Ruberson et al. 1994b). Stewart et al. (1996) showed that the occurrence of beet armyworm outbreaks was correlated with insecticide applications being made for boll weevil (*Anthonomous grandis grandis* Boheman) eradication, as well as for cotton aphids (*Aphis gossypii* Glover) and plant bug (*Lygus* spp.) control. The Boll Weevil Eradication Program has been partially responsible for beet armyworm outbreaks in Georgia (Ruberson et al. 1994a) and Texas (Arrilago 1995, Huffman 1996).

In addition to environmental (weather and temperature) and operational (plant stand, irrigation, fertilization, insecticide usage, and others) factors, there are other contributing factors that enable beet armyworm populations to increase rapidly. First, beet armyworms are highly mobile (French 1969, Mitchell 1979), which allows large numbers of insects to infest an area in a relative short time. Second, they have a high reproductive rate, with individual female moths laying an average of 500 eggs (approximately 80 eggs per mass). Third, under optimum growing temperatures for cotton production, the generation time (from egg to adult) for this pest may be as short
as 17 days (Ali and Gaylor 1992). A factor that is commonly overlooked, but that can contribute to the development of high beet armyworm populations, is that low to moderate infestations are not always detected. Adult moths usually prefer to deposit their eggs on the abaxial surface of mature leaves in the bottom half of the cotton canopy, thus they are not easily observed by crop consultants (Smith 1989a, Huffman 1996). Common scouting techniques often fail to detect beet armyworms at an early stage of development because of the location of the egg masses and because young larvae feed gregariously near the oviposition site until they have matured into a late second or third instar larva. As with other lepidopteran insect pests of cotton, effective control efforts should be targeted at newly hatched larvae, which are generally more susceptible than older larvae.

In the past decade, severe beet armyworm outbreaks have been reported in Alabama (1988, 1989, 1990, 1993, and 1995), Georgia (1988, 1989, and 1990), Mississippi (1993), and more recently in Texas (1995). In Georgia alone, population outbreaks of this pest caused an estimated loss of $10.9 and $25.9 million during the 1989 and 1990 growing seasons, respectively (Douce and McPherson 1991, 1992). During the outbreak of 1995 in the Lower Rio Grande Valley of Texas, 75% of the cotton acreage received an average of three insecticide applications targeted at beet armyworms. Despite control efforts, regional yields were reduced by an average of 50% (Huffman 1996, Summy et al. 1996). In the Southern Rolling Plains of Texas, two insecticide applications were made against beet armyworms on over 61% of the cotton acreage; nevertheless, severe yield losses (30%) occurred. At the climax of the outbreaks in these two regions, the population density of this insect pest was estimated
at 700,000 to 1.1 million larvae per acre (Huffman 1996). The damage caused by beet armyworm outbreaks along with other insect pests was estimated to approach $200 million in the Lower Rio Grande Valley and Southern Rolling Plains of Texas (Sharp 1995).

Much of the concern associated with beet armyworm outbreaks is the lack of efficacious insecticides for their control. Beet armyworms are inherently tolerant to most classes of insecticides, including some carbamates, chlorinated hydrocarbons, organophosphates, and pyrethroids (Layton 1994). Chlorpyrifos and thiodicarb are the only labeled insecticides presently recommended for beet armyworm control in Louisiana (Bagwell et al. 1997). Reduced field efficacy of these products has been reported in many cotton growing regions of the southeast (Layton 1994, Smith 1994). In Louisiana, thiodicarb was the most effective insecticide against beet armyworm in 1984, providing control in excess of 95% (Burris 1983). However, by the mid 1990's, control with this product was highly variable and unsatisfactory (Burris et al. 1994, Graves et al. 1995). Variable beet armyworm control also has been reported for chlorpyrifos in the southeast and mid-south regions of the U.S. (Elzen 1989, Sparks et al. 1996). In Louisiana, satisfactory control (87%) has been achieved with chlorpyrifos (Graves et al. 1995), although much lower control (38%) has been reported previously (Burris et al. 1994).

Unsatisfactory field efficacy of many insecticides against beet armyworm has been associated with decreased susceptibility of field populations. Variations in beet armyworm susceptibility to insecticides have been reported for several field-collected strains (Cobb and Bass 1975; Meinke and Ware 1978; Brewer and Trumble 1989, 1994;
Aldosari et al. 1996; Chandler and Ruberson 1996) and among four laboratory reference strains (Wolfenbarger and Brewer 1993). Chandler and Ruberson (1996) reported a 15.4- and 23.6-fold difference in the range of LC$_{50}$s among field populations from Alabama, Georgia, and Mississippi in chlorpyrifos and thiodicarb bioassays, respectively.

In Louisiana, the Boll Weevil Eradication Program began during August, 1997 in the Red River Valley area. The potential for disruption of natural enemies due to insecticide applications that will be made during the eradication program (Stewart et al. 1996) combined with the reduced efficacy of insecticides currently recommended for beet armyworm control will create conditions that are conducive for population outbreaks in Louisiana. Therefore, it is urgent that field populations from Louisiana are monitored for their susceptibility to labeled and experimental insecticides and to determine the efficacy of these compounds under field conditions.

Cotton approaching the “cutout” stage of maturity (when flower buds at nodes near the plant’s terminal have bloomed) is generally not at risk of economic yield losses, because bolls that will significantly contribute to yield are sufficiently mature that insects typically are unable to injure them. The economic threshold (in numbers of egg masses and/or larvae per length of row) for beet armyworms in many regions of the mid-south and southeast generally increases once cotton has reached “cutout”. In Mississippi, the treatment threshold for beet armyworms in cotton is 2 to 5 “hits” (egg masses or clusters of small larvae) per 100 feet of row in early to mid-season. However, for cotton nearing maturity, “relatively higher” populations can be tolerated without yield losses (Anonymous 1997a). Similarly in Texas, the mid-season threshold for this
pest is 1-2 larvae per foot of row, but increases to 10 larvae per foot of row at post-
cutout (Huffman et al. 1996). In Louisiana, the treatment threshold for beet armyworm
is set at 5-6 “hits” per 300 feet of row. Although a late season threshold is not specified,
a statement that “infestations on mature cotton may not cause economic damage” is
made (Anonymous 1997b). The intensity of late-season infestations, as well as crop
maturity at the time of infestations are the two most important factors determining the
economic damage that this pest may cause. Thus, yield loss associated with late season
beet armyworm infestations in Louisiana must be clarified to avoid potential economic
losses as well as unnecessary insecticide applications late in the growing season.

The studies presented in this dissertation were initiated to quantify the yield
losses caused by beet armyworm infestations in cotton approaching the “cutout” stage,
and to ascertain the toxicological responses of beet armyworms to labeled and
experimental insecticides in both laboratory and field tests. This information may be
used to monitor insecticide resistance development in beet armyworm populations and
to refine the overall insect pest management program on cotton in Louisiana.

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RESEARCH OBJECTIVES

I: To determine the effects of late season beet armyworm infestations on fruit damage, defoliation, and yield.

II: To determine the susceptibility of field populations of beet armyworm from Louisiana and other states to insecticides recommended for its control and to establish baseline mortality data for new insecticides.
   A. Determine the efficacy of selected labeled and experimental insecticides against beet armyworms in replicated small plot field tests.
   B. Determine toxicological responses of 2-d old beet armyworm larvae to chorfenapyr, chlorpyrifos, spinosad, tebufenozide, and thiodicarb using a laboratory reference strain and field-collected strains.
   C. Determine toxicological responses of third-instar beet armyworms to chorfenapyr, chlorpyrifos, emamectin benzoate, methoxyfenozide, spinosad, tebufenozide, and thiodicarb using a laboratory reference strain and field-collected strains.
CHAPTER 1

LATE SEASON BEET ARMYWORM INFESTATIONS: EFFECTS ON FRUIT DAMAGE, DEFOLIATION, AND YIELD

Introduction

The beet armyworm, *Spodoptera exigua* (Hübner), has been an occasional pest of cotton in the U.S. since the early 1900's (Sanderson 1905) causing damage primarily as a defoliator (Smith 1989, Leser et al. 1996). Upon hatching, young larvae feed gregariously on the abaxial surface of mature leaves in the lower canopy of the cotton plant. Larvae tend to consume all leaf tissues except the upper epidermis, resulting in a "window-pane" appearance in the area surrounding the egg mass, generally referred to as a "hit". Once these insects have matured into third-instar larvae, they disperse throughout the plant canopy feeding singly or in small groups. Damage to cotton associated with beet armyworm has traditionally been in the form of foliage and flower feeding, as well as etching on the bracts of fruiting forms (Smith 1989). These insects have been reported to occasionally feed on squares and small bolls late in the growing season, but this feeding typically does not result in economic yield losses because fruiting forms that are set late in the growing season generally do not significantly contribute to yield (Jenkins et al. 1990).

During population outbreaks in mid to late 1980's in Alabama (Smith 1989) and in 1993 in Mississippi (Layton 1994), the infestation pattern and feeding behavior of beet armyworms appeared to change. In these areas, populations of this pest uniformly infested many fields, and larvae fed almost exclusively on squares, flowers, and young bolls during most of the fruiting stage of plant development (Smith 1989, Layton 1994).
During these outbreaks in Alabama and Mississippi, many growers sustained extensive yield losses despite exhaustive control efforts, which in some areas exceeded $371 per hectare. Similar devastation by beet armyworm outbreaks has occurred in areas of Georgia (Douce and McPherson 1991, 1992) and Texas (Summy et al. 1996).

The economic impact of beet armyworm infestations include the yield losses and the costs associated with insecticide applications. Because beet armyworms are tolerant to most classes of insecticides (Layton 1994), control costs can become prohibitive under outbreak conditions. During beet armyworm outbreaks reported in many areas of the southeast in 1993, insecticide control costs ranged from $30 to $35 per application per hectare (Williams 1994). In the Lower Rio Grande Valley of Texas, the cost of insecticides targeted at beet armyworms exceeded $44 per application per hectare in 1995 (Williams 1996).

Cotton production in Louisiana has not been threatened by severe beet armyworm outbreaks. Isolated outbreaks have been reported every two to three years since the mid 1980's (Burris et al. 1994), however, these have not been as severe as in other states. The relative lack of serious beet armyworm infestations in Louisiana is evident by the fact that 1986 was the first year in which armyworms as a group were included in the Louisiana Cooperative Extension Service Insect Control Guide (Anonymous 1986). Additionally, separation of the two most common species occurring in cotton, the fall armyworm (*S. frugiperda* (J. E. Smith)) and the beet armyworm, was only recently made in the 1994 Insect Control Guide (Anonymous 1994). Although during the past 4 growing seasons this pest infested an estimated 1.4 million acres of cotton in the state (Williams 1994, 1995, 1996, 1997), its pest status remains as a sporadic, secondary pest.
In Louisiana, cotton yield losses associated with beet armyworm damage have been less severe than in other states (Burris et al. 1994).

Chlorpyrifos and thiodicarb are the only two insecticides currently recommended for beet armyworm control in cotton in Louisiana (Bagwell et al. 1997). Unsatisfactory field efficacy of these insecticides against beet armyworm populations have been reported in most cotton producing states of the mid-south and southeastern U.S. (Elzen 1989, Burris et al. 1994, Layton 1994, Smith 1994, Graves et al. 1995, Sparks et al. 1996).

The Boll Weevil Eradication Program was implemented in Louisiana in August, 1997. The intensive insecticide regime associated with this program will likely release beet armyworms from their natural enemies (Evellens et al. 1973, Gaylor and Graham 1991, Ruberson et al. 1994), a condition that can lead to population outbreaks of this pest. Thus, the potential yield losses associated with beet armyworm damage to cotton in Louisiana should be investigated so that cost-effective management strategies can be implemented in the event of future infestations.

Materials and Methods

Field studies were conducted during 1996 and 1997 to determine the effects of defoliation and fruit feeding by beet armyworm on cotton yields. Field-collected beet armyworm strains were used to artificially infest plots within cages. Beet armyworm larvae collected from cotton in Tift County, Georgia on 20 and 21 June were used in 1996, while larvae collected from cotton in St. Joseph, Louisiana on 7 and 8 August were used in 1997. Field-collected larvae were transported to a laboratory in the
Department of Entomology at Louisiana State University Agricultural Center (Baton Rouge) and reared using an artificial wheat-germ and soybean protein diet (King and Hartley 1985). Egg masses of the F$_2$ and F$_1$ generation were used in field infestations during 1996 and 1997, respectively.

Studies were conducted at the Northeast Research Station near St. Joseph, Louisiana. Plots consisted of three adjacent rows (approximately 1 m centers) by 1.7 m in length covered by a translucent 32 mesh nylon cage (Synthetic Industries, Greenville, Georgia) measuring 1.7 X 3.4 X 1.7 m. Plots were planted to ‘Stoneville 474’ cotton, an early maturing variety, on 1 May in 1996 and on 4 June in 1997. In both years, plots were arranged in a randomized block design with 4 replications. Plots were treated as needed with insecticides to minimize defoliation and fruit damage, starting at first square and ending 7-10 d before artificial infestation. Before covering them with cages, plots were sprayed with methyl parathion and acephate (tank mixed) to reduce populations of natural enemies within the caged area.

Cotton plots were artificially infested when plants reached the 5 nodes above white flower stage and had accumulated approximately 300 heat units (Oosterhuis et al. 1993). Heat unit accumulation was calculated according to Bagwell and Tugwell (1982). Artificial infestations were made on 2 and 27 August in 1996 and 1997, respectively. At this stage of plant development, the 5 nodes below the plants’ terminal were the only ones which had not bloomed at the first fruiting position. At this stage of maturity, cotton plants are beginning to cease their vegetative growth and utilize most of their photosynthates to fill older bolls (Gutierrez et al. 1975, Hake et al. 1989). This stage of plant development in cotton is commonly referred to as “cutout”.

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The center row of individual plots was artificially infested with 0, 1, 3, or 6 egg masses. Egg masses on wax paper oviposition sheets were attached with a paper clip to the abaxial surface of fully expanded leaves in the middle one-third of the cotton canopy. Larvae were thinned to approximately 60-80 insects per egg mass 2-3 d after larval hatching (DAH). All shed fruiting structures were removed from within the cages before artificial infestation. Square and boll damage was estimated by collecting all shed fruiting structures two times per week and examining them for larval feeding. Shed fruiting forms were categorized into two groups. Fruiting forms that were shed but no evidence of larval feeding were categorized as undamaged, while those that were shed with evidence of larval feeding were categorized as damaged. Fruit damage was measured from the period when larvae began to disperse from the leaf where the egg masses were attached (5-6 DAH) until larvae had pupated in the soil (20-22 DAH).

Defoliation was estimated by measuring the photosynthetically active radiation (PAR) that penetrated through the cotton canopy. A 1 m light ceptometer (Decagon Devices, Inc. Pullman, Washington) probe equipped with 80 independent sensors was used to measure PAR. All PAR sampling was conducted between the hours of 11:00 am and 1:30 pm to minimize the effects of sun position on the data. Six PAR samples were taken above the canopy by placing the ceptometer probe parallel to the top of the cages and perpendicular to the cotton rows. This measurement supplied the base level of PAR inside the cage. PAR samples below the canopy were taken by placing the probe perpendicular to the rows at the base of the cotton plants. Samples below the canopy were taken at 10 different locations within the cage. Sampling PAR above and below the canopy was conducted sequentially within a cage. Percent light penetration...
through the canopy was estimated by dividing the PAR below the canopy by the PAR above the canopy and multiplying that number by 100. Visual defoliation ratings made at the end of the larval cycle, once artificially infested larvae had pupated in the ground, were used to estimate total defoliation. The leaf area consumed in infested plots were visually compared to leaf area in control plots. Cotton yields were estimated by manually harvesting the plots and measuring seed cotton weights. Data were analyzed by ANOVA and means were separated according to Fisher's Protected LSD ($P = 0.05$) (SAS Institute 1988). Statistical comparisons ($\alpha = 0.05$) were made within sampling date and across infestation densities.

Results

Defoliation. Light penetration through the cotton canopy was significantly higher in plots infested with beet armyworm eggs masses compared with control plots at most sampling dates (Table 1.1). In 1996, all beet armyworm infested plots had significantly more (1.5 to 1.7-fold) light penetrating the canopy than the control plots at 9 DAH. At 13 and 16 DAH, infested plots had 1.3 to 1.5-fold and 1.2 to 1.4-fold more light penetrating the canopy than the control plots, respectively. At 13 DAH, all infested plots, except for those infested with 3 egg masses, had significantly more light penetration than the control plots. At 16 DAH, all infested plots, except for those infested with 1 egg mass, had significantly higher light penetration than the control plots.

