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ARTHROPOD MANAGEMENT

Laboratory and Field Evaluations of *Bacillus thuringiensis* Berliner Insecticides Against Tobacco Budworm (Lepidoptera: Noctuidae)

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INTERPRETIVE SUMMARY

Research Question. *Bacillus thuringiensis* Berliner insecticides have demonstrated considerable potential in cotton insect pest management, although problems with persistence have limited commercial use. One option for the control of insecticide resistant tobacco budworm includes the use of *B. thuringiensis* insecticides with chemical ovicides for control of low infestations of tobacco budworm in normal non-transgenic *B. thuringiensis* cotton cultivars during phase I (June) of the cotton production season. The primary objective of these studies was to determine the efficacy and persistence of two *B. thuringiensis* insecticides, Dipel ES and Condor OF, compared with a standard chemical insecticide, Larvin 3.2F, against this pest in laboratory and field tests.

Literature Summary. The tobacco budworm has developed resistance to all recommended classes of insecticides used on cotton. Applied entomologists have recommended the use of *B. thuringiensis* at rates of 2.0 to 64.0 oz acre^{-1} as a component of insecticide resistance management guidelines to manage tobacco budworm populations resistant to pyrethroid insecticides. Researchers in Texas have suggested that low rates are not recommended to produce mortality but rather to slow development of tobacco budworm and expose them to natural mortality factors. Other information suggests rates less than 48 oz acre^{-1} is generally ineffective against tobacco budworm. Therefore, cost-effective rates of *B. thuringiensis* insecticides need to be defined for tobacco budworm management in cotton.

Study Description. In 1992 through 1994, the *B. thuringiensis* Berliner var. *kurstaki* insecticides, Dipel ES and Condor OF, were evaluated for efficacy against tobacco budworm larvae in laboratory (plant terminal) and field trials in Louisiana. These insecticides were tested at rates of 0.29, 0.58, 1.17, 2.34, and 4.67 liters ha^{-1} (4, 8, 16, 32 and 64 oz acre^{-1}) against the tobacco budworm, *Heliothis virescens* (F.).

Applied Question. *What levels of tobacco budworm mortality and control can be expected from Dipel ES and Condor OF, used at rates of 0.29, 0.58, 1.17, 2.34, and 4.67 liters ha^{-1} (4, 8, 16, 32 and 64 oz acre^{-1}) at 2 and 72 h post-treatment in cotton?*

Both products used at rates $\geq$16 oz acre^{-1} can produce significant levels of tobacco budworm mortality initially. Residual efficacy is highly variable, and only the higher labeled rates will consistently produce mortality levels comparable with that provided by Larvin. Field trials with Dipel ES and Condor OF at rates $\geq$16 oz acre^{-1} will significantly reduce damaged squares below that found in the untreated plots but may not always provide satisfactory control of high population densities.

ABSTRACT

Studies were conducted to determine the effectiveness of *Bacillus thuringiensis* (Dipel ES, Condor OF) Berliner insecticides in controlling the tobacco budworm, *Heliothis virescens* (F.). Laboratory tests (plant terminal bioassays) indicated that Dipel ES and Condor OF rates $\geq$1.17 L ha^{-1} produced significantly higher mortality of tobacco budworm larvae than did the untreated control on treated plant tissue harvested 2 h post-treatment. Dipel ES at 4.68 L ha^{-1} and Condor OF $\leq$ 0.58 L ha^{-1} caused significantly higher tobacco budworm

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mortality than did the untreated control on treated plant tissue harvested 72 h post-treatment. Tobacco budworm mortality levels did not increase as Dipel ES or Condor OF dosage rates increased. Larvin at 1.17 L ha^{-1} generally produced mortality levels equal to or higher than those observed with the higher rates of Dipel ES or Condor OF. Field trials evaluating Dipel ES and Condor OF indicated that rates $\geq$1.17 L ha^{-1} significantly reduced tobacco budworm damaged squares below that observed in the untreated control.