In visual defoliation ratings made at 22 DAH in 1996, only the plots infested with 6 egg masses had significantly higher defoliation (14%) than the control plots (4%).
Table 1.1. Percent light penetration and yield of cotton in plots infested with 0, 1, 3, or 6 beet armyworm egg masses.

<table>
<thead>
<tr>
<th>Number of Egg Masses</th>
<th>% Light Penetration(^1) (1996)</th>
<th>9 DAH</th>
<th>13 DAH</th>
<th>16 DAH</th>
<th>% Light Penetration (1997)</th>
<th>9 DAH</th>
<th>12 DAH</th>
<th>16 DAH</th>
<th>19 DAH</th>
<th>Visual % Defoliation(^3)</th>
<th>Seed Cotton Yield (kg/ha) (1996)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.94 b(^d) 5.77 b 7.76 b</td>
<td>7.90 b</td>
<td>9.38 b</td>
<td>9.24 b</td>
<td>10.00 b</td>
<td>4.0 b</td>
<td></td>
<td></td>
<td></td>
<td>3550 a</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7.78 a 8.44 a 9.44 ab</td>
<td>10.52 ab</td>
<td>11.52 ab</td>
<td>10.98 b</td>
<td>13.74 b</td>
<td>7.8 ab</td>
<td></td>
<td></td>
<td></td>
<td>3611 a</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7.47 a 7.66 ab 10.42 a</td>
<td>11.61 a</td>
<td>14.86 a</td>
<td>16.72 a</td>
<td>19.37 a</td>
<td>6.3 b</td>
<td></td>
<td></td>
<td></td>
<td>3625 a</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>8.62 a 8.38 a 10.64 a</td>
<td>9.05 ab</td>
<td>14.86 a</td>
<td>16.67 a</td>
<td>22.37 a</td>
<td>13.8 a</td>
<td></td>
<td></td>
<td></td>
<td>4071 a</td>
<td></td>
</tr>
</tbody>
</table>

Means within a column not followed by a common letter differ significantly (Fisher's Protected LSD; \(P = 0.05\)).

\(^1\) Light penetration measured in Photosynthetic Active Radiation (PAR) using light ceptometer. % Light penetration = (PAR bottom canopy / PAR top canopy) X 100.

\(^2\) DAH = days after larval hatching.

\(^3\) Estimated defoliation based on visual ratings made at 22 DAH in 1996.
In 1997, only the plots infested with 3 egg masses had significantly more (1.5-fold) light penetrating the canopy at 9 DAH than the control plots (Table 1.1). At the remaining sampling dates (12, 16, and 19 DAH), plots infested with 3 and 6 egg masses had significantly more light penetrating through the canopy than the control plots. At 12, 16, and 19 DAH, plots infested with 3 egg masses had 1.6, 1.8, and 1.9-fold more light penetration than the control plots, respectively. Similarly, plots infested with 6 egg masses had 1.6, 1.8, and 2.2-fold more light penetration than the control plots at 12, 16, and 19 DAH, respectively (Table 1.1).

**Fruiting Form Damage 1996.** The numbers of undamaged and damaged fruiting forms (squares and bolls) in the non-infested control plots were similar at all sampling dates (Figure 1.1A). Numbers of undamaged and damaged fruiting forms in the control plot from 6 through 20 DAH ranged from 27.8 to 34.3 and 3.5 to 7.3, respectively. Variation in the numbers of undamaged and damaged fruiting forms across sampling dates was higher in beet armyworm infested plots and variation appeared to be associated with increases in egg mass density (Figures 1.1B-D). In plots infested with 1 egg mass, numbers of undamaged and damaged fruiting forms ranged from 17.8 to 36.0 and 3 to 18, respectively. Similarly, in plots infested with 3 egg masses, numbers of undamaged and damaged fruiting forms ranged from 16.5 to 35.3 and 5.0 to 24.8, respectively. The widest range in numbers of undamaged (15.8 to 44.0) and damaged (5.8 to 34.3) fruiting forms across sampling dates was observed in plots infested with 6 egg masses.
Figure 1.1. Numbers of undamaged and damaged fruiting forms in plots infested with 0 (A), 1 (B), 3 (C), or 6 (D) beet armyworm egg masses at 6, 9, 13, 16, and 20 days after larval hatching in 1996. Statistical comparisons of undamaged and damage fruiting forms were made within sampling dates. Different letters above bars indicates significant ($P = 0.05$) differences.
A distinct peak in numbers of damaged fruiting forms was observed 13 DAH in infested plots (Figures 1.1B-D). At this sampling date, numbers of damaged fruiting forms in plots infested with 1, 3, or 6 egg masses were 2.5, 3.4, and 4.7-fold higher than that observed in the control plots (Figures 1.1A-D). However, numbers of damaged fruiting forms in infested plots were not significantly different from that in the control plots at 13 DAH. No significant differences in the number of damaged fruiting forms between the control and infested plots were observed at the other sampling dates, except for plots infested with 6 egg masses at 6 DAH.

Cumulative numbers of damaged fruiting forms in plots infested with 1, 3, or 6 egg masses was 2.4, 3.0, and 3.3-fold higher than that in the control plots (Figure 1.2). Although a trend for increased numbers of damaged fruiting forms with increases in egg mass density was observed, the cumulative number of damaged fruiting forms in infested plots were not significantly different from that in the control. In addition, there were no differences in the cumulative number of undamaged (Figure 1.2) or shed (undamaged + damaged) fruiting forms (Figure 1.3) between infested and control plots.

In all infested plots, a significantly higher percentage of the shed fruiting forms were damaged compared with the control plots at 6, 9, 13, and 16 DAH (Table 1.2). In addition, plots infested with 6 egg masses had a significantly higher percentage of shed fruiting forms that were damaged than the plots infested with 1 egg mass at 6 and 16 DAH. No differences were observed in the percentage of shed fruiting forms that were damaged between infested and control plots at 20 DAH. Similar results were obtained in the percentage of cumulative shed fruiting forms which were damaged (Table 1.2).
Figure 1.2. Cumulative numbers of undamaged and damaged fruiting forms in plots infested with 0, 1, 3, or 6 beet armyworm egg masses in 1996. Statistical comparisons of undamaged and damaged fruiting forms were made across egg mass densities. Different letters above bars indicates significant ($P = 0.05$) differences.

Figure 1.3. Cumulative numbers of shed (undamaged + damaged) fruiting forms in plots infested with 0, 1, 3, or 6 beet armyworm egg masses in 1996. Different letters above bars indicates significant ($P = 0.05$) differences.
Table 1.2. Percent of shed fruiting forms that were damaged in plots infested with 0, 1, 3, and 6 beet armyworm egg masses at various sampling dates.

<table>
<thead>
<tr>
<th>No. Egg Masses</th>
<th>% Damaged Fruiting Forms (1996)</th>
<th>% Damaged Fruiting Forms (1997)</th>
<th>Cumulative % Damaged Fruiting Forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10.9 c</td>
<td>18.4 b</td>
<td>14.7 b</td>
</tr>
<tr>
<td>1</td>
<td>18.7 b</td>
<td>36.5 a</td>
<td>35.0 a</td>
</tr>
<tr>
<td>3</td>
<td>21.7 ab</td>
<td>38.8 a</td>
<td>39.2 a</td>
</tr>
<tr>
<td>6</td>
<td>25.3 a</td>
<td>36.3 a</td>
<td>42.9 a</td>
</tr>
</tbody>
</table>

Means within a column not followed by a common letter differ significantly according to Fisher's Protected LSD (P = 0.05).

1 Percent damage fruiting form = (No. damaged fruiting form / No. shed fruiting form)* 100.

2 DAH = days after larval hatching.
All infested plots had a significantly higher percentage of the cumulative shed fruiting forms that were damaged than in the control plots.

**Fruiting Form Damage 1997.** Numbers of undamaged fruiting forms decreased over time in both infested and control plots (Figure 1.4 A-D). Numbers of undamaged and damaged fruiting forms in the control plots from 9 through 19 DAH ranged from 2.3 to 16.3 and 0.1 to 0.8, respectively. In plots infested with 1 egg mass, the numbers of undamaged and damaged fruiting forms ranged from 0.5 to 8.3 and 0.5 to 2.5, respectively. Similarly, in plots infested with 3 egg masses, the numbers of undamaged and damaged fruiting forms ranged from 0.8 to 9.0 and 0.5 to 2.0, respectively. Numbers of undamaged and damaged fruiting forms in plots infested with 6 egg masses ranged from 0.3 to 6.8 and 0.3 to 3.5, respectively. There were no significant differences in the number of undamaged fruiting forms among treatments at all sampling dates, except at 16 DAH, where control plots shed significantly more undamaged fruiting forms than all infested plots. Numbers of damaged fruiting forms in infested and control plots were similar 3 of the 4 sampling dates. At 12 DAH, plots infested with 6 egg masses had significantly more damaged fruiting forms than the control, as well as plots infested with 1 or 3 egg masses (Figure 1.4A-D).

The cumulative numbers of damaged fruiting forms in plots infested with 1, 3, or 6 egg masses was 2.1, 1.8, and 3.3-fold higher than that in the control plots (Figure 1.5). Although a trend for increased numbers of cumulative damaged fruiting forms with increases in egg mass density was observed, no significant differences were found. In
Figure 1.4. Numbers of undamaged and damaged fruiting forms in plots infested with 0 (A), 1 (B), 3 (C), or 6 (D) beet armyworm egg masses at 9, 12, 16, and 19 days after larval hatching in 1997. Statistical comparisons of undamaged and damaged fruiting forms were made within sampling dates. Different letters above bars indicates significant ($P = 0.05$) differences.

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Figure 1.5. Cumulative numbers of undamaged and damaged fruiting forms in plots infested with 0, 1, 3, or 6 beet armyworm egg masses in 1997. Statistical comparisons of undamaged and damaged fruiting forms were made across egg mass densities. Different letters above bars indicates significant ($P = 0.05$) differences.

Figure 1.6. Cumulative numbers of shed (undamaged + damaged) fruiting forms in plots infested with 0, 1, 3, or 6 beet armyworm egg masses in 1997. Different letters above bars indicates significant ($P = 0.05$) differences.
addition, there were no significant differences in the cumulative numbers of undamaged (Figure 1.5) or shed (Figure 1.6) fruiting forms between infested and control plots.

The percentage of shed fruiting forms that were damaged tended to increase with increases in egg mass density. However, there were no significant differences among treatments on 3 of the 4 sampling dates. At 12 DAH, plots infested with 6 egg masses had a significantly higher percentage of the shed fruiting forms that were damaged than control plots, as well as plots infested with 1 or 3 egg masses (Table 1.2). Similar results were obtained in the percentage of cumulative numbers of shed fruiting forms that were damaged. Plots infested with 6 egg masses had a significantly higher percentage of the cumulative shed fruiting forms that were damaged than the control plots and those infested with 1 or 3 egg masses.

**Yield.** In 1996, there was a trend for slight increases in seed cotton yield with increases in egg mass density, but differences among treatments were not significant (Table 1.1). Plots infested with 1, 3, or 6 egg masses yielded 1.7, 2.1, and 14.7% more seed cotton that the control plots.

**Discussion**

Yield losses associated with beet armyworm damage may result from direct damage to fruiting forms, as well as indirect damage from larvae feeding on foliage. Foliage feeding can indirectly affect yield by reducing the leaf area that produces photosynthates required to mature bolls. In previous studies, Kerby et al. (1988) showed that cotton can withstand up to 57% defoliation (artificial removal of leaves) before first square without significant reduction in lint yield. Additionally, Russell et al. (1993) conducted simulated defoliation studies in which cotton was repeatedly...
defoliated (20%) over a period of 7 consecutive weeks, from early squaring to mid-bloom, with no effect on yield. Russell et al. (1993) speculated that severe defoliation (>20%) during boll formation could significantly impact yield by reducing the production of photosynthates by leaves which is critical to boll development.

The beet armyworm densities examined in these studies were from 2.7 to 16.7-fold higher than the currently accepted threshold of 6 hits per 91.5 meter of row. At these infestation densities, a significant increase in the amount of light penetrating the canopy was generally observed in plots infested with 3 or 6 egg masses, which suggests a significant decrease in leaf area in these plots. In visual defoliation ratings, plots infested with 1, 3, or 6 egg masses were 1.9, 1.6, and 3.5-fold, respectively, more defoliated than the control plots. However, the decreased leaf area was not sufficient to reduce yield in these plots compared to the control plots. These data corroborate research by Guitierrez et al. (1975), where defoliation by beet armyworms and cabbage looper, *Trichoplusia ni* (Hübner), late in the growing season was found to have little effect on cotton yield. Results obtained in this study could have been caused by a compensatory effect (Oosterhuis et al. 1991), where the plants were able to produce new leaf material at a rate in which the demands for photosynthates by the maturing bolls were met. Thus no reduction in yield was observed. Defoliation at this late stage of plant maturity (NAWF =5 plus 300 heat units) may not have affected yield because (1) the harvestable bolls already had obtained all the photosynthates needed, or (2) there was sufficient leaf area remaining to mature the bolls. It appears that cotton plants are relatively unaffected by moderate (<40%) defoliation by insect pests from early season
to mid-flowering (Kerby et al. 1988, Russell et al. 1993) and again when they have reached 5 NAWF and have accumulated heat units in excess of 300.

Although beet armyworms historically are recognized as defoliators, their direct feeding on fruiting forms generally is of a much greater yield consequence (Smith 1989, Layton 1994). In 1996, a definite trend for increased fruit damage with increases in egg mass density was observed. During the period that this study was conducted (one larval cycle or approximately 22 d), larvae in plots infested with 1, 3, or 6 egg masses damaged approximately 60, 70, and 90 fruiting forms, respectively (Figure 1.2). However, this level of fruit damage was not significantly different from damage observed in the control plots (28 damaged fruiting forms). Damage recorded in control plots was likely due to fruiting forms being damaged before cages were placed over the plots, with abscission of the fruit themselves occurring at a later date. Additionally, some lepidopteran insect pests that survived the preventative weekly insecticide applications made prior to the initiation of the study may have contributed to the low level (< 7 fruiting forms per sampling date) of damage observed in the control plots (Figure 1.1A).

The levels of fruit damage observed in 1996 had no significant effect on yield. In fact, a trend for slight increases in seed cotton yield with increases in egg mass density was observed (Table 1.1). A similar trend also was observed in the cumulative number of shed fruiting forms (Figure 1.3). By having a slightly higher incidence of shed fruiting forms, plants in infested plots may have been able to concentrate their photosynthate resources on older fruiting forms, thus producing slightly bigger bolls than produced in the control plots. Hake et al. (1989) stated that "small fruit abscission
can be beneficial because it allows for the maturation of bigger bolls which the plant already has invested time and energy”. In addition, the fact that there were no significant differences in the cumulative numbers of shed fruiting forms (Figure 1.3), along with a significantly higher percentage of shed fruiting forms damaged in infested plots (Table 1.2), indicates that the majority of the fruiting forms damaged by beet armyworm larvae were those that the plant would have naturally shed in the absence of insect damage. Thus, no yield effect was observed.

Another factor which may have contributed to numerically higher yields with increases in egg mass density is the fact that infested plots suffered greater defoliation. Previous studies have shown that cultural practices designed to improve light penetration through the canopy, such as frego bract (Jones and Andries 1969), okra leaf (Andries et al. 1969), and skip-row plantings (Roncadori et al. 1975) can increase cotton yields by reducing the incidence of boll rot. In the studies reported herein, the significant increase in light penetration through the canopy due to defoliation in infested plots may have resulted in the slight increase in yields by reducing boll rot. Incidence of boll rot in experimental plots was not empirically measured in these studies.

The shedding of undamaged fruiting forms observed in 1996, particularly in plots infested with 3 or 6 egg masses, tended to follow the same temporal pattern as the numbers of damaged fruiting forms shed (Figures 1.1A-D). This suggests that the shedding of undamaged fruiting forms may be linked with the incidence of fruit damage. Gutierrez et al. (1975), reported that fruit shedding caused by insect damage may often trigger the shedding of undamaged fruiting forms. In this study however, plants in cages infested with 6 egg masses appeared to have responded to peak insect
damage (13 DAH) by decreasing the numbers of undamaged fruiting forms they shed. At 16 and 20 DAH, plots infested with 6 egg masses had 1.5 and 1.7-fold, respectively, fewer undamaged shed fruiting forms than the control plots (Figures 1.1A-D). This plant response to insect damage may have been caused by the depletion of smaller fruiting forms that the plant could shed in infested versus control plots. At 13 DAH, plots infested with 6 egg masses had shed (undamaged and damaged) 1.9-fold more fruiting forms than the control plots, thus these plants had fewer remaining fruiting forms to shed at latter dates.

The trends observed in fruit shedding and damage during 1996 were not repeated during 1997. Some of the differences observed can be directly attributed to distinctions between the growing seasons during these two years. The cotton crop in 1997 had an unusually slow start because the planting date of the experimental plots was delayed by 33 days compared with 1996. Wet and cool conditions during early summer in 1997 had a significant impact on seedling cotton by slowing plant development, as well as by possibly increasing the incidence of seedling diseases. In addition, abnormally hot and dry conditions occurred during late season. The combination of late planting, poor early season growing conditions, and abnormally hot and dry late season growing conditions in 1997 likely impacted the outcome of this study by reducing the overall yield potential of the plants due to stresses during the seedling and boll development stages. In short, differences in plant condition (fruit load and canopy mass) between 1996 and 1997 likely had some influence in the feeding behavior of beet armyworms.

A distinct difference observed between the 1996 and 1997 studies was the overall numbers of shed fruiting forms. In the control plots, the cumulative number of shed
(undamaged + damaged) fruiting forms in 1996 was 4.8-fold higher than in 1997.

Similarly, in plots infested with 1, 3, or 6 egg masses, the cumulative number of shed fruiting forms in 1996 was 9.5, 11.5, and 13.5-fold higher than in 1997, respectively. These differences in the numbers of shed fruiting forms were partially due to the lower fruit load in 1997 because of the conditions discussed previously.

Other factors also influenced the overall fruit load in the experimental plots during 1997. Availability of a field strain of beet armyworms in 1997 delayed the infestation date by 25 days compared to 1996. Plants in the experimental plots initially prepared for 1997 studies had accumulated 438 heat units in excess of that targeted for infestation (300 heat units) by the time that beet armyworms were available. Thus, a new location was selected where crop maturity was equivalent to that in 1996 (NAWF = 5 plus 300 heat units). Cotton at the new location had not been closely monitored and protected from insect damage. Thus, a large portion of its fruit load had suffered considerable damage from other insects and were aborted before cages were in place. This affected the overall numbers of fruiting forms available to be damaged and shed due to beet armyworm feeding. This is evident by the fact than most fruit shedding occurred at the first two sampling dates (Figures 1.2A-D) in all plots. After those initial fruiting forms were shed, the remaining bolls were probably too mature to have been damaged by beet armyworm larvae. Despite the differences in growing conditions between 1996 and 1997, a general trend for increased numbers of damaged fruiting forms with increases in egg mass density was observed in 1997 (Figure 1.5).
In summary, results from these studies indicate that neither defoliation or fruit
damage caused by late season beet armyworm infestation levels as high as 16.7 times
the current threshold of 6 hits per 91.5 meters of row significantly affected cotton yields.

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induction of beet armyworms by experimental insecticide applications in cotton in


CHAPTER 2

BEET ARMYWORM (LEPIDOPTERA: NOCTUIDAE) CONTROL ON COTTON IN LOUISIANA *

Introduction

The beet armyworm, *Spodoptera exigua* (Hübner), has historically been viewed as a secondary pest of cotton in most of the mid-south and southeastern United States. However, population outbreaks experienced in the 1980's and early 1990's in Alabama, Georgia, Louisiana, Mississippi (Douce & McPherson 1991, Burris et al. 1994, Layton 1994, Smith 1994), and more recently in Texas (Arrillago 1995, Sparks et al. 1996) have demonstrated the potential damage associated with outbreaks of this pest and the ineffective control provided by most currently labeled insecticides. From 1993 through 1996, an average of 30% of U.S. cotton hectares were treated for beet armyworms, which despite control measures, resulted in a loss of over 195 million kg of cotton over the 4 years period (Williams 1994, 1995, 1996, 1997).

The economic impact of beet armyworm infestations varies from region to region and includes both the direct yield loss caused by insect injury and the high production costs associated with frequent and costly insecticide usage. During the outbreak years of 1993 and 1995, an average of 0.3 insecticide application per hectare was targeted at controlling beet armyworms, with an average associated cost of $32 per application (Williams 1994 and 1996). However, these figures represent U.S. averages and in some regions of the southeast, such as Alabama and Mississippi, where the outbreak of 1993

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was particularly devastating, numerous cotton hectares were abandoned after the control costs exceeded $250-370/ha (Layton 1994, Smith 1994). More recently, beet armyworm infestations were a contributing factor in the total devastation of 75% of the cotton crop in Lower Rio Grande Valley and the Southern Rolling Plain regions of Texas (Huffman 1996, Sparks et al. 1996, Summy et al. 1996). In these areas, an average of three insecticide applications per treated hectare were made (Huffman 1996) at a cost of $4 per application (Williams 1996).

Chlorpyrifos and thiodicarb are the only two labeled insecticides currently recommended for beet armyworm control in Louisiana (Bagwell et al. 1997). Unsatisfactory field control obtained with both of these insecticides have been reported for most of the southeastern cotton growing states (Layton 1994, Smith 1994). In Louisiana, thiodicarb was the most effective insecticide against beet armyworm in 1984, providing control in excess of 95% (Burris 1983). However, by the mid 1990’s, control was highly variable and in many cases unsatisfactory (Burris et al. 1994, Graves et al. 1995). Variable beet armyworm control also has been reported for chlorpyrifos in much of the southeast and mid-south (Elzen 1996, Sparks et al. 1996). In Louisiana, satisfactory control (87%) has been achieved with chlorpyrifos (Graves et al. 1995), although much lower control (38%) has been previously reported (Burris et al. 1994).

This study was designed to evaluate the susceptibility of natural populations of beet armyworm in Louisiana to standard and experimental insecticides under field conditions. These data will aid in refining recommendation guides for beet armyworm control among southern states.
Materials and Methods

Field experiments were conducted to evaluate the efficacy of standard and experimental insecticides against the beet armyworm. Insecticides tested included commercial formulations of two currently recommended insecticides, chlorpyrifos (Lorsban® 4EC [emulsifiable concentrate], DowElanco, Indianapolis, Indiana) and thiodicarb (Larvin® 3.2F [flowable], Rhone-Poulenc Ag. Co., Research Triangle Park, North Carolina), as well as three experimental compounds, chlorfenapyr (Pirate® 3F, American Cyanamid Co., Wayne, New Jersey), spinosad (Tracer® 4F, DowElanco, Indianapolis, Indiana), and tebufenozide (Confirm® 2F, Rohm & Haas Co., Philadelphia, Pennsylvania). Spod-X® (Crop Genetics International, Wilmington, Delaware), a NPV (nuclear polyhedrosis virus) product which is labeled for beet armyworm control in cotton, also was included in field tests.

Field tests were conducted at the Northeast Research Station (Test 1) near St. Joseph, Louisiana and at the Macon Ridge location of the Northeast Research Station (Test 2) near Winnsboro, Louisiana during the summer of 1995. Both tests were arranged in a randomized block design with 4 replications. Plots measured four rows (approximately 1 m centers) by 15.25 m. Test 1 was planted to ‘Stoneville LA 887’ cotton on 16 May and Test 2 was planted to ‘DPL 5690’ cotton on 20 June.

Larval densities in each block were estimated before insecticide application by taking 6-10 drop cloth (approximately 1 row meter each) samples. Treatments for Tests 1 and 2 were applied on 15 and 30 August, respectively, with a high clearance sprayer. In Test 1, the sprayer was calibrated to deliver 93.5 liters total spray volume/ha through Teejet X-12 hollow cone nozzles (2/row) at 3.6 kg/cm². In Test 2, the sprayer was calibrated
to deliver 105.5 liters total spray volume/ha through Teejet X-8 hollow cone nozzles (2/row) at 3.1 kg/cm².

Treatment effect was measured by taking 2 drop cloth samples in each plot and counting the number of live larvae. Sampling was done in areas within a row where evidence of a ‘hit’ (recently hatched egg mass) and/or larval feeding was observed. This sampling procedure was adopted because randomly sampling for a clump-distributed pest population would not appropriately reflect larval densities in field plots. At each sampling period (2, 5, 7, and 10 days after treatment [DAT]), one row of each plot was sampled, so that rows 1, 2, 3, and 4 were sampled at 3, 5, 7, and 10 DAT, respectively. This sampling pattern was used to avoid sampling an individual ‘hit’, which may have been disturbed during an earlier sampling period. Recently deposited egg masses were avoided during the last two sampling dates, because these ‘hits’ represented infestations which would not have received the full treatment effect. With this sampling approach, neonates through second instar larvae were not included in samples taken at 7 and 10 DAT. Total number of live larvae per 0.3 m of row was used in the data analysis. Data were analyzed by ANOVA and means were separated according to Fischer's protected LSD (SAS Institute 1988).

**Results**

The average number of beet armyworm larvae per 0.3 m of row in Tests 1 and 2 before the application of the various treatments was 5.1 and 12.5, respectively. In Test 1, numbers of beet armyworm larvae were significantly lower than that of the untreated control for all treatments at 3 and 5 DAT, except for Spod-X (Table 2.1). Similar
Table 2.1. Efficacy of selected insecticides against beet armyworm at 3, 5, 7, and 10 days after treatment (DAT) in Test 1 at the Northeast Research Station, St. Joseph, Louisiana.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate (kg Al/ha)</th>
<th>3 DAT</th>
<th>5 DAT</th>
<th>7 DAT</th>
<th>10 DAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorfenapyr</td>
<td>0.22</td>
<td>0.5 b</td>
<td>0.3 c</td>
<td>0.6 b</td>
<td>0.3 b</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>1.12</td>
<td>0.9 b</td>
<td>0.5 c</td>
<td>1.2 b</td>
<td>0.5 b</td>
</tr>
<tr>
<td>Spinosad</td>
<td>0.08</td>
<td>0.7 b</td>
<td>0.2 c</td>
<td>0.4 b</td>
<td>0.2 b</td>
</tr>
<tr>
<td>Spod-X</td>
<td>185.5 1</td>
<td>6.1 a</td>
<td>3.7 ab</td>
<td>4.0 a</td>
<td>1.1 b</td>
</tr>
<tr>
<td>Tebufenozide</td>
<td>0.14</td>
<td>2.1 b</td>
<td>0.6 c</td>
<td>1.1 b</td>
<td>0.5 b</td>
</tr>
<tr>
<td>Thiodicarb</td>
<td>0.67</td>
<td>1.7 b</td>
<td>2.7 b</td>
<td>1.9 ab</td>
<td>0.9 b</td>
</tr>
<tr>
<td>Untreated</td>
<td></td>
<td>5.1 a</td>
<td>5.1 a</td>
<td>3.9 a</td>
<td>2.4 a</td>
</tr>
</tbody>
</table>

P > F

0.01  0.01  0.01  0.01

Means within a column not followed by a common letter differ significantly according to Fisher’s Protected LSD (P = 0.05).

1 ml formulated material/ha.
results were observed at 7 DAT, when all treated plots, except for Spod-X and thiodicarb, had fewer live larvae than the untreated control. At the final observation (10 DAT), all treatments had significantly reduced the number of beet armyworm larvae relative to the untreated control.

In Test 2, no significant differences among treatments were observed at 3 DAT (Table 2.2). At 5 DAT, only the chlorfenapyr and spinosad treatments significantly reduced the number of beet armyworm larvae compared with the untreated control. All treated plots, except for thiodicarb and Spod-X, had significantly fewer larvae than the control plots at 7 DAT. By 10 DAT, all treatments, except for thiodicarb, had significantly fewer larvae relative to the untreated control (Table 2.2).

**Discussion**

Efficacy of chlorpyrifos and thiodicarb insecticides against beet armyworm populations in Northeast Louisiana was highly variable, and control was generally lower in Test 2 than in Test 1. Chlorpyrifos control was generally less than 83% in these studies. Although thiodicarb did suppress beet armyworm populations in Test 1, its control was unsatisfactory (< 70%). Similar inconsistent and unsatisfactory control of beet armyworms with chlorpyrifos and thiodicarb have been reported across the southeastern U.S. (Smith 1985, Burris et al. 1994, Layton 1994, Reed et al. 1994, Elzen 1996, Sparks et al. 1996). Such variability of field control may be associated with several factors, including operational factors (insecticide application rates, timing, and coverage) and/or decreased susceptibility of field populations to insecticides (Cobb and Bass 1975; Meinke and Ware 1978; Brewer and Trumble 1989, 1994; Aldosari et al. 1996; Chandler and Ruberson 1996). Variation in susceptibility of beet armyworm
Table 2.2. Efficacy of selected insecticides against beet armyworm at 3, 5, 7, and 10 days after treatment (DAT) in Test 2 at the Macon Ridge location of the Northeast Research Station, Winnsboro, Louisiana.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate (kg Al/ha)</th>
<th>3 DAT</th>
<th>5 DAT</th>
<th>7 DAT</th>
<th>10 DAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorfenapyr</td>
<td>0.22</td>
<td>2.8 a</td>
<td>0.6 c</td>
<td>1.1 b</td>
<td>0.4 c</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>1.12</td>
<td>4.7 a</td>
<td>3.6 bc</td>
<td>1.2 b</td>
<td>0.3 c</td>
</tr>
<tr>
<td>Spinosad</td>
<td>0.08</td>
<td>5.8 a</td>
<td>0.7 c</td>
<td>1.3 b</td>
<td>0.4 c</td>
</tr>
<tr>
<td>Spod-X</td>
<td>185.5 ^1</td>
<td>10.7 a</td>
<td>7.9 a</td>
<td>3.4 ab</td>
<td>0.7 bc</td>
</tr>
<tr>
<td>Tebufenozide</td>
<td>0.14</td>
<td>14.5 a</td>
<td>1.4 bc</td>
<td>0.4 b</td>
<td>0.7 bc</td>
</tr>
<tr>
<td>Thiodicarb</td>
<td>0.67</td>
<td>12.6 a</td>
<td>4.4 ab</td>
<td>5.2 a</td>
<td>1.4 ab</td>
</tr>
<tr>
<td>Untreated</td>
<td></td>
<td>9.2 a</td>
<td>4.4 ab</td>
<td>5.4 a</td>
<td>1.8 a</td>
</tr>
</tbody>
</table>

P > F

|       | 0.41 | 0.02 | 0.04 | 0.05 |

Means within a column not followed by a common letter differ significantly according to Fisher's Protected LSD (P = 0.05).

^1 ml formulated material/ha.
field strains from Louisiana to chlorpyrifos and thiodicarb have been documented in Chapters 3 and 4 of this dissertation.

In both field tests, chlorfenapyr and spinosad provided excellent and rapid beet armyworm control, and performed as well as or better than the standard, chlorpyrifos. Efficacy of chlorfenapyr and spinosad against beet armyworm also has been documented in numerous EUP trials throughout the southeast (Farlow et al. 1992, Burris et al. 1994, Wiley et al. 1995) where 90-98% control was reported. Tebufenozide, an insect growth regulator, provided satisfactory control of beet armyworm. However, this compound generally had a slower mode of action that required 5 days or more to obtain maximum control. Similar findings were reported by Furr & Harris (1995) where maximum control (83%) was achieved with tebufenozide at 9 DAT. Although this product has a slightly slower mode of action than chlorfenapyr and spinosad, it appears to be well suited for integration into an overall pest management program.

Commercialization of these new compounds for beet armyworm control in cotton may lower the insecticide inputs (kg Al/ha) required to maintain this pest under an economic threshold level.