The cotton bollworm, *Helicoverpa* (=*Heliothis*) *zea* (Boddie), and the tobacco budworm are primary insect pests in cotton (Brazzel et al., 1953; Sparks, 1981). During the 5-yr period 1989 to 1993, these pests accounted for an average yield reduction of 4.9% per year with control costs exceeding $30 million per year in Louisiana alone (adapted from Head, 1990; Head, 1991; Head, 1992; 1 Head, 993; Williams, 1994). The tobacco budworm has developed resistance to all recommended classes of insecticides used on cotton (Sparks, 1981; Leonard et al., 1988; Campanhola and Plapp, 1989; Elzen et al., 1992; Elzen et al., 1993; Martin et al., 1992). However, widespread field control failures with chemical insecticides have been prevented with the implementation of resistance management (IRM) strategies (Roush and Luttrell, 1987; Graves et al., 1988; Leonard et al., 1993; Leonard et al., 1994; Plapp, 1993). However, these IRM strategies are only a short-term solution, and innovative cotton insect pest management strategies are desperately needed. Even with the introduction of genetically engineered cotton cultivars containing the *B. thuringiensis* Berliner delta-endotoxin protein and spinosad (Tracer 4F; Dow Agrosciences, Indianapolis, IN), there are limited alternatives to control tobacco budworm.

Foliar applications of *B. thuringiensis* Berliner insecticides have potential in cotton insect pest management, although problems with their persistence have limited commercial use. Their efficacy is highly sensitive to the environmental conditions in cotton fields. When exposed to UV light, the insecticidal proteins undergo rapid degradation (Ignoffo et al., 1974; Krieg, 1975; Ignoffo et al., 1977). Considerable research has attempted to improve *B. thuringiensis* field persistence using ultraviolet absorbers (Jacques, 1972; Hostetter et al., 1975; Morris, 1983), encapsulation (Raun and Jackson, 1966) and addition of clay granules (Raun and Jackson, 1966; Ahmed et al., 1973) to spray formulations. Transgenic *B. thuringiensis* cotton plants have overcome the field persistence problems associated with foliar applications of these products. Nearly all plant tissues of these transgenic cotton plants express the insecticidal delta-endotoxin throughout the production season. An obvious disadvantage is the extreme selection pressure placed upon tobacco budworm that could result in resistant populations and loss of these products as effective insecticides. In addition, transgenic cotton plants express the delta-endotoxin continuously, regardless of population density, but only have value to the producer when tobacco budworm is an economic problem.

The primary objective of these studies was to determine the efficacy and persistence of two *B. thuringiensis* insecticides, Dipel ES and Condor OF, compared with a standard insecticide, Larvin 3.2F, at several rates in laboratory and field tests. The information generated in these studies will be used to define effective rates of *B. thuringiensis* insecticides used for tobacco budworm management in cotton.

MATERIALS AND METHODS

Insects

Tobacco budworm larvae were obtained from the Louisiana State Univ. Dep. of Entomology laboratory reference colony (LSU-LAB) or from field collections in the Macon Ridge region of Louisiana (MRS93) during June, 1993 and near Ferriday, LA (FDY94) during June, 1994. Tests with field-collected tobacco budworm larvae were conducted within three generations of their removal from the field. All tobacco budworm larvae were reared on a pinto bean and wheat germ diet (Leonard et al., 1988) at ambient conditions in a field insectary prior to laboratory tests.

Application of Insecticides

Treatments were applied with a tractor-mounted spray boom and compressed air delivery system calibrated to deliver 93.5 to 102.9 L ha^{-1} at a pressure of 2.0 to 3.8 kg cm^{-2} through two TX-8, TX-10, 8001, 80015 or 8002 nozzles (TeeJet Co.

Wheaton, IL) equally spaced per row. Treatments also were applied with a high clearance sprayer equipped with a CO_2 system calibrated to deliver 93.5 L ha^{-1} at 4.4 kg cm^{-2} through two TX-12 nozzles equally spaced per row.