References Cited


CHAPTER 3

SUSCEPTIBILITY OF FIELD POPULATIONS OF BEET ARMYWORM
(LEPIDOPTERA: NOCTUIDAE) TO COMMERCIAL
AND EXPERIMENTAL INSECTICIDES

Introduction

The beet armyworm, *Spodoptera exigua* (Hübner), is a sporadic pest of cotton throughout most of the cotton belt. However, population outbreaks experienced in Alabama, Georgia, Mississippi, and Texas in the last decade have increased awareness of economic losses associated with population outbreaks of this pest. Nationwide, the beet armyworm was the third most destructive insect pest of cotton during 1995 and was responsible for an estimated 15% of the total yield losses attributed to insects (Williams 1996). Outbreaks in Mississippi during 1993 (Layton 1994) and Texas during 1995 (Arrillago 1995, Summy et al. 1996) have demonstrated that most insecticides registered for control of the beet armyworm have become ineffective against this pest (Layton 1994, Sparks et al. 1996). Variations in susceptibility of beet armyworms to insecticides have been reported for several field-collected strains (Cobb and Bass 1975; Meinke and Ware 1978; Brewer and Trumble 1989, 1994; Aldosari et al. 1996; Chandler and Ruberson 1996) and among four laboratory reference strains (Wolfenbarger and Brewer 1993). Unsatisfactory field efficacy of many insecticides against this pest has been associated with decreased susceptibility of field populations.

The lack of efficacious insecticides for the control of this pest was partially responsible for the destruction of over 75% of the cotton acreage in the Lower Rio Grande Valley and in the Southern Rolling Plain regions of Texas (Huffman 1996,
Summy et al. 1996). Chlorpyrifos and thiodicarb are the only two insecticides currently recommended for beet armyworm control in Louisiana (Bagwell et al. 1997). Reduced field efficacy of these products has been reported in many cotton growing regions of the southeast (Layton 1994, Smith 1994). In 1983 and 1984, large scale Experimental Use Permit trials were conducted across the cotton belt to evaluate thiodicarb field efficacy against the beet armyworm. In these studies, beet armyworm control in treated plots ranged from 87 to 99% compared to untreated plots (Smith 1985). In Louisiana, thiodicarb was the most effective insecticide against beet armyworms in 1984, providing control in excess of 95% (Burris 1983). However, by the mid 1990’s, control with thiodicarb was highly variable and in many cases unsatisfactory (Burris et al. 1994, Graves et al. 1995, Mascarenhas et al. 1996).

Variable beet armyworm control also has been reported for chlorpyrifos in much of the southeast and mid-south. In Mississippi, Elzen (1989) reported 76% control of larvae exposed to chlorpyrifos-treated cotton terminals, while in field tests, control ranged from 58 to 84%. In Louisiana, control achieved with chlorpyrifos ranged from 87 to 90% (Graves et al. 1995, Mascarenhas et al. 1996), although much lower control (38%) had been reported previously (Burris et al. 1994). During 1995, chlorpyrifos did not effectively control (51%) beet armyworm populations in Texas (Sparks et al. 1996).

Several experimental compounds have excellent activity against numerous lepidopteran pests, including the beet armyworm. Chlorfenapyr, the lead chemical in the pyrrole class of insecticides, has consistently provided satisfactory beet armyworm control (Farlow et al. 1992, Burris et al. 1994, Wier et al. 1994, Wiley et al. 1995) and has been available to growers in several states under a section 18 label (Mascarenhas et
al. 1996, Sparks et al. 1996). Spinosad, a nerve poison which has received full registration for the 1997 growing season, has shown excellent activity against beet armyworm (Mascarenhas et al. 1996, Sparks et al. 1996, Hendrix et al. 1997). Tebufenozide, an insect growth regulator that accelerates the molting process in certain insects, also is effective against beet armyworm and has been used successfully for several years under a section 18 label (Walton et al. 1995).

Beet armyworm population outbreaks often have been associated with early season insecticide applications against other pests, such as the boll weevil (Anthonomus grandis grandis Boheman) and tarnished plant bugs (Lygus lineolaris [Palisot de Beauvois]). Organophosphate and pyrethroid insecticides typically used in the control of these pests apparently release beet armyworm populations from their natural enemies (Stewart et al. 1996). Economic infestations of beet armyworm occurred annually in Georgia during the Boll Weevil Eradication Program, and damage resulting from such infestations ranged from $10.9 to 25.9 million (Ruberson et al. 1994). Beet armyworm outbreaks in Texas during 1995 were in part associated with insecticide applications used in area-wide boll weevil eradication programs (Arrillago 1995).

In Louisiana, a Boll Weevil Eradication Program is scheduled to begin in the fall of 1997 in the Red River Valley area. The potential for disruption of natural enemies due to insecticide applications that will be made during the eradication program combined with the reduced efficacy of insecticides currently recommended for beet armyworm control will create conditions that are conducive for population outbreaks in Louisiana and other states with on-going boll weevil eradication programs. Therefore, it is urgent that field populations from these states be monitored for their susceptibility to
insecticides. This study was initiated to determine the susceptibility of field populations of beet armyworms from several states to labeled insecticides and to establish baseline dosage-mortality data for experimental insecticides that may become labeled for the control of this pest in the future.

Materials And Methods

A beet armyworm strain obtained from the USDA-ARS Southern Insect Management Laboratory (SIML) at Stoneville, Mississippi was used as a reference strain in bioassays. Ten field strains of beet armyworm from 5 states (Alabama, California, Louisiana, Mississippi, and Texas), as well as a strain from Rio Bravo, Mexico were used in bioassays (Table 3.1).

Field-collected larvae were transported to the laboratory on artificial diet or on cotton leaves within inflated plastic bags. In the laboratory, 1-2 larvae were transferred into individual 30 ml plastic cups (Schneider Paper Co., New Orleans, LA) containing ca. 5 ml of an artificial wheat-germ and soybean protein diet (King and Hartley 1985) and allowed to pupate. Larvae were reared at 28 ± 3°C, 60 ± 8% RH, and 14:10 h (L:D) photoperiod regime. Pupae were washed in a 10% hypochlorite solution (The Clorox Co., Oakland, CA) for 2 min, rinsed under running water for 3 min, and allowed to surface-dry at room temperature. Approximately 50 pupae were placed in 3.87 l cardboard containers lined with wax paper oviposition sheets and covered with cheese cloth and allowed to eclose. Moths were fed a 10% sucrose solution and held under the same rearing conditions as larvae. Oviposition sheets were replaced daily and larvae were allowed to hatch within inflated plastic bags. Upon hatching, 30-40 neonate larvae
Table 3.1. Beet armyworm field and laboratory reference strains used in bioassays.

<table>
<thead>
<tr>
<th>Strain, Location of Collection</th>
<th>Collection Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIML, USDA-ARS, Stoneville, Mississippi</td>
<td>Reference</td>
</tr>
<tr>
<td>Prattville, Alabama</td>
<td>July 21, 1995</td>
</tr>
<tr>
<td>Farmington, California</td>
<td>August 6, 1995</td>
</tr>
<tr>
<td>Evelyn, Louisiana</td>
<td>July 21, 1995</td>
</tr>
<tr>
<td>Newellton, Louisiana</td>
<td>July 28, 1995</td>
</tr>
<tr>
<td>Red Cross, Louisiana</td>
<td>July 27, 1995</td>
</tr>
<tr>
<td>St. Joseph, Louisiana, Starkville, Mississippi</td>
<td>August 1, 1995</td>
</tr>
<tr>
<td>Yazoo County, Mississippi</td>
<td>August 1, 1995</td>
</tr>
<tr>
<td>Lyford, Texas</td>
<td>July 19, 1995</td>
</tr>
<tr>
<td>Merita, Texas</td>
<td>June 28, 1995</td>
</tr>
<tr>
<td>Rio Bravo, Mexico</td>
<td>July 21, 1995</td>
</tr>
</tbody>
</table>
were transferred into 295 ml paper cups (Schneider Paper Co., New Orleans, LA) containing artificial diet and held until they reached appropriate age (2-d-old) for the bioassays.

A diet overlay bioassay similar to that described by Joyce et al. (1986) was used to evaluate the activity of selected insecticides against 2-d-old beet armyworm larvae. Three ml of liquefied diet were poured into 30 ml plastic cups using an Eppendorf repeater pipette (Brinkmann Instruments Co., Westbury, New York). Serial dilutions of each insecticide were prepared in distilled water based on percent active ingredient (AI) of formulated insecticides. The insecticides evaluated were chlorfenapyr (Pirate® 3F, American Cyanamid Co., Wayne, New Jersey), chlorpyrifos (Lorsban® 4EC, DowElanco, Indianapolis, Indiana), tebufenozide (Confirm® 2F, Rohm & Haas Co., Philadelphia, Pennsylvania), thiodicarb (Larvin® 3.2F, Rhone-Poulenc Ag. Co., Research Triangle Park, North Carolina), and spinosad (Tracer® 4F, DowElanco, Indianapolis, Indiana). One hundred μl of each insecticide concentration were applied onto the surface of the diet in individual cups using a repeater pipette. Cups were rotated to evenly distribute the insecticide solution over the diet. Diet treated with distilled water was used as the control. After the insecticide solutions had dried (ca. 45 min), one larva was placed in each cup and cups were capped. If insufficient larvae (< 30 individuals per concentration) were available at a given time, or if desired confidence limits (CL) were not obtained, multiple bioassays were conducted using larvae from different generations (i.e., F1 and F3). In such cases, data presented are the results of combined bioassays.
Because of the relatively slow mode of action of the insect growth regulator tebufenozide, mortality in all bioassays was scored 120 h after larvae were placed on treated diet. Larvae were considered dead if they did not respond to prodding with a dissecting probe. Data were corrected for mortality observed in the control group (Abbott 1925) and analyzed by probit analysis using POLO-PC (LeOra Software 1987). LC$_{50}$s were calculated and susceptibility of field strains was considered to be significantly different from that of the reference strain if their respective 95% CL did not overlap. When 95% CL were not obtained due to variability of the data (see LeOra Software 1987, page 11), results were discussed based on 90% CL. Toxicity ratios (TR) were calculated according to Robertson and Preisler (1992).

**Results and Discussion**

In chlorpyrifos bioassays, LC$_{50}$s ranged from 11.7 to 51.1 ppm for strains from Farmington, California and Starkville, Mississippi, respectively (Table 3.2). Seven of the 11 strains had significantly higher LC$_{50}$s compared with the SIIML strain based on 95% CL. The Prattville and Red Cross strains from Alabama and Louisiana, respectively, had significantly higher LC$_{50}$s than the reference strain based on 90% CL (2.3-7.8 ppm). TRs ranged from 2.4 to 10.7 for the Farmington, California and Starkville, Mississippi strains, respectively. Chlorpyrifos LC$_{50}$s obtained in this study were lower than the LC$_{50}$s for most colonies tested by Chandler and Ruberson (1996). In their study, LC$_{50}$s ranged from 63 to 973 ppm at 48 h after exposure, which is approximately 5-19 times greater than those observed 120 hours after exposure herein (11.7 to 51.1 ppm). In our study, nearly all field strains were significantly more tolerant

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Table 3.2. Toxicity of chlorpyrifos-treated diet to 2-d-old beet armyworm larvae 120 h after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(± SE)</th>
<th>LC&lt;sub&gt;50&lt;/sub&gt; (95% CL)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>χ&lt;sup&gt;2&lt;/sup&gt;</th>
<th>TR (95% CL)&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIML</td>
<td>Reference</td>
<td>180</td>
<td>1.9 (0.48)</td>
<td>4.8 (1.9-8.6)</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Prattville, Alabama</td>
<td>F1&amp;3</td>
<td>375</td>
<td>3.8 (0.40)</td>
<td>21.2 (12.3-32.1)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>8.8&lt;sup&gt;4&lt;/sup&gt;</td>
<td>4.4 (2.3-8.5)</td>
</tr>
<tr>
<td>Farmington, California</td>
<td>F1</td>
<td>250</td>
<td>4.1 (0.53)</td>
<td>11.7 (5.7-18.5)</td>
<td>3.1</td>
<td>2.4 (1.2-4.8)</td>
</tr>
<tr>
<td>Evelyn, Louisiana</td>
<td>F1</td>
<td>250</td>
<td>4.2 (0.50)</td>
<td>25.4 (17.4-35.7)</td>
<td>2.3</td>
<td>5.3 (2.7-10.3)</td>
</tr>
<tr>
<td>Newellton, Louisiana</td>
<td>F1&amp;2</td>
<td>250</td>
<td>2.6 (0.39)</td>
<td>34.2 (26.6-42.3)</td>
<td>0.2</td>
<td>7.1 (3.6-14.1)</td>
</tr>
<tr>
<td>Red Cross, Louisiana</td>
<td>F1&amp;3</td>
<td>375</td>
<td>2.8 (0.35)</td>
<td>29.1 (15.8-42.2)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>4.3</td>
<td>6.0 (3.1-11.9)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>F1&amp;2</td>
<td>250</td>
<td>3.5 (0.40)</td>
<td>14.5 (7.7-24.0)</td>
<td>3.5</td>
<td>3.0 (1.5-5.9)</td>
</tr>
<tr>
<td>Starkville, Mississippi</td>
<td>F1&amp;5</td>
<td>250</td>
<td>4.6 (0.58)</td>
<td>51.1 (34.1-78.4)</td>
<td>2.7</td>
<td>10.7 (5.5-20.9)</td>
</tr>
<tr>
<td>Yazoo Co, Mississippi</td>
<td>F1</td>
<td>125</td>
<td>3.9 (0.63)</td>
<td>42.5 (35.0-52.2)</td>
<td>1.4</td>
<td>8.8 (4.5-17.3)</td>
</tr>
<tr>
<td>Lyford, Texas</td>
<td>F5</td>
<td>275</td>
<td>3.8 (0.61)</td>
<td>14.4 (11.5-16.9)</td>
<td>0.1</td>
<td>3.0 (1.5-5.9)</td>
</tr>
<tr>
<td>Merita, Texas</td>
<td>F1&amp;2</td>
<td>150</td>
<td>3.1 (0.65)</td>
<td>32.3 (22.2-41.7)</td>
<td>0.9</td>
<td>6.7 (3.3-13.7)</td>
</tr>
<tr>
<td>Rio Bravo, Mexico</td>
<td>F3</td>
<td>250</td>
<td>4.9 (0.62)</td>
<td>20.5 (17.7-23.5)</td>
<td>0.1</td>
<td>4.3 (2.2-8.3)</td>
</tr>
</tbody>
</table>

<sup>1</sup> LC<sub>50</sub> expressed in ppm.

<sup>2</sup> Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).

<sup>3</sup> 90% CL reported.

<sup>4</sup> Significant χ<sup>2</sup> (P = 0.05).
to chlorpyrifos than the reference strain, and the highest LC\textsubscript{50}s were obtained for beet armyworm strains collected from locations in Louisiana (Newellton), Mississippi (Yazoo Co.), and Texas (Merita) where control difficulties with this insecticide have been reported. The low efficacy of chlorpyrifos in these regions combined with elevated toxicity ratios obtained in this study indicate that beet armyworm populations in these areas have developed resistance to this insecticide.

In thiodicarb bioassays, LC\textsubscript{50}s of field strains ranged from 238.4 to 906.6 ppm, and 6 of the 10 strains responded similarly to this insecticide (based on overlap of 95% CL) as the SIML reference strain (Table 3.3). The LC\textsubscript{50} of the Rio Bravo, Mexico strain also was not significantly different from the LC\textsubscript{50} of the SIML reference strain based on 90% CL (249.3-441.8 ppm). The Newellton and Red Cross strains from Louisiana and the Starkville strain from Mississippi had significantly higher LC\textsubscript{50}s compared to the SIML reference strain. TRs of field strains were low, ranging from 0.8 to 2.8. In previous studies, Chandler and Ruberson (1996) reported LC\textsubscript{50}s of 3-d-old larvae to thiodicarb ranging from 330 to 7775 ppm 48 h after exposure to treated diet. Only 1 of the 7 colonies tested by Chandler and Ruberson (1996) had an LC\textsubscript{50} in the range of those reported in this study, while the remaining colonies had LC\textsubscript{50}s that were approximately 7 times greater than the ones reported herein.