Plant Terminal Bioassays

In 1992, 1993, and 1994, Dipel ES (*B. thuringiensis* Berliner var. *kurstaki* strain HD-1, 242.2 billion international units (BIU) L^{-1}, Abbott Laboratories, North Chicago, IL) and Condor OF (*B. thuringiensis* Berliner var. *kurstaki* strain EG2348, 329.3 BIU L^{-1}, Ecogen, Inc., Langhorne, PA) were evaluated for efficacy against tobacco budworm larvae. These trials were designed to measure the toxicity of a single field application to tobacco budworm larvae infested on treated leaf tissue.

Field plots consisted of three to four rows of cotton plants (1.02 m centers) by 15.2 m. that were maintained at Northeast Research Station (near Winnsboro and St. Joseph, LA). These insecticides were tested at rates of 0.29, 0.58, 1.17, 2.34 and 4.67 L ha^{-1} compared with thiodicarb (Larvin 3.2 F; Rhone Poulenc Ag. Co., Research Triangle Park, NC) at 1.17 L ha^{-1} . Treatments were arranged in a randomized complete block design with three to five blocks (replications) for each insecticide and tobacco budworm colony combination.

Dipel ES was evaluated against the LSU-LAB tobacco budworm colony in 1992 and against field-collected tobacco budworm in 1993 (MRS93 colony) and 1994 (FDY94 colony). Treatments were applied on 1 and 29 July to plots of “Stoneville 453" cotton and on 3 August to plots of “Deltapine 51" cotton in 1992. No rainfall was recorded after these applications. In 1993, treatments were applied on 27 July to plots of “Chembred 1233" and on 10 September to plots of “Stoneville 453" cotton. These plots received trace amounts of rainfall on 29 July and 13 September, respectively. In 1994, treatments were applied on 12 July to plots of “Deltapine 5690" and on 16 August to plots of “Deltapine 51" cotton. In 1994 these plots received rainfall in amounts of 5.1 mm on 13 July, 15.7 mm on 14 July, and 10.4 mm on 15 July.

Condor OF was evaluated against the LSU-LAB colony in 1993 and against a field-collected colony (FDY94) in 1994. In 1993, treatments were applied on 11, 15 and 29 June and 6 July to plots of Deltapine 51 cotton. These plots received 0.40 mm rainfall on 12 June and a trace of rainfall on 17 June. In 1994, treatments were applied on 19, 22, 23, and 30 August to plots of Deltapine 51 cotton. The plots received the following rainfall, 47.8 mm on 20 August and 14.5 mm on 1 September.

For each treatment, 25 cotton plant terminals (apical portion of the main stem containing one fully expanded leaf and all unexpanded leaves) were randomly collected from each field plot, placed in 12-mL florist water pics (Aqua Pic; Dakota Plastics, Watertown, SD), transported to the laboratory, and held in wooden trays within 2 h of insecticide application. In addition, 25 plant terminals were harvested 72 h post-treatment and maintained exactly like the 2-h sample. One or two second instar tobacco budworms (4 d old, ca. 3.3 to 7.7 mg) were placed on each plant terminal and the entire terminal was covered with a 473.2-mL plastic drinking cup (Dixie from the James River Corp., Norwalk, CT, or Solo from the Solo Cup Co., Urbana, IL). The caged larvae were maintained at ca. 30 ± 4 ^{o}C in a 14:10 (light:dark) photoperiod. Larvae were confined to plant terminals for 72 h, after which time mortality was recorded. A larva was considered dead if it was unable to right itself within 15 s after being prodded on its dorsum.

All data for each insecticide and tobacco budworm colony combination were pooled and analyzed as a single experiment. Mortality within each test was corrected for that observed on untreated terminals using Abbott's formula (Abbott, 1925). Data were transformed using Arcsine square root (X + 0.01) and subjected to analysis of variance (ANOVA) using the general linear models (SAS Institute, 1989). Means were compared using Least Squares Means of the transformed mortality values. Un-transformed data are reported.

Field Efficacy Tests with Dipel ES and Condor OF

During 1992 to 1994, the efficacy of these two products were evaluated against native infestations of tobacco budworm at the Macon Ridge Location (Winnsboro) of the Northeast Research Station in field trials. Dipel ES and Condor OF were tested at the same rates used in the plant terminal bioassays.

In 1992, Dipel ES was evaluated against tobacco budworm in three tests. Test 1 consisted of Deltapine 51 cotton planted 17 May, test 2 consisted of Stoneville 453 cotton planted 10 May and test 3 consisted of Stoneville 453 cotton planted 10 July. Treatments were applied on 21 July (≈5% tobacco budworm infested plant terminals), 29 July (5–10% tobacco budworm infested plant terminals) and 6 August (5–10% tobacco budworm infested plant terminals) to plots in test 1, test 2 and test 3, respectively. Test 1 was evaluated on 24 July (3 days after treatment [DAT]), test 2 on 3 August (5 DAT) and test 3 on 10 August (6 DAT). In test 1, the plots received 4.3 and 2.8-mm rainfall on 22 and 23 July, respectively. In test 2, no rainfall occurred. In test 3, the plots received 12-mm rainfall on 9 August. Larvae were collected from the test sites at the time of treatment application and reared to adults. Tobacco budworm comprised the majority (>90%) Heliothine spp. in the field infestations.

Condor OF was evaluated in a single test during 1993 and again in 1994. Plots consisted of Stoneville 453 cotton planted 1 July and Deltapine 51 cotton planted 1 July in 1993 and 1994, respectively. Treatments were applied on 30 August in 1993 (25% tobacco budworm infested plant terminals) and 22 August (30% tobacco budworm infested plant terminals) in 1994. Pheromone trap collections and identification of larvae in the untreated controls indicated that tobacco budworm was the primary Heliothine species (>70%) across the test sites in 1993 and 1994. The plots received 7.6-mm rainfall on 3 September in the 1993 test, and no rainfall occurred during the 1994 test.

Treatments were evaluated by sampling a minimum of 50 to 200 randomly harvested squares (within five nodes below the plant terminal) from the center rows of each plot for tobacco budworm injury and squares infested with larvae. A square was recorded as damaged by larvae if feeding penetrated entirely through the corolla or calyx. Both variables, square damage and larval presence, were subjected to analysis of variance (ANOVA) within each test and across multiple tests for each insecticide using the general linear models (SAS Institute, 1989). Means were compared using Least Squares Means.

RESULTS

Cotton Plant Terminal Bioassays, Dipel ES

In 1992, mortality of the LSU-LAB tobacco budworm colony in the untreated control averaged 22.4% for the 2 h post-treatment sample and 20.2% for the 72 h post-treatment sample. Dipel ES at 1.17 L ha^{-1} caused 29.0% mortality and was the lowest rate of Dipel ES that produced mortality significantly higher than that in the untreated control at 2 h post-treatment (F = 9.24; df = 6, 12; P = 0.0006) (Fig. 1). Dipel ES caused 36.4% mortality at 4.67 L ha^{-1} , which was significantly lower than mortality caused by thiodicarb (66.4%). The highest rate of Dipel ES did not produce higher mortality than rates of Dipel ES ≥0.58 L ha^{-1} . In the 72 h post-treatment sample, only the highest rate of Dipel ES and thiodicarb caused higher mortality than the untreated control (F = 6.67; df = 6, 12; P = 0.0027) (Fig. 1). Thiodicarb caused 46.5% mortality, which was significantly higher than mortality values for all rates of Dipel ES except 4.67 L ha^{-1} .