The lower chlorpyrifos and thiodicarb LC\textsubscript{50}s reported herein, compared to LC\textsubscript{50}s reported by Chandler and Ruberson (1996), can be attributed to the fact that larvae in this study were exposed to treated diet for a period 2.5 times longer (120 h) than the exposure in Chandler and Ruberson studies (48 h). In addition, Chandler and Ruberson

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Table 3.3. Toxicity of thiodicarb-treated diet to 2-d-old beet armyworm larvae 120 h after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(± SE)</th>
<th>LC50 (95% CL) (^1)</th>
<th>(\chi^2)</th>
<th>TR (95% CL) (^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIML</td>
<td>Reference</td>
<td>250</td>
<td>1.7 (0.34)</td>
<td>319.8 (238.0-479.9)</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Prattville, Alabama</td>
<td>F1&amp;3</td>
<td>275</td>
<td>1.6 (0.34)</td>
<td>251.6 (115.7-373.6)</td>
<td>0.5</td>
<td>0.8 (0.4-1.4)</td>
</tr>
<tr>
<td>Farmington, California</td>
<td>F3</td>
<td>150</td>
<td>4.5 (0.98)</td>
<td>289.8 (223.9-345.0)</td>
<td>0.4</td>
<td>0.9 (0.6-1.3)</td>
</tr>
<tr>
<td>Evelyn, Louisiana</td>
<td>F1&amp;4</td>
<td>525</td>
<td>2.3 (0.22)</td>
<td>239.7 (98.1-398.5)</td>
<td>5.1</td>
<td>0.8 (0.6-1.0)</td>
</tr>
<tr>
<td>Newellton, Louisiana</td>
<td>F1&amp;2</td>
<td>275</td>
<td>2.8 (0.35)</td>
<td>614.4 (510.2-728.4)</td>
<td>0.3</td>
<td>1.9 (1.4-2.7)</td>
</tr>
<tr>
<td>Red Cross, Louisiana</td>
<td>F2&amp;3</td>
<td>275</td>
<td>3.4 (0.44)</td>
<td>849.8 (717.6-993.4)</td>
<td>1.8</td>
<td>2.7 (1.9-3.7)</td>
</tr>
<tr>
<td>St Joseph, Louisiana</td>
<td>F2&amp;3</td>
<td>375</td>
<td>3.3 (0.33)</td>
<td>641.5 (406.4-926.0)</td>
<td>2.8</td>
<td>2.0 (1.4-2.8)</td>
</tr>
<tr>
<td>Starkville, Mississippi</td>
<td>F5</td>
<td>275</td>
<td>2.1 (0.29)</td>
<td>906.6 (513.0-2195.1)</td>
<td>2.6</td>
<td>2.8 (2.1-3.9)</td>
</tr>
<tr>
<td>Lyford, Texas</td>
<td>F5</td>
<td>400</td>
<td>3.6 (0.35)</td>
<td>347.5 (210.0-520.6)</td>
<td>3.8</td>
<td>1.1 (0.8-1.5)</td>
</tr>
<tr>
<td>Merita, Texas</td>
<td>F2</td>
<td>150</td>
<td>2.7 (0.57)</td>
<td>530.0 (331.4-723.4)</td>
<td>0.4</td>
<td>1.7 (1.1-2.6)</td>
</tr>
<tr>
<td>Rio Bravo, Mexico</td>
<td>F6</td>
<td>250</td>
<td>3.0 (0.54)</td>
<td>238.4 (64.8-354.2)</td>
<td>3.1</td>
<td>0.8 (0.5-1.1)</td>
</tr>
</tbody>
</table>

\(^1\) LC50 expressed in ppm.
\(^2\) Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).
\(^3\) 90% CL reported.
tested all of their colonies at the $F_1$ generation, whereas many of the strains in this study were reared for more than one generation before being tested.

Insect populations that express resistance to certain insecticides may revert toward susceptibility when selection pressure is removed (Roush and Daly 1990). The rate (in numbers of generations removed from selection) in which populations revert to susceptibility is dependent on many factors, including the type of insecticide to which it has been selected, the inheritance of the resistant trait(s), and the initial frequency of resistance in that population. Stability of resistance in beet armyworm populations has not been clearly defined. Meinke and Ware (1978) concluded that susceptibility of 3 Arizona strains of beet armyworm to methomyl was not reduced after 15 generations of laboratory rearing in the absence of insecticide selection. Chandler and Ruberson (1996) reported a 50% reduction in LC$_{50}$ values for thiodicarb in larvae reared one generation (from $F_1$ to $F_2$) without selection. In the case of chlorpyrifos, 50% reduction in LC$_{50}$ values generally took 2 to 6 generations without selection, while in some instances, LC$_{50}$ values tended to increase from the $F_1$ to the $F_3$ generation in laboratory culture. The increase in LC$_{50}$ as number of generations removed from selection increased was attributed to natural variation in the insect population (Chandler and Ruberson 1996).

In the present study, 3 strains that had significantly higher thiodicarb LC$_{50}$s than the reference strain were tested from 1 to 3 (Newellton and Red Cross, Louisiana), and as many as 5 (Starkville, Mississippi) generations removed from selection (Table 3.3). Similarly, in chlorpyrifos bioassays, most strains were tested after several generations in
the laboratory and yet the majority of these had significantly higher LC$_{50}$s than the SIML reference strain.

Interpretation of results comparing LC$_{50}$s of field-collected to that of a laboratory reference strain can be confounded by the "susceptibility" of the reference strain. Wolfenbarger and Brewer (1993) reported significant differences in the response of 4 laboratory reference strains to selected insecticides. There was a 670-, 134-, 87- and 14-fold difference in the response between the most (Richmond, California) and least (Phoenix, Arizona) susceptible reference strain to fenvalerate, methyl parathion, permethrin, and methomyl, respectively. In thiodicarb bioassays reported in our study and in Chandler and Ruberson (1996), only a small proportion of the field strains tested had significantly higher LC$_{50}$s compared to the reference strains, even though field collections were made from regions where growers have had difficulties controlling beet armyworms with most available insecticides.

As a general practice, the Southern Insect Management Laboratory at Stoneville, Mississippi introduces wild males from local sources into their colony every 2 years to maintain the genetic vigor of their strains (Dr. D. Hardee, Laboratory Director, Southern Insect Management Laboratory, P. O. Box 346, Stoneville, Mississippi, personal communication). In previous studies, Elzen (1996) reported little temporal change in the toxicity of thiodicarb to field strains of beet armyworm collected from the same location near Stoneville, Mississippi during a 5 year period (1989-1993). Elzen reported poor beet armyworm control with thiodicarb at recommended field rates, ranging from 63.3% in 1989 to 68.9% in 1993. Beet armyworms are highly mobile and polyphagous, and adults freely move between non-sprayed wild hosts and sprayed
cultivated hosts. It is possible that the introduction of wild males from local sources may have imparted some thiodicarb tolerance to the SIML reference strain. Perhaps in the case of thiodicarb, the SIML reference strain should not be considered a "susceptible" strain.

All field strains bioassayed with chlorfenapyr responded similarly to the reference strain, except for the Red Cross strain from Louisiana, which had a significantly higher LC$_{50}$. A narrow range of LC$_{50}$ values (4.0-8.7 ppm) also was obtained among field strains in the chlorfenapyr bioassays (Table 3.4). TRs were low, ranging from 0.8 to 1.8. Chlorfenapyr has not been used extensively in commercial cotton production. Field trials conducted throughout the southeast showed that chlorfenapyr was very effective in controlling native populations of beet armyworms (Farlow et al. 1992). Although this product has been used by growers under a section 18 label, its use has not been such that selection pressure upon population would have likely occurred. Thus, factors leading to significant differences in LC$_{50}$ values between the Red Cross and the SIML reference strain have not been elucidated, and could be partially due to natural variation (Robertson et al. 1995).

LC$_{50}$s of field strains to spinosad ranged from 0.1 to 4.8 ppm (Table 3.5). The Prattville strain from Alabama, the Evelyn strain from Louisiana, and the Rio Bravo strain from Mexico had LC$_{50}$s which were significantly lower than the SIML reference strain. The LC$_{50}$ of the reference strain (2.8 ppm) was in the mid-range of LC$_{50}$s of field strains. TRs ranged from 0.04 to 1.7. In previous studies, an LC$_{50}$ of 0.16 ppm was reported for first instar beet armyworm tested in drench assays (DowElanco 1994), which is within the lower range of LC$_{50}$s reported herein. Although spinosad has been
Table 3.4. Toxicity of chlorfenapyr-treated diet to 2-d-old beet armyworm larvae 120 h after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope (± SE)</th>
<th>LC\textsubscript{50} (95% CL)\textsuperscript{1}</th>
<th>χ\textsuperscript{2}</th>
<th>TR (95% CL)\textsuperscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIML Reference</td>
<td>400</td>
<td>3.9 (0.50)</td>
<td>5.0 (2.8-6.7)</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prattville, Alabama F1&amp;4</td>
<td>250</td>
<td>6.0 (0.79)</td>
<td>8.1 (5.7-11.3)</td>
<td>2.6</td>
<td>1.6 (1.4-2.0)</td>
<td></td>
</tr>
<tr>
<td>Evelyn, Louisiana F1&amp;2</td>
<td>275</td>
<td>3.5 (0.39)</td>
<td>6.1 (3.7-9.5)</td>
<td>3.2</td>
<td>1.2 (1.0-1.5)</td>
<td></td>
</tr>
<tr>
<td>Newellton, Louisiana F3</td>
<td>250</td>
<td>4.0 (0.68)</td>
<td>4.0 (3.2-4.7)</td>
<td>0.5</td>
<td>0.8 (0.7-1.0)</td>
<td></td>
</tr>
<tr>
<td>Red Cross, Louisiana F2&amp;3</td>
<td>425</td>
<td>2.7 (0.37)</td>
<td>8.7 (7.1-10.4)</td>
<td>1.2</td>
<td>1.8 (1.4-2.2)</td>
<td></td>
</tr>
<tr>
<td>St. Joseph, Louisiana F1&amp;2</td>
<td>250</td>
<td>3.0 (0.40)</td>
<td>6.1 (2.6-9.6)</td>
<td>2.8</td>
<td>1.2 (1.0-1.6)</td>
<td></td>
</tr>
<tr>
<td>Starkville, Mississippi F5</td>
<td>275</td>
<td>3.2 (0.37)</td>
<td>7.5 (6.4-8.7)</td>
<td>0.3</td>
<td>1.5 (1.2-1.9)</td>
<td></td>
</tr>
<tr>
<td>Lyford, Texas F3&amp;4</td>
<td>275</td>
<td>2.3 (0.30)</td>
<td>7.6 (3.3-12.7)\textsuperscript{3}</td>
<td>5.7</td>
<td>1.5 (1.2-2.0)</td>
<td></td>
</tr>
<tr>
<td>Merita, Texas F1&amp;2</td>
<td>150</td>
<td>6.1 (1.24)</td>
<td>6.6 (5.4-7.6)</td>
<td>0.1</td>
<td>1.3 (1.1-1.6)</td>
<td></td>
</tr>
<tr>
<td>Rio Bravo, Mexico F6</td>
<td>250</td>
<td>2.0 (0.38)</td>
<td>4.0 (2.4-5.4)</td>
<td>0.7</td>
<td>0.8 (0.6-1.2)</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{1} LC\textsubscript{50} expressed in ppm.

\textsuperscript{2} Toxicity ratio (TR) calculated according to Roertson and Preisler (1992).

\textsuperscript{3} 90\% CL reported.
<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(± SE)</th>
<th>LC&lt;sub&gt;50&lt;/sub&gt; (95% CL)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>χ²</th>
<th>TR (95% CL)&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIML</td>
<td>Reference</td>
<td>250</td>
<td>1.8 (0.39)</td>
<td>2.8 (1.3-4.5)</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Prattville, Alabama</td>
<td>F1&amp;2</td>
<td>275</td>
<td>1.1 (0.14)</td>
<td>0.1 (0.1-0.4)</td>
<td>2.5</td>
<td>0.004 (0.01-0.2)</td>
</tr>
<tr>
<td>Farmington, California</td>
<td>F3</td>
<td>250</td>
<td>0.7 (0.09)</td>
<td>0.6 (0.1-2.6)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>3.6</td>
<td>0.2 (0.1-0.5)</td>
</tr>
<tr>
<td>Evelyn, Louisiana</td>
<td>F1&amp;4</td>
<td>250</td>
<td>1.3 (0.21)</td>
<td>0.5 (0.3-0.9)</td>
<td>1.9</td>
<td>0.2 (0.1-0.4)</td>
</tr>
<tr>
<td>Newellton, Louisiana</td>
<td>F2&amp;3</td>
<td>275</td>
<td>1.3 (0.22)</td>
<td>4.8 (2.7-7.9)</td>
<td>1.0</td>
<td>1.7 (0.8-3.6)</td>
</tr>
<tr>
<td>Red Cross, Louisiana</td>
<td>F2&amp;3</td>
<td>275</td>
<td>1.0 (0.11)</td>
<td>0.9 (0.1-7.2)</td>
<td>3.9</td>
<td>0.3 (0.2-0.7)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>F2&amp;4</td>
<td>250</td>
<td>1.8 (0.23)</td>
<td>2.1 (1.5-3.1)</td>
<td>0.7</td>
<td>0.8 (0.4-1.5)</td>
</tr>
<tr>
<td>Starkville, Mississippi</td>
<td>F5</td>
<td>250</td>
<td>2.3 (0.45)</td>
<td>3.3 (2.3-4.6)</td>
<td>1.0</td>
<td>1.2 (0.6-2.2)</td>
</tr>
<tr>
<td>Lyford, Texas</td>
<td>F4&amp;5</td>
<td>275</td>
<td>1.2 (0.14)</td>
<td>3.3 (1.0-17.1)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>6.3&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.2 (0.6-2.4)</td>
</tr>
<tr>
<td>Merita, Texas</td>
<td>F2</td>
<td>150</td>
<td>1.6 (0.26)</td>
<td>4.3 (2.6-7.2)</td>
<td>0.6</td>
<td>1.5 (0.7-3.2)</td>
</tr>
<tr>
<td>Rio Bravo, Mexico</td>
<td>F6</td>
<td>250</td>
<td>1.3 (0.19)</td>
<td>0.6 (0.3-1.0)</td>
<td>0.5</td>
<td>0.2 (0.1-0.5)</td>
</tr>
</tbody>
</table>

<sup>1</sup> LC<sub>50</sub> expressed in ppm.

<sup>2</sup> Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).

<sup>3</sup> 90% CL reported.

<sup>4</sup> Significant χ² (P = 0.05)
labeled for commercial use in cotton during 1997, its use to date has been limited to experimental plots. Thus the significant variations in LC$_{50}$s among field strains probably reflect natural variation (Robertson et al. 1995).

Susceptibility to tebufenozide was similar among all field strains, and LC$_{50}$ values ranged from 2.7 to 7.2 ppm (Table 3.6). The strain from Starkville, Mississippi was the only strain which had a significantly higher LC$_{50}$ than the SIML reference strain. TRs ranged from 1.0 to 2.8. Chandler (1994) evaluated the toxicity of tebufenozide (RH-5992) to 1-d-old larvae from a laboratory strain (Insect Biology and Population Management Research Laboratory, Tifton, Georgia) of beet armyworm and reported an LC$_{50}$ of 2.5 ppm (0.00025%). The LC$_{50}$ of the SIML reference strain (2.6 ppm) for tebufenozide was similar to that reported by Chandler (1994). Like chlorfenapyr, tebufenozide use by growers has been limited to relatively small acreage under a section 18 label. Thus, the significant difference detected between the Starkville field strain and the SIML reference strain does not necessarily indicate resistance within this field population.

For most field strains, the order of toxicity of the insecticides tested from least toxic to most toxic was thiodicarb < chlorpyrifos < chlorfenapyr < tebufenozide < spinosad. The toxicity of tebufenozide compared with the other compounds varied according to the endpoint of the assay. The slower mode of action of this insecticide required that the endpoint of the bioassay be extended from the typical 72 h after exposure to 120 h. The range of concentrations used in tebufenozide bioassays was such that 50% mortality was never achieved at 72 h after exposure, although dosage-mortality lines at 120 h were well fitted (low chi-squares) to the probit model.
Table 3.6. Toxicity of tebufenozide-treated diet to 2-d-old beet armyworm larvae 120 h after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(± SE)</th>
<th>LC$_{50}$ (95% CL)$^1$</th>
<th>$\chi^2$</th>
<th>TR (95% CL)$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIML</td>
<td>Reference</td>
<td>250</td>
<td>2.3 (0.40)</td>
<td>2.6 (1.5-4.0)</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Prattville, Alabama</td>
<td>F1&amp;3</td>
<td>375</td>
<td>2.6 (0.37)</td>
<td>5.6 (1.6-9.2)</td>
<td>2.5</td>
<td>2.2 (1.3-3.6)</td>
</tr>
<tr>
<td>Farmington, California</td>
<td>F1</td>
<td>125</td>
<td>3.0 (0.71)</td>
<td>2.7 (1.6-3.5)</td>
<td>0.3</td>
<td>1.0 (0.6-1.8)</td>
</tr>
<tr>
<td>Evelyn, Louisiana</td>
<td>F1&amp;3</td>
<td>250</td>
<td>1.7 (0.33)</td>
<td>3.7 (2.0-5.2)</td>
<td>1.3</td>
<td>1.4 (0.8-2.6)</td>
</tr>
<tr>
<td>Newellton, Louisiana</td>
<td>F2&amp;3</td>
<td>250</td>
<td>1.8 (0.32)</td>
<td>3.5 (1.2-5.4)$^3$</td>
<td>2.9</td>
<td>1.4 (0.8-2.3)</td>
</tr>
<tr>
<td>Red Cross, Louisiana</td>
<td>F1&amp;3</td>
<td>250</td>
<td>3.1 (0.43)</td>
<td>4.9 (4.0-5.9)</td>
<td>1.7</td>
<td>1.9 (1.2-3.1)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>F1&amp;3</td>
<td>400</td>
<td>2.7 (0.29)</td>
<td>4.4 (2.6-6.2)</td>
<td>2.4</td>
<td>1.7 (1.1-2.7)</td>
</tr>
<tr>
<td>Starkville, Mississippi</td>
<td>F1&amp;5</td>
<td>250</td>
<td>3.2 (0.40)</td>
<td>7.2 (6.0-8.5)</td>
<td>1.3</td>
<td>2.8 (1.7-4.5)</td>
</tr>
<tr>
<td>Lyford, Texas</td>
<td>F5</td>
<td>250</td>
<td>2.5 (0.34)</td>
<td>5.2 (2.2-8.9)</td>
<td>2.9</td>
<td>2.0 (1.2-3.3)</td>
</tr>
<tr>
<td>Merita, Texas</td>
<td>F1&amp;2</td>
<td>150</td>
<td>2.0 (0.35)</td>
<td>4.6 (2.9-7.3)</td>
<td>0.2</td>
<td>1.8 (0.9-3.4)</td>
</tr>
<tr>
<td>Rio Bravo, Mexico</td>
<td>F6</td>
<td>275</td>
<td>2.5 (0.49)</td>
<td>3.0 (2.0-3.9)</td>
<td>1.6</td>
<td>1.2 (0.7-2.0)</td>
</tr>
</tbody>
</table>

$^1$ LC$_{50}$ expressed in ppm.

$^2$ Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).

$^3$ 90% CL reported.
Results obtained in this study corroborate reports by Cobb and Bass (1975) and Wolfenbarger and Brewer (1993) that beet armyworms from California are more susceptible to insecticides than eastern strains. In thiodicarb bioassays, the Farmington, California strain had the third lowest LC$_{50}$, which was significantly lower than the Newellton, Red Cross, and St. Joseph strains from Louisiana as well as the Starkville strain from Mississippi (Table 3.3). Similar findings were observed in chlorpyrifos, spinosad, and tebufenozide bioassays, where the LC$_{50}$ of the California strain was numerically lowest compared to that of the other field strains (Tables 3.2, 3.5, and 3.6).

Considerable variability was measured in the responses of field strains to the insecticides chlorpyrifos and thiodicarb, which are currently recommended for beet armyworm control in Louisiana. Three of the 4 strains from Louisiana (Evelyn, Newellton, and Red Cross) were significantly less susceptible to chlorpyrifos than the reference strain, and the latter 2 strains also were significantly less susceptible to thiodicarb. The susceptibility of the Louisiana field strains observed in these bioassays and the reduced efficacy of these compounds in Louisiana field tests (Burris 1983, Burris et al. 1994, Graves et al. 1995, Mascarenhas et al. 1996) indicate that these insecticides may not be effective in controlling future population outbreaks of this pest. In areas of Louisiana where the Boll Weevil Eradication Program is scheduled to begin in the fall of 1997, beet armyworm infestations may increase in frequency, and new control tactics will be required to prevent economic losses associated with beet armyworm outbreaks. The experimental insecticides evaluated in this study show good activity against the beet armyworm, although considerable natural variation among field strains were observed. In field studies conducted throughout the cotton belt, these new
chemistries have performed well against native beet armyworm infestations (Farlow et al. 1992, Graves et al. 1995, Walton et al. 1995, Wiley et al. 1995, Mascarenhas et al. 1996, Sparks et al. 1996, Hendrix et al. 1997). The data presented herein will serve as a historical record that may be utilized to monitor the efficacy of these new insecticides against populations of beet armyworm in Louisiana and other states.

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CHAPTER 4

RESPONSES OF THIRD-INSTAR BEET ARMYWORMS (LEPIDOPTERA: NOCTUIDAE) TO SELECTED INSECTICIDES

Introduction

The beet armyworm, *Spodoptera exigua* (Hübner), has emerged as an important economic pest throughout most of the cotton producing regions of the U.S. During the past decade, population outbreaks have occurred in Alabama, Georgia, Mississippi, and Texas. During 1993, 60% of the cotton acreage in the mid-south and southeastern states was infested with beet armyworms, and on 35% of this acreage, infestations were above the economic injury level (Smith 1994). Nationwide, the beet armyworm was the third most destructive cotton insect pest in 1995 and was responsible for an estimated 15% of the total damage attributed to insects (Williams 1996). In Louisiana, beet armyworm infestations historically have been sporadic and generally less severe than in other states (Burris et al. 1994); however, in 1995 state-wide outbreaks were reported. Population outbreaks of this pest in 1995 were a significant factor contributing to the complete destruction of 75% of the cotton crop in some regions of Texas (Sparks et al. 1996). The estimated acreage infested by beet armyworm in the U.S. has steadily increased since the beginning of this decade (Head 1991; Williams 1994, 1996). In 1990, an estimated 1.6 million acres were infested with beet armyworms, which increased to 3.5 million acres in 1993 and 6.8 million acres by the 1995 growing season.

A growing concern involving the pest status of beet armyworms includes not only its rapid expansion throughout the cotton acreage in the U.S., but also its inherent tolerance to many insecticides (Layton 1994). Reduced insecticide efficacy has been reported in
many cotton growing regions of the southeast (Layton 1994, Smith 1994). Chlorpyrifos and thiodicarb are the only insecticides presently recommended for beet armyworm in Louisiana (Bagwell et al. 1997). Thiodicarb was the most effective insecticide against beet armyworm in 1984, providing control in excess of 95% (Burris 1983). However, by the mid 1990’s, control was highly variable and in many cases unsatisfactory (Burris et al. 1994, Graves et al. 1995, Mascarenhas et al. 1996). Variable beet armyworm control also has been reported for chlorpyrifos in much of the southeast and mid-south (Elzen 1989, Sparks et al. 1996). In Louisiana, control with chlorpyrifos ranged from 87 (Graves et al. 1995) to 90% (Mascarenhas et al. 1996), although much lower control (38%) has been previously reported (Burris et al. 1994).

Decreased susceptibility of beet armyworm field populations to insecticides has been associated with reduced field control. Variations in susceptibility of beet armyworm to several insecticides have been reported for field-collected strains (Cobb & Bass 1975, Brewer & Trumble 1989, Aldosari et al. 1996, Chandler & Ruberson 1996) and among four laboratory reference strains (Wolfenbarger & Brewer 1993).

Several experimental compounds have exhibited excellent control of numerous lepidopteran pests, including the beet armyworm. Chlorfenapyr, the lead chemical in a new class of insecticides called the pyrroles, has shown satisfactory activity against beet armyworm (Farlow et al. 1992, Burris et al. 1994, Wier et al. 1994a, Wiley et al. 1995) and has been available to growers in several states under a section 18 label (Mascarenhas et al. 1996, Sparks et al. 1996). Emamectin benzoate, a nerve poison in the avermectin class of insecticides, is very active against beet armyworms at reduced rates (0.009 kg/ha) (Wier et al. 1994b, Sparks et al. 1996). Methoxyfenozide (proposed
common name, RH-2485), an insect growth regulator (IGR) affecting the molting process of target insect species, also has been effective against beet armyworms and may become labeled for its control in the future. Spinosad, a nerve poison in the naturalyte class of insecticides, is very toxic to beet armyworms (Mascarenhas et al. 1996, Sparks et al. 1996, Hendrix et al. 1997) and received a section 3 registration in 1997. Tebufenozide, another IGR that accelerates the molting process in certain insect species, also is effective against beet armyworms and has been successfully used in recent years under a section 18 label (Walton et al. 1995).

This study was initiated to determine the susceptibility of field populations of beet armyworm to registered insecticides as well as experimental insecticides that may become labeled for the control of this pest in the future. This information will serve as a historical record that can be used to monitor insecticide susceptibility of beet armyworm populations.

Materials and Methods

Field-collected beet armyworm larvae were transported to the laboratory and placed on an artificial wheat-germ and soybean protein diet (King and Hartley 1985). Larvae were reared at 28 ± 3°C, 60 ± 8% RH, and 14:10 h (L:D) photoperiod regime until pupation. Pupae were washed in 10% sodium hypochlorite solution (The Clorox Co., Oakland, CA) for 2 min, rinsed under running water for 3 min, and allowed to surface-dry at room temperature. Pupae were placed in 3.87 l cardboard containers lined with wax paper oviposition sheets and allowed to eclose. Moths were fed a 10% sucrose solution and held under the same rearing conditions as the larvae. Oviposition sheets were replaced daily, and eggs were held and allowed to hatch within inflated plastic
bags. Upon hatching, 30-40 neonate larvae were transferred into 295 ml paper cups containing artificial diet and held until they reached the appropriate size for bioassay (30-45 mg).

A beet armyworm strain obtained from Ecogen Inc. (Langhorne, Pennsylvania) was used as a reference strain in bioassays. The ECOGEN strain originated from a laboratory colony at the USDA-ARS Southern Insect Management Laboratory at Stoneville, Mississippi, and has been in laboratory culture for at least 10 years. Native, field-collected males have been added to the colony every 2-3 years to maintain genetic vigor. The last influx of wild genes into this strain occurred in 1993 (Ken Johnson, Ecogen Inc, Langhorne, Pennsylvania, personal communication). Nine field strains of beet armyworms collected from cotton in 3 states (Georgia, Louisiana, and Mississippi) were used in bioassays. Field strains and their collection sites are presented in Table 4.1.

A diet overlay bioassay, similar to that described by Joyce et al. (1986), was used to evaluate the activity of selected insecticides against third-instar beet armyworms. Three ml of hot diet were dispensed into 30 ml plastic cups using an Eppendorf repeater pipette (Brinkmann Instruments Co., Westbury, New York) and allowed to cool at room temperature. Serial dilutions of each insecticide were prepared in distilled water based on percent active ingredient (AI) of formulated insecticides. Formulated insecticides evaluated in bioassays are presented in Table 4.2. Each insecticide concentration was applied (in 100 µl aliquots) onto the diet surface of individual cups and cups were rotated by hand to evenly distribute the insecticide solution over the diet. Diet treated
### Table 4.1. Field and laboratory reference strains of beet armyworms used in bioassays.

<table>
<thead>
<tr>
<th>Strain, Location of Collection</th>
<th>Collection Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOGEN, Ecogen Inc., Langhorne, Pennsylvania</td>
<td>Reference</td>
</tr>
<tr>
<td>Tift County, Georgia</td>
<td>June 20, 1996</td>
</tr>
<tr>
<td>Bayou Macon, Louisiana</td>
<td>September 15, 1996</td>
</tr>
<tr>
<td>Macon Ridge, Louisiana</td>
<td>August 27, 1996</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>July 7, 1996</td>
</tr>
<tr>
<td>Tallulah, Louisiana</td>
<td>September 9, 1996</td>
</tr>
<tr>
<td>Tensas Parish, Louisiana</td>
<td>August 25, 1996</td>
</tr>
<tr>
<td>Winnsboro, Louisiana</td>
<td>September 9, 1996</td>
</tr>
<tr>
<td>Benton County, Mississippi</td>
<td>September 18, 1996</td>
</tr>
<tr>
<td>Starkville, Mississippi</td>
<td>August 1, 1996</td>
</tr>
</tbody>
</table>

### Table 4.2. Formulated insecticides used in bioassays.

<table>
<thead>
<tr>
<th>Common Name (Trade name)</th>
<th>% Al (w/w)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Registered Insecticides</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorpyrifos (Lorsban® 4EC)</td>
<td>40.7</td>
<td>DowElanco, Indianapolis, IN</td>
</tr>
<tr>
<td>Spinosad (Tracer® 4F)</td>
<td>44.2</td>
<td>DowElanco, Indianapolis, IN</td>
</tr>
<tr>
<td>Thiodicarb (Larvin® 3.2F)</td>
<td>32.5</td>
<td>Rhone-Poulenc Ag. Co., Research Triangle Park, NC</td>
</tr>
<tr>
<td><strong>Experimental Insecticides</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorfenapyr (Pirate® 3F)</td>
<td>36.1</td>
<td>American Cyanamid, Princeton, NJ</td>
</tr>
<tr>
<td>Emamectin benzoate (Proclaim® 5SG)</td>
<td>5.0</td>
<td>Merck Research Lab., Rahway, NJ</td>
</tr>
<tr>
<td>Methoxyfenozide, (Intrepid® 80WP)</td>
<td>80.0</td>
<td>Rohm &amp; Haas Co., Philadelphia, PA</td>
</tr>
<tr>
<td>Tebufenozide (Confirm® 2F)</td>
<td>22.7</td>
<td>Rohm &amp; Haas Co., Philadelphia, PA</td>
</tr>
</tbody>
</table>

1. EC = emulsifiable concentrate.
2. F = aqueous flowable.
3. SG = soluble granular.
4. WP = wettable powder.
5. Proposed common name.
with distilled water was used as the control. After the insecticide solutions had dried (approximately 45 min), one larva was placed in each cup and cups were capped. All bioassays were conducted under constant light, 23 ± 3°C, and 57 ± 8% RH. If insufficient numbers of larvae (<30 individuals per concentration) were available at a given time, or if desired CL were not obtained, multiple bioassays were conducted using larvae from different generations (i.e., F₁ and F₂). In such cases, data presented are the result of combined bioassays.

Because of the relatively slow mode of action of the IGRs, mortality in all bioassays was scored 120 h after larvae were placed on treated diet. Larvae were considered dead if they did not respond to prodding with a dissecting probe. Data were corrected for mortality observed in the control group (Abbott 1925) and analyzed by probit analysis using POLO-PC (LeOra Software 1987). LC₅₀s of field strains were considered to be significantly different from that of the reference strain if their respective 95% confidence limits (CL) did not overlap. Toxicity ratios (TRs) were calculated according to Robertson and Preisler (1992).

**Results**

The LC₅₀s of field strains ranged from 73.2 to 295.2 ppm for chlorpyrifos, a 4.0-fold difference (Table 4.3). All field strains had significantly higher LC₅₀s than the ECOGEN reference strain (28.0 ppm). TRs ranged from 2.6 to 10.5 for the Winnsboro and Benton County strains, respectively.