Against field-collected tobacco budworm in 1993 and 1994, mortality in the untreated control averaged 9.3% at 2 h post-treatment and 10.7% at 72 h post-treatment. Only rates of Dipel ES ≥2.34

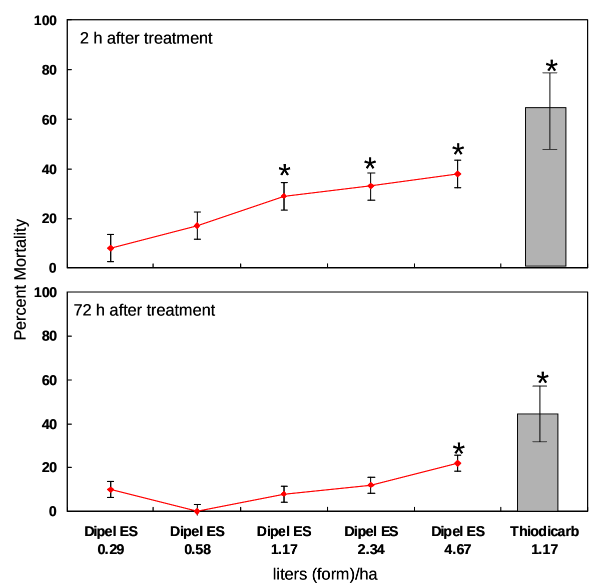

Fig. 1. Mortality (± SE) of LSU-LAB tobacco budworm larvae exposed to plant terminals at 2 and 72 h posttreatment with Dipel ES® and thiodicarb. An "*" indicates a significant difference from the untreated control at P=0.025, Least Squares Means.

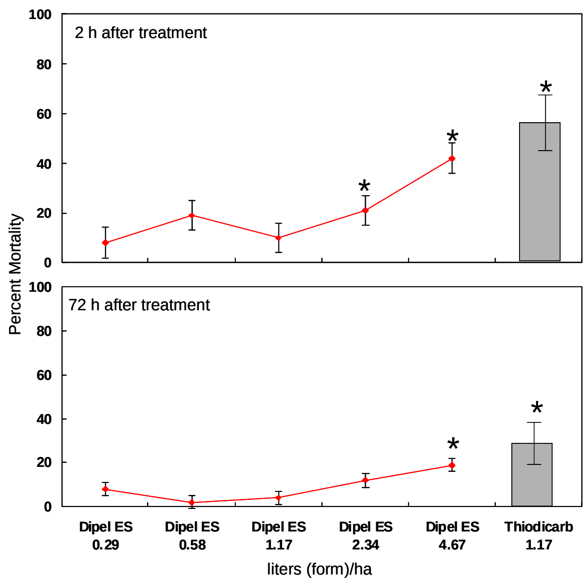

Fig. 2. Mortality (± SE) of field-collected tobacco budworm larvae exposed to plant terminals at 2 and 72 h posttreatment with Dipel ES® and thiodicarb. An "*" indicates a significant difference from the untreated control at P=0.025, Least Squares Means.

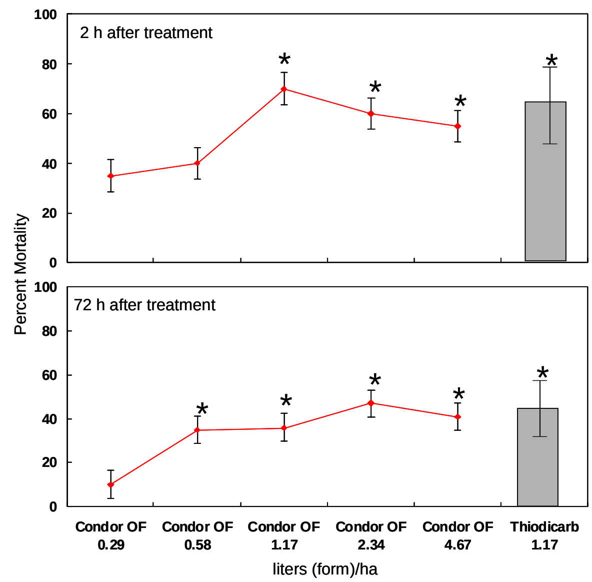

Fig. 3. Mortality (± SE) of LSU-LAB tobacco budworm larvae exposed to plant terminals at 2 and 72 h posttreatment with Condor OF® and thiodicarb. An "*" indicates a significant difference from the untreated control at P=0.025, Least Squares Means.

L ha^{-1} produced significantly higher mortality than that in the untreated control at 2 h post-treatment (F = 11.7; df = 6, 18; P = 0.0001) (Fig. 2). Dipel ES at 4.67 L ha^{-1} produced 43.4% mortality at 2 h post-treatment and was not significantly different from that of thiodicarb (52.6% mortality). At 72 h post-treatment, only Dipel ES at 4.67 L ha^{-1} (16.9%) and thiodicarb (21.3%) caused significantly higher mortality of tobacco budworm larvae than that in the untreated control (F = 3.85; df = 6, 18; P = 0.0120) (Fig. 2). Dipel ES at 2.34 L ha^{-1} did not increase mortality compared with that of Dipel ES at 0.29 L ha^{-1}.

Cotton Plant Terminal Bioassays, Condor OF

Mortality of the LSU-LAB colony in the untreated control averaged 38.2% in the 2 h post-treatment sample and 34.0% in the 72 h post-treatment sample. Condor OF at 1.17 L ha^{-1} caused mortality (67.3%) of tobacco budworm that was significantly higher than that in the untreated control and comparable with that of thiodicarb (65%) at 2 h post-treatment (F = 3.12; df = 6, 18; P = 0.0282) (Fig. 3). Rates of Condor OF $\geq$1.17 L ha^{-1} and thiodicarb caused mortality levels higher than that in the untreated control. However, Condor OF at 0.29 L ha^{-1} produced 36.2% mortality, which was not significantly different from that of Condor OF at higher rates or thiodicarb. At 72 h post-treatment, Condor OF $\geq$0.58 L ha^{-1} and thiodicarb produced significantly higher mortality compared with that in the untreated control (F = 4.95; df = 6, 18; P = 0.0037) (Fig. 3). Condor OF $\geq$0.58 L ha^{-1} caused mortality levels that were not significantly different from those of thiodicarb at 72 h post-treatment.

Against field-collected tobacco budworm larvae, mortality in the untreated control averaged 27.4% at 2 h post-treatment and 21.2% at 72 h post-treatment. All rates of Condor OF $\geq$1.17 L ha^{-1} and thiodicarb produced mortality significantly higher than that in the untreated control in the 2 h post-treatment sample (F = 9.73; df = 6, 18; P = 0.0001) (Fig. 4). Condor OF at 1.17 L ha^{-1} caused 18.2% mortality, and thiodicarb caused 55% mortality at 2 h post-treatment. Only rates of Condor OF $\geq$2.34 L ha^{-1} produced mortality levels that were similar to that of thiodicarb. At 72 h post-treatment, there was no difference in tobacco budworm mortality among treatments (F = 1.22; df = 6, 18; P = 0.3417) (Fig. 4). However, 4.78 cm rainfall on 20 August probably influenced the results of the 72 h post-treatment sample.