In thiodicarb bioassays, LC₅₀s ranged from 956.2 to 7181.3 ppm, a 7.5-fold difference (Table 4.4). All field strains for which 95% CL were obtained had

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Table 4.3. Toxicity of chlorpyrifos-treated diet to third-instar beet armyworms 120 hours after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(SE)</th>
<th>LC$_{50}$ (95% CL)$^1$</th>
<th>$\chi^2$</th>
<th>TR (95% CL)$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOGEN</td>
<td>Reference</td>
<td>260</td>
<td>3.5 (0.40)</td>
<td>28.0 (15.0-46.2)</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Tift County, Georgia</td>
<td>F5</td>
<td>190</td>
<td>3.3 (0.50)</td>
<td>168.1 (132.7-203.2)</td>
<td>0.9</td>
<td>6.0 (4.6-7.8)</td>
</tr>
<tr>
<td>Bayou Macon, Louisiana</td>
<td>F2</td>
<td>150</td>
<td>3.3 (0.50)</td>
<td>240.2 (195.5-292.0)</td>
<td>1.3</td>
<td>8.6 (6.7-11.0)</td>
</tr>
<tr>
<td>Macon Ridge, Louisiana</td>
<td>F1</td>
<td>250</td>
<td>4.5 (0.51)</td>
<td>268.0 (163.7-456.9)</td>
<td>3.8</td>
<td>9.6 (7.8-11.7)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>F3</td>
<td>285</td>
<td>3.0 (0.52)</td>
<td>275.3 (199.7-347.5)</td>
<td>0.6</td>
<td>9.8 (7.3-13.2)</td>
</tr>
<tr>
<td>Tallulah, Louisiana</td>
<td>F1</td>
<td>315</td>
<td>2.3 (0.29)</td>
<td>179.6 (78.7-285.0)</td>
<td>2.8</td>
<td>6.4 (5.0-8.3)</td>
</tr>
<tr>
<td>Tensas Parish, Louisiana</td>
<td>F1&amp;2</td>
<td>300</td>
<td>2.0 (0.27)</td>
<td>156.9 (100.8-224.6)</td>
<td>3.5</td>
<td>5.6 (4.5-7.0)</td>
</tr>
<tr>
<td>Winnsboro, Louisiana</td>
<td>F2</td>
<td>270</td>
<td>2.5 (0.40)</td>
<td>73.2 (52.3-91.4)</td>
<td>0.2</td>
<td>2.6 (0.4-18.4)</td>
</tr>
<tr>
<td>Benton County, Mississippi</td>
<td>F1</td>
<td>190</td>
<td>2.2 (0.35)</td>
<td>295.2 (234.0-374.4)</td>
<td>0.1</td>
<td>10.5 (8.2-13.6)</td>
</tr>
<tr>
<td>Starkville, Mississippi</td>
<td>F2</td>
<td>150</td>
<td>2.7 (0.45)</td>
<td>207.3 (160.2-258.9)</td>
<td>0.7</td>
<td>7.4 (5.6-9.8)</td>
</tr>
</tbody>
</table>

$^1$ LC$_{50}$ expressed in ppm.

$^2$ Toxicity ratio calculated according to Robertson and Preisler (1992).
<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(SE)</th>
<th>LC₅₀ (95% CL)¹</th>
<th>χ²</th>
<th>TR (95% CL)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOGEN</td>
<td>Reference</td>
<td>240</td>
<td>3.0 (0.48)</td>
<td>356.9 (265.3-441.5)</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Tift County, Georgia F5</td>
<td>190</td>
<td>2.9 (0.41)</td>
<td>4392.5 (2641.9-10393.1)</td>
<td>2.5</td>
<td>11.5 (8.5-15.5)</td>
<td></td>
</tr>
<tr>
<td>Bayou Macon, Louisiana F2</td>
<td>190</td>
<td>3.1 (0.42)</td>
<td>2314.3 (1921.4-2756.8)</td>
<td>0.1</td>
<td>6.1 (4.6-8.0)</td>
<td></td>
</tr>
<tr>
<td>Macon Ridge, Louisiana F1</td>
<td>225</td>
<td>2.5 (0.34)</td>
<td>956.2 (767.8-1150.9)</td>
<td>1.1</td>
<td>2.5 (1.9-3.3)</td>
<td></td>
</tr>
<tr>
<td>St. Joseph, Louisiana F3</td>
<td>360</td>
<td>3.9 (0.87)</td>
<td>4039.5 (-----)⁴</td>
<td>6.5</td>
<td>10.6 (7.8-14.4)</td>
<td></td>
</tr>
<tr>
<td>Tallulah, Louisiana F1</td>
<td>190</td>
<td>2.8 (0.40)</td>
<td>2279.5 (1153.4-3921.7)</td>
<td>2.4</td>
<td>5.9 (4.5-7.8)</td>
<td></td>
</tr>
<tr>
<td>Tensas Parish, Louisiana F1&amp;2</td>
<td>180</td>
<td>2.5 (0.59)</td>
<td>3307.6 (-----)⁴</td>
<td>6.2³</td>
<td>8.6 (6.2-12.0)</td>
<td></td>
</tr>
<tr>
<td>Winnsboro, Louisiana F1</td>
<td>230</td>
<td>2.3 (0.38)</td>
<td>1868.9 (826.8-3818.0)³</td>
<td>4.0</td>
<td>4.9 (3.7-6.5)</td>
<td></td>
</tr>
<tr>
<td>Benton County, Mississippi F1</td>
<td>190</td>
<td>4.5 (1.29)</td>
<td>7181.3 (5978.5-9367.5)</td>
<td>0.2</td>
<td>18.8 (14.4-24.4)</td>
<td></td>
</tr>
</tbody>
</table>

¹ LC₅₀ expressed in ppm.
² Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).
³ 90% CL reported.
⁴ Unable to calculate CL. Index of significance of potency estimator (g) > 0.5.
⁵ Significant χ² (P = 0.05).
significantly higher LC50S than the ECOGEN strain. Ninety-five percent CL were not obtained for the Winnsboro strain; however, its LC50 was significantly higher than the ECOGEN strain based on the 90% CL (281.3-427.6 ppm) of the reference strain.

Although CL could not be calculated for the St. Joseph and Tensas Parish strains, their LC50s fell within the range of the other field strains and were 11.3 and 9.3 times higher than the LC50 of the ECOGEN strain. TRs of field strains ranged from 2.5 to 18.8.

A narrow range in LC50s values (20.2 to 27.6 ppm) was observed among field strains in chlorfenapyr bioassays (Table 4.5). Strains from Bayou Macon, St. Joseph, Tallulah, Tensas Parish, and Tift County had significantly higher LC50s compared with the reference strain, although TRs were low (1.3 to 1.8).

Emamectin benzoate was the most active insecticide evaluated in this study with LC50s ranging from 0.2 to 0.6 ppm (Table 4.6). All field strains for which 95% CL were obtained had significantly lower LC50s than the ECOGEN strain. The Winnsboro strain had a significantly lower LC50 than the ECOGEN strain based on the 90% CL (1.7-3.4 ppm) of the reference strain. Although CL could not be calculated for the Tift county strain, its LC50 fell within the range of the other field strains. TRs ranged from 0.01 to 0.2.

Methoxyfenozide LC50s for field strains ranged from 5.7 to 80.0 ppm, a 14.0-fold difference (Table 4.7). The St. Joseph strain was the only field strain with a significantly higher LC50 than the ECOGEN strain. TRs were highly variable. Three field strains (St. Joseph, Tift County, and Winnsboro) had TRs ranging from 7.1 to 9.3, while the remaining 4 strains (Bayou Macon, Benton County, Macon Ridge, and Tallulah) had TRs ranging from 0.7 to 2.9.
Table 4.5. Toxicity of chlorfenapyr-treated diet to third instar beet armyworms 120 hours after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(SE)</th>
<th>LC$_{50}$ (95% CL)$^1$</th>
<th>$\chi^2$</th>
<th>TR (95% CL)$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOGEN Reference</td>
<td>Reference</td>
<td>240</td>
<td>7.0 (1.15)</td>
<td>15.1 (13.2-17.0)</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Tift County, Georgia F5</td>
<td></td>
<td>190</td>
<td>4.4 (0.79)</td>
<td>27.6 (21.7-32.7)</td>
<td>0.6</td>
<td>1.8 (1.5-2.3)</td>
</tr>
<tr>
<td>Bayou Macon, Louisiana F2</td>
<td></td>
<td>190</td>
<td>5.9 (0.85)</td>
<td>24.8 (21.8-28.0)</td>
<td>0.7</td>
<td>1.6 (1.4-2.0)</td>
</tr>
<tr>
<td>Macon Ridge, Louisiana F1</td>
<td></td>
<td>250</td>
<td>3.5 (0.50)</td>
<td>20.6 (16.6-24.4)</td>
<td>0.6</td>
<td>1.3 (1.0-1.7)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana F3</td>
<td></td>
<td>190</td>
<td>4.3 (0.69)</td>
<td>21.9 (17.9-25.9)</td>
<td>0.5</td>
<td>1.5 (1.2-1.8)</td>
</tr>
<tr>
<td>Tallulah, Louisiana F1</td>
<td></td>
<td>190</td>
<td>3.8 (0.71)</td>
<td>24.3 (17.7-30.2)</td>
<td>0.6</td>
<td>1.6 (1.2-2.1)</td>
</tr>
<tr>
<td>Tensas Parish, Louisiana F1&amp;2</td>
<td></td>
<td>275</td>
<td>4.2 (0.65)</td>
<td>21.5 (17.2-25.3)</td>
<td>0.3</td>
<td>1.4 (1.1-1.8)</td>
</tr>
<tr>
<td>Winnsboro, Louisiana F1&amp;2</td>
<td></td>
<td>425</td>
<td>4.2 (0.41)</td>
<td>20.2 (12.0-29.1)$^3$</td>
<td>9.6$^4$</td>
<td>1.3 (1.1-1.8)</td>
</tr>
<tr>
<td>Benton County, Mississippi F1</td>
<td></td>
<td>190</td>
<td>3.3 (0.46)</td>
<td>23.3 (14.1-34.5)$^3$</td>
<td>4.0</td>
<td>1.5 (1.2-1.9)</td>
</tr>
</tbody>
</table>

$^1$ LC$_{50}$ expressed in ppm.

$^2$ Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).

$^3$ 90% CL reported.

$^4$ Significant $\chi^2$ ($P = 0.05$).
Table 4.6. Toxicity of emamectin benzoate-treated diet to third-instar beet armyworms 120 hours after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(SE)</th>
<th>LC&lt;sub&gt;50&lt;/sub&gt; (95% CL)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>χ²</th>
<th>TR (95% CL)&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOGEN</td>
<td>Reference</td>
<td>230</td>
<td>1.4 (0.19)</td>
<td>2.4 (1.6-3.7)</td>
<td>0.2</td>
<td>0.2 (0.1-0.4)</td>
</tr>
<tr>
<td>Tift County, Georgia</td>
<td>F5</td>
<td>190</td>
<td>1.2 (0.15)</td>
<td>0.4 (--------)&lt;sup&gt;4&lt;/sup&gt;</td>
<td>7.5&lt;sup&gt;5&lt;/sup&gt;</td>
<td>0.2 (0.1-0.4)</td>
</tr>
<tr>
<td>Bayou Macon, Louisiana</td>
<td>F2</td>
<td>210</td>
<td>2.1 (0.50)</td>
<td>0.5 (0.2-0.7)</td>
<td>0.2</td>
<td>0.2 (0.1-0.4)</td>
</tr>
<tr>
<td>Macon Ridge, Louisiana</td>
<td>F2</td>
<td>190</td>
<td>1.6 (0.30)</td>
<td>0.4 (0.2-0.7)</td>
<td>1.4</td>
<td>0.2 (0.1-0.4)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>F4</td>
<td>190</td>
<td>2.7 (0.50)</td>
<td>0.2 (0.1-0.3)</td>
<td>0.5</td>
<td>0.01 (0.004-0.1)</td>
</tr>
<tr>
<td>Tallulah, Louisiana</td>
<td>F2</td>
<td>190</td>
<td>2.4 (0.80)</td>
<td>0.6 (0.2-0.9)</td>
<td>0.3</td>
<td>0.2 (0.1-0.5)</td>
</tr>
<tr>
<td>Winnsboro, Louisiana</td>
<td>F2</td>
<td>210</td>
<td>1.4 (0.20)</td>
<td>0.3 (0.1-1.0)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>4.5</td>
<td>0.2 (0.1-0.3)</td>
</tr>
<tr>
<td>Benton County, Mississippi</td>
<td>F1</td>
<td>190</td>
<td>1.4 (0.30)</td>
<td>0.3 (0.1-0.5)</td>
<td>0.7</td>
<td>0.1 (0.04-0.3)</td>
</tr>
</tbody>
</table>

<sup>1</sup> LC<sub>50</sub> expressed in ppm.
<sup>2</sup> Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).
<sup>3</sup> 90% CL reported.
<sup>4</sup> Unable to calculate CL. Index of significance of potency estimator (g) > 0.5.
<sup>5</sup> Significant χ² (P = 0.05).
Table 4.7. Toxicity of methoxyfenozide-treated diet to third-instar beet armyworms 120 hours after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(SE)</th>
<th>LC(_{50}) (95% CL)(^1)</th>
<th>(\chi^2)</th>
<th>TR (95% CL)(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOGEN</td>
<td>Reference</td>
<td>230</td>
<td>1.2 (0.16)</td>
<td>8.7 (4.3-15.3)</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Tift County, Georgia</td>
<td>F5</td>
<td>190</td>
<td>0.9 (0.13)</td>
<td>61.5 (14.1-358.5)(^3)</td>
<td>4.5</td>
<td>7.1 (3.1-16.5)</td>
</tr>
<tr>
<td>Bayou Macon, Louisiana</td>
<td>F2</td>
<td>190</td>
<td>0.8 (0.12)</td>
<td>20.4 (-----)(^4)</td>
<td>6.3(^5)</td>
<td>2.4 (1.0-5.8)</td>
</tr>
<tr>
<td>Macon Ridge, Louisiana</td>
<td>F2</td>
<td>190</td>
<td>1.0 (0.13)</td>
<td>14.6 (1.5-87.4)</td>
<td>2.8</td>
<td>1.7 (0.7-3.9)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>F4</td>
<td>190</td>
<td>0.6 (0.11)</td>
<td>80.0 (28.4-247.0)</td>
<td>0.3</td>
<td>9.3 (3.0-28.8)</td>
</tr>
<tr>
<td>Tallulah, Louisiana</td>
<td>F2</td>
<td>190</td>
<td>0.9 (0.12)</td>
<td>24.8 (3.6-145.6)</td>
<td>5.1</td>
<td>2.9 (0.5-15.5)</td>
</tr>
<tr>
<td>Winnsboro, Louisiana</td>
<td>F1</td>
<td>230</td>
<td>0.8 (0.10)</td>
<td>79.5 (12.2-1365.4)</td>
<td>3.1</td>
<td>9.2 (3.8-22.2)</td>
</tr>
<tr>
<td>Benton County, Mississippi</td>
<td>F1</td>
<td>190</td>
<td>0.9 (0.13)</td>
<td>5.7 (2.7-10.3)</td>
<td>1.9</td>
<td>0.7 (0.1-3.77)</td>
</tr>
</tbody>
</table>

\(^1\) LC\(_{50}\) expressed in ppm.

\(^2\) Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).

\(^3\) 90% CL reported.

\(^4\) Unable to calculate CL. Index of significance of potency estimator (g) > 0.5.

\(^5\) Significant \(\chi^2\) (\(P = 0.05\)).
In spinosad bioassays, LC$_{50}$s of field strains ranged from 47.0 to 164.7 ppm, a 3.5-fold difference (Table 4.8). Ninety five percent CL for the ECOGEN strain were not obtained even with increased numbers of individuals assayed (125 per dose), thus 90% CL were reported. Toxicity of spinosad was similar among all field strains and the ECOGEN strain, except for the Tallulah strain. Based on the 90% CL of the Tallulah strain (93.8-781.4 ppm), it had a significantly higher LC$_{50}$ than the ECOGEN strain. TRs ranged from 0.9 to 3.2 among field strains.

Tebufenozide LC$_{50}$s of field strains ranged from 39.7 to 176.3 ppm, a 4.4-fold difference (Table 4.9). Despite the large numbers of larvae tested (130 individuals per dose), 95% CL were not obtained for the ECOGEN strain. Thus, comparisons between field strains and the reference strain were based on 90% CL. The Tift County strain (91.1-235.8 ppm) and the Winnsboro strain (91.8-241.5 ppm) were the only strains which had significantly higher LC$_{50}$s than the reference strain, based on their respective 90% CL. As with methoxyfenozide, TRs of tebufenozide were highly variable. Four strains (Bayou Macon, St. Joseph, Tift County, and Winnsboro) had TRs ranging from 8.1 to 10.0, while the remaining 3 strains (Benton County, Macon Ridge, and Tallulah) had TRs ranging from 2.3 to 3.1.

**Discussion**

For most field strains, the order of toxicity of the insecticides evaluated from least toxic to most toxic was thiodicarb < chlorpyrifos < tebufenozide < spinosad < methoxyfenozide < chlorfenapyr < emamectin benzoate. The average LC$_{50}$ (0.38 ppm) obtained for emamectin benzoate was 6296, 545, 292, 232, 109, and 61 times lower.
Table 4.8. Toxicity of spinosad-treated diet to third-instar beet armyworms 120 hours after exposure.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(SE)</th>
<th>LC$_{50}$ (95% CL)$^1$</th>
<th>$\chi^2$</th>
<th>TR (95% CL)$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOGEN</td>
<td>Reference</td>
<td>360</td>
<td>2.0 (0.25)</td>
<td>52.2 (34.7-88.6)$^3$</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>Tift County, Georgia</td>
<td>F5</td>
<td>190</td>
<td>1.2 (0.36)</td>
<td>118.9 (71.1-443.1)</td>
<td>0.2</td>
<td>2.3 (1.1-4.6)</td>
</tr>
<tr>
<td>Bayou Macon, Louisiana</td>
<td>F2</td>
<td>190</td>
<td>1.4 (0.32)</td>
<td>71.9 (51.0-128.2)</td>
<td>0.1</td>
<td>1.4 (0.9-2.2)</td>
</tr>
<tr>
<td>Macon Ridge, Louisiana</td>
<td>F1</td>
<td>150</td>
<td>1.4 (0.44)</td>
<td>70.5 (41.2-157.2)</td>
<td>0.1</td>
<td>1.4 (0.8-2.4)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>F3&amp;4</td>
<td>295</td>
<td>1.4 (0.35)</td>
<td>88.5 (58.8-160.9)</td>
<td>0.2</td>
<td>1.7 (1.1-2.7)</td>
</tr>
<tr>
<td>Tallulah, Louisiana</td>
<td>F1</td>
<td>190</td>
<td>1.1 (0.37)</td>
<td>164.7 (86.5-1807.0)</td>
<td>0.1</td>
<td>3.2 (1.2-8.3)</td>
</tr>
<tr>
<td>Winnsboro, Louisiana</td>
<td>F1</td>
<td>275</td>
<td>1.8 (0.30)</td>
<td>55.2 (43.0-72.9)</td>
<td>0.7</td>
<td>1.1 (0.8-1.5)</td>
</tr>
<tr>
<td>Benton County, Mississippi</td>
<td>F1</td>
<td>190</td>
<td>2.1 (0.37)</td>
<td>47.0 (35.2-61.9)</td>
<td>0.5</td>
<td>0.9 (0.7-1.2)</td>
</tr>
</tbody>
</table>

$^1$ LC$_{50}$ expressed in ppm.

$^2$ Toxicity ratio calculated according to Robertson and Preisler (1992).

$^3$ 90% CL reported.
<table>
<thead>
<tr>
<th>Strain</th>
<th>Generation Tested</th>
<th>n</th>
<th>Slope(SE)</th>
<th>LC$_{50}$ (95% CL)$^1$</th>
<th>$\chi^2$</th>
<th>TR (95% CL)$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECOGEN</td>
<td>Reference</td>
<td>260</td>
<td>0.9(0.11)</td>
<td>17.6 (3.1-76.5)$^3$</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>Tift County, Georgia</td>
<td>F5</td>
<td>190</td>
<td>1.1 (0.15)</td>
<td>143.3 (83.5-262.8)</td>
<td>0.6</td>
<td>8.1 (3.7-17.8)</td>
</tr>
<tr>
<td>Bayou Macon, Louisiana</td>
<td>F2</td>
<td>190</td>
<td>0.9 (0.14)</td>
<td>176.3 (59.7-810.1)$^3$</td>
<td>2.8</td>
<td>10.0 (1.2-81.8)</td>
</tr>
<tr>
<td>Macon Ridge, Louisiana</td>
<td>F2</td>
<td>190</td>
<td>0.8 (0.12)</td>
<td>47.1 (24.9-90.6)</td>
<td>1.8</td>
<td>2.7 (1.2-6.2)</td>
</tr>
<tr>
<td>St. Joseph, Louisiana</td>
<td>F4</td>
<td>190</td>
<td>0.8 (0.12)</td>
<td>160.0 (29.6-4209.0)</td>
<td>2.2</td>
<td>9.1 (3.7-22.8)</td>
</tr>
<tr>
<td>Tallulah, Louisiana</td>
<td>F1</td>
<td>190</td>
<td>1.0 (0.13)</td>
<td>54.0 (11.5-277.5)$^3$</td>
<td>4.7</td>
<td>3.1 (1.4-6.7)</td>
</tr>
<tr>
<td>Winnsboro, Louisiana</td>
<td>F1&amp;2</td>
<td>275</td>
<td>1.2 (0.23)</td>
<td>155.6 (80.8-263.0)</td>
<td>0.5</td>
<td>8.9 (4.1-19.1)</td>
</tr>
<tr>
<td>Benton County, Mississippi</td>
<td>F1</td>
<td>190</td>
<td>0.7 (0.11)</td>
<td>39.7 (7.0-250.5)</td>
<td>3.6</td>
<td>2.3 (0.9-5.6)</td>
</tr>
</tbody>
</table>

$^1$ LC$_{50}$ expressed in ppm.

$^2$ Toxicity ratio (TR) calculated according to Robertson and Preisler (1992).

$^3$ 90% CL reported.
than the average LC$_{50}$s obtained for thiodicarb, chlorpyrifos, tebufenozide, spinosad, methoxyfenozide, and chlorfenapyr, respectively. The toxicity of the IGRs (methoxyfenozide and tebufenozide) compared with the other insecticides was dependent on the endpoint of the bioassay. The slower mode of action of the IGRs required that the bioassays be extended to 120 h exposure to treated diet instead of the typical 72 h. At this shorter time interval, 50% larval mortality would not have occurred even at the highest doses tested. Although methoxyfenozide and tebufenozide have similar modes of action, the former appears to be more active against beet armyworm larvae with an average LC$_{50}$ 2.7 times lower than the average LC$_{50}$ for tebufenozide.

The experimental insecticides evaluated in this study show satisfactory activity against the beet armyworm, although considerable variation in the responses of the field strains was observed to the new compounds. In bioassays of both IGRs, considerable variation in the responses of field strains also was observed, resulting in elevated TRs of some strains (St. Joseph, Tift County, and Winnsboro). Both of these compounds have not been extensively used in the field and differences reported herein may in part be due to natural variation (Robertson et al. 1995). The shallower slopes of the dose-mortality lines observed in both the methoxyfenozide (0.6-1.0) and tebufenozide (0.7-1.2) bioassays also indicates a high degree of heterogeneity in the responses of these field strains to the IGRs (Chilcutt and Tabashnik 1995). Considerable variation in the responses of field strains also was observed in spinosad bioassays. Although spinosad was made available for commercial use during 1997, its use to date has been limited to experimental plots. Thus, significantly higher LC$_{50}$s observed for the Tallulah strain may due to natural variation (Robertson et al. 1995).
The most consistent responses from the field strains, in terms of range of LC\textsubscript{50} values, was obtained in chlorfenapyr bioassays. The consistency of LC\textsubscript{50}s obtained with this insecticide compared with the other experimental insecticides is likely related to the greater steepness (3.3-5.9) of the slopes of the dosage-mortality lines, which indicates a higher degree of homogeneity in the responses of field strains to this insecticide. Similar results have been reported by Wier et al. (1994a), where chlorfenapyr LC\textsubscript{50}s, ranged from 13.3 to 31.0 ppm, and slopes of dose-mortality lines ranged from 2.9 to 7.2. In their bioassay, Wier et al. evaluated mortality of third-instar beet armyworms at 72 h after exposure to treated soybean leaves. Although LC\textsubscript{50}s reported herein are based on 120 h exposure of larvae to treated diet, these results are comparable to Wier et al. (1994a) because chlorfenapyr is a relatively quick acting insecticide with minimal additional mortality occurring beyond 72 h of exposure. Although chlorfenapyr is available under a section 18 label against beet armyworms, its use has been limited. Thus, significantly higher LC\textsubscript{50}s observed in 5 of the 8 field strains does not necessarily indicate the development of resistance in those populations. To date, this product has performed very well against native populations of beet armyworm in field tests (Farlow et al. 1992, Wiley et al. 1995, Mascarenhas et al. 1996, Sparks et al. 1996).

The data presented in this study show considerable variability in the responses of field strains to the commercial insecticides chlorpyrifos and thiodicarb. All field strains from Louisiana, for which 95% CLs were obtained, required significantly higher concentrations of chlorpyrifos and thiodicarb to provide comparable mortality to that of the ECOGEN reference strain (Tables 4.3 and 4.4). In addition, the steep slopes of dose-mortality lines obtained in chlorpyrifos (2.0-4.5) and thiodicarb (2.3-4.5) bioassays...
suggest that these field strains are becoming more homozygous in their responses to
these insecticides, indicating a rightward shift of the dose-mortality lines compared with
the reference strain (Lande 1981, Falconer 1989). The combination of higher LCsos, a
rightward shift in the dose-mortality lines, and reports of reduced field efficacy indicate
that beet armyworms have developed resistance to chlorpyrifos and thiodicarb. New
insecticides along with appropriate resistance management strategies must be
implemented to prevent economic losses associated with future population outbreaks of
this pest.

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SUMMARY AND CONCLUSIONS

Field studies were conducted at the Northeast Research Station near St. Joseph, Louisiana in 1996 and 1997 to evaluate the potential yield effect of late season beet armyworm infestations on cotton. At infestation levels (1, 3, or 6 egg masses per cage) that were from 2.7 to 16.7-fold higher than the current economic threshold (5-6 egg masses per 91.5 row m), significantly higher light penetration through the canopy was observed in most infested plots at all sampling dates compared with non-infested control plots. Additionally, a trend for increased numbers of damaged fruiting forms with increases in egg mass density was observed. Plots infested with 1, 3, or 6 egg masses had an average of 2.3, 2.4, and 3.3-fold more damaged fruiting forms than the control plots, but these differences were not significant. Although infested plots were significantly more defoliated and suffered numerically greater fruit damage than the control plots, their yields were not significantly different. In fact, plots infested with 1, 3, or 6 egg masses harvested 1.7, 2.1, and 14.7% more seed cotton (based on 1996 data) than the control plots. Non-significant differences in yields observed in infested plots compared with control plots are likely due to the fact that, at the maturity (NAWF = 5 plus 300 heat units accumulated) stage in which plots were infested, the majority of the harvestable bolls were sufficiently mature to avoid damage by beet armyworm larvae. Additionally, the numerical increase in total shed fruiting forms (squares and small bolls) observed in infested plots in 1996, could have resulted in the plant shifting photosynthate supplies to older maturing bolls, resulting in larger bolls and consequently possibly increased yields. Furthermore, increased defoliation in infested
plots late in the growing season may have improved yields by increasing light penetration through the canopy and decreasing the incidence of boll rot.

'Much of the concern associated with beet armyworm infestations is the lack of effective insecticides available for its control. Currently registered (chlorpyrifos, spinosad, Spod-X, and thiodicarb) and experimental (chlorfenapyr and tebufenozide) insecticides were evaluated against native populations of beet armyworm in field tests conducted at the Northeast Research Station, near St. Joseph Louisiana and at the Macon Ridge location of the Northeast Research Station near Winnsboro, Louisiana. Chlorpyrifos provided adequate larval control (80%) when averaged over the four sampling dates at the St. Joseph trial. However, control (58%) at the Winnsboro trial was poor. Thiodicarb did not effectively control beet armyworms in St. Joseph (57%), and in Winnsboro, no control was observed. The microbial insecticide Spod-X did not provide control of larval populations at either location. Spinosad, a newly registered insecticide, provided satisfactory control of beet armyworm populations in both St. Joseph (91%) and Winnsboro (80%). Chlorfenapyr also provided satisfactory beet armyworm control in both St. Joseph (89%) and Winnsboro (83%). At both locations, the insect growth regulator tebufenozide provided adequate control (74%) of beet armyworm larvae. Tebufenozide, with its slower mode of action, generally required from 5 to 7 days to cause mortality. In general, beet armyworm populations in Winnsboro were slightly more difficult to control than those in St. Joseph.

Variation in the susceptibility of field populations of beet armyworms to selected insecticides was evaluated in a diet overlay bioassay using 2-d old and third instars. For most field strains, the order of toxicity of the insecticides evaluated against 2-d old
larvae from least to most toxic was thiodicarb < chlorpyrifos < chlorfenapyr < tebufenozide < spinosad. Two additional compounds were tested in third instar bioassays and the order of toxicity from least to most toxic was thiodicarb < chlorpyrifos < tebufenozide < spinosad < methoxyfenozide < chlorfenapyr < emamectin benzoate.

Several field strains exhibited reduced susceptibility to chlorpyrifos and thiodicarb. In chlorpyrifos bioassays, 64 to 100% of the field strains had significantly higher LC$_{50}$S than the laboratory reference strain and toxicity ratios (TR) (2.4 to 10.7) indicated moderate levels of resistance. In thiodicarb bioassays, 30 to 63% of the field strains had significantly higher LC$_{50}$S than the reference strain. TRs were lower for 2-d old (0.8 to 2.8) than for third instars (2.5 to 18.8).

Generally, responses of field strains to the experimental insecticides were comparable to that of the reference strain. Although 11 to 63% of the field strains bioassayed with chlorfenapyr had significantly higher LC$_{50}$S than the reference strain, their TRs were low (0.8 to 1.8), suggesting that natural variation in these field populations may be partially responsible for differences in LC$_{50}$S. In spinosad bioassays, considerable variation in the response of field strains was observed. Some strains (14%) had significantly lower LC$_{50}$S, while others (30%) had significantly higher LC$_{50}$S. In general, TRs were low indicating no measurable resistance to spinosad has developed in these field strains. In tebufenozide bioassays, 10 to 29% of the field strains had significantly higher LC$_{50}$S than the reference strain. Low TRs of 2-d old larvae (1.0 to 2.2) were observed, while those of third instars (2.3 to 10.0) suggested that moderate levels of resistance may be present in some of these populations. As in
field tests, larval mortality in tebufenozide bioassays usually required 3-4 days to occur. Methoxyfenozide, another insect growth regulator, also required longer to kill larvae compared with the other insecticides evaluated. Although only one of the field strains had a significantly higher LC$_{50}$ than the reference strain, TRs were highly variable (0.7-9.3). In emamectin benzoate bioassays, 71% of the field strains had significantly lower LC$_{50}$s than the reference strain. This compound was 6295, 545, 292, 232, 109, and 61 times more active against beet armyworms than thiodicarb, chlorpyrifos, tebufenozide, spinosad, methoxyfenozide, and chlorfenapyr, respectively.

In conclusion, late season beet armyworm infestations on cotton appear to have a negligible effect on yield. Larger cotton bolls that are the major yield contributors seems to be sufficiently mature to avoid damage. In the event of population outbreaks that occur earlier in the growing season when the risk of economic yield losses is still of concern, new insecticide chemistries will likely provide better control of these insects than current standards. Monitoring the susceptibility of field population of beet armyworm to standard and new chemistries is critical so that appropriate resistance management strategies be implemented to ensure that these insecticides remain effective.
September 17, 1997

Mr. Victor J. Mascarenhas
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402 Life Sciences Blgd.
Baton Rouge, LA 70803

Dear Mr. Mascarenhas

Per your recent request, as an author of the manuscript "Beet army-worm (Lepidoptera: Noctuidae) control on cotton in Louisiana" by Mascarenhas, Leonard, Burns and Graves, published in the Florida Entomologist, Vol. 79, no. 3, you retain the right to use material from the article at your discretion. As such, this letter serves as confirmation that you are indeed an author of the article and thus have the right to use any and all material from the article in your dissertation or other outlets of your choosing.

Sincerely,

R. M. Baranowski
Editor
VITA

Victor James Mascarenhas, the last of six children of Aristides Augusto Alvares Mascarenhas and Mary Agnes Gunn, was born in Rio de Janeiro, Brazil, on March 19, 1965. He graduated from military school in Rio de Janeiro in 1982. In 1990, he obtained his bachelor of science degree in Agronomy from the University of Florida. He initiated graduate studies in Entomology in 1992 at Mississippi State University under the direction of Dr. Randy Luttrell and received a master of science degree in 1994. Victor met his wife, Rosanne Nicholson, while in Graduate School at Mississippi State University and they married in 1993. Victor is presently a candidate for the doctor of philosophy degree in Entomology at Louisiana State University.
Candidate: Victor J. Mascarenhas

Major Field: Entomology

Title of Dissertation: Pest Status and Management of Beet Armyworm, *Spodoptera exigua* (Hübner), on Cotton in Louisiana

Approved:

[Signatures]

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:

October 17, 1997