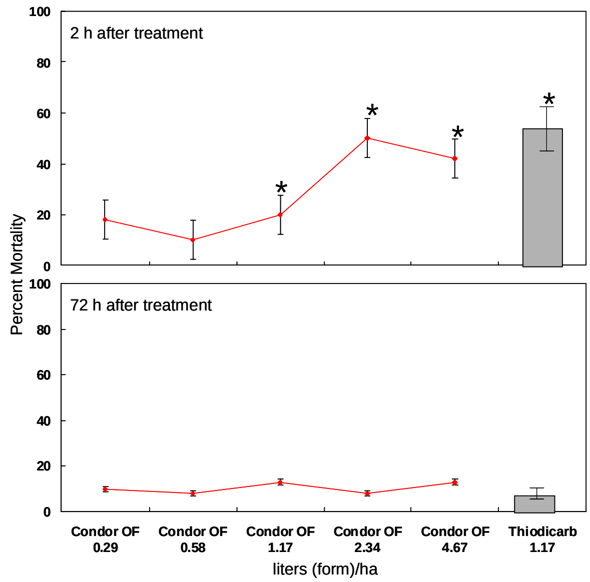

Fig. 4. Mortality (± SE) of field-collected tobacco budworm larvae exposed to plant terminals at 2 and 72 h posttreatment with Condor OF® and thiodicarb. An "*" indicates a significant difference from the untreated control at P=0.025, Least Squares Means.

Field Efficacy Tests with Dipel ES and Condor OF

The results of the Dipel ES field efficacy tests in 1992 (Table 1) are similar to the plant terminal bioassays. In test 1, none of the treatments reduced the number of damaged squares below that observed in the untreated control (F = 2.43; df = 6, 24; P > 0.05). Dipel ES at 4.67 L ha^{-1} was the only treatment to reduce numbers of squares infested with larvae below that found in the untreated plots (F = 4.02; df = 6, 24; P = 0.0063). In test 2, Dipel ES at 1.17 and 4.67 liters /ha and thiodicarb significantly reduced damaged square numbers below those observed in the untreated plots (F = 2.72; df = 6, 18; P = 0.0461). Only Dipel ES at 4.67 L ha^{-1} and thiodicarb significantly reduced numbers of squares infested with larvae below that in the untreated plots (F = 3.35; df = 6, 18; P = 0.0214). In test 3, Dipel ES at 0.58 and 4.67 L ha^{-1} significantly reduced damaged squares compared with the untreated plots (F = 3.22; df = 6, 18; P = 0.0249). There were no significant differences among treatments in squares infested with larvae for this test (F = 1.24; df = 6, 18; P > 0.05). Across tests, all treatments except Dipel ES at 0.29 L ha^{-1} significantly reduced damaged squares below that in the untreated plots, and the highest rate of Dipel ES was the only treatment with significantly fewer damaged squares compared with the lowest rate (F = 4.58; df = 6, 70; P = 0.0021). Furthermore, damaged square numbers in all Dipel ES treatments were not different from that of thiodicarb. Only Dipel ES at 4.67 L ha^{-1} and thiodicarb significantly reduced numbers of squares infested with larvae

Table 1. Evaluation of Dipel ES at selected rates in field studies against tobacco budworm in Louisiana, 1992.

Treatment	Rate	Test 1†	Test 2‡	Test 3§	Mean
	L ha^{-1}		% damaged squares¶		
Dipel ES	0.29	3.3 a	9.1 ab	6.6 a	6.1 ab
Dipel ES	0.58	2.6 a	7.9 ab	5.1 b	5.0 bc
Dipel ES	1.17	2.5 a	7.4 b	6.3 ab	5.2 bc
Dipel ES	2.34	2.3 a	8.1 ab	6.1 ab	5.3 bc
Dipel ES	4.67	1.8 a	6.6 b	4.0 b	4.0 c
Thiodicarb	1.17	2.4 a	5.9 b	5.6 ab	4.5 bc
Untreated	0.00	3.8 a	11.3 a	7.9 a	7.3 a
			% squares infested with larvae		
Dipel ES	0.29	1.5 b	2.1 a	1.4 a	1.7 a
Dipel ES	0.58	0.9 ab	1.8 ac	0.8 a	1.1 ab
Dipel ES	1.17	1.1 ab	1.3 ab	1.1 a	1.2 a
Dipel ES	2.34	0.7 ac	1.5 ab	1.1 a	1.1 ab
Dipel ES	4.67	0.2 c	0.8 bc	1.0 a	0.6 b
Thiodicarb	1.17	1.0 ab	0.5 b	0.4 a	0.7 b
Untreated	0.00	1.1 ab	1.6 a	1.0 a	1.2 a

† Deltapine 51 cotton planted 17 May, treated on 21 July (when ≈5% tobacco budworm infested plant terminals), and evaluated on 24 July (3 d after treatment [DAT]).

‡ Stoneville 453 cotton planted 10 May, treated on 29 July (when 5–10% tobacco budworm infested plant terminals), and evaluated on 3 August (5 DAT).

§ Stoneville 453 cotton planted 10 July, treated 6 August (when 5–10% tobacco budworm infested plant terminals), and evaluated on 10 August (6 DAT).

¶ Means for each variable within a column followed by the same letter are not significantly different, (P = 0.05, Least Squares Means).

Table 2. Evaluation of Condor OF at selected rates in field studies against tobacco budworm in Louisiana, 1992–1993.

Treatment	Rate	Test 1†	Test 2‡	Mean
	L ha^{-1}		% damaged squares§	
Condor OF	0.29	11.0 ab	16.0 a	13.9 a
Condor OF	0.58	14.7 a	17.0 a	16.0 a
Condor OF	1.17	7.0 b	19.0 a	13.9 a
Condor OF	2.34	8.7 b	12.6 a	10.9 a
Condor OF	4.67	8.0 b	21.0 a	15.4 a
Thiodicarb	1.17	9.0 b	13.0 a	11.3 a
Untreated	0.00	15.0 a	24.0 a	20.1 a
			% squares infested with larvae	
Condor OF	0.29	2.7 a	3.6 a	3.1 a
Condor OF	0.58	2.0 a	4.0 a	3.1 a
Condor OF	1.17	4.7 a	5.0 a	4.9 a
Condor OF	2.34	0.7 a	3.0 a	2.0 a
Condor OF	4.67	0.7 a	4.6 a	2.9 a
Thiodicarb	1.17	4.0 a	4.0 a	4.0 a
Untreated	0.00	1.3 a	7.0 a	4.6 a

† Stoneville 453 cotton planted 1 July 1993 and treatments applied on 30 August 1993 (when 25% tobacco budworm infested plant terminals).

‡ Deltapine 51 cotton planted 1 July in 1994 and treated 22 August (when 30% tobacco budworm infested plant terminals).

§ Means for each variable within a column followed by the same letter are not significantly different, ($P = 0.025$, Least Squares Means).

below that observed in the untreated plots for the mean across tests ($F = 3.88$; df = 6, 70; $P = 0.0114$).

In test 1 of the Condor OF study, rates ≥1.17 L ha^{-1} and thiodicarb significantly reduced damaged squares below that observed in the untreated plots ($F = 4.29$; df = 6, 12; $P = 0.0154$) (Table 2). There were no significant differences among treatments in numbers of squares infested with larvae ($F = 1.79$; df = 6, 12; $P > 0.05$).

In test 2, there were no differences in damaged square numbers (F = 1.09; df = 6, 18; P > 0.05) or the number of squares infested with larvae (F = 0.76; df = 6, 18; P > 0.05) among treatments (Table 2). There were also no significant differences across tests in number of damaged squares (F = 1.38; df = 6, 35; P > 0.05) or squares infested with larvae ($F = 0.95$; df = 6, 35; $P > 0.05$).

DISCUSSION

The data for rate evaluations of Dipel ES and Condor OF are similar to the results obtained by Ali and Young (1993a) in their determination of dose response values for another commercial *B. thuringiensis* formulation, Javelin WG. In their study, increasing the rate of Javelin WG did not always improve residual toxicity. With many insecticides, increasing the application rate usually improves control by providing higher initial residues to decay with time. With *B. thuringiensis* insecticides, residue decay on leaf surfaces is fairly rapid, but can vary according to the post-treatment environmental conditions. Data from the plant terminal bioassays with Dipel ES and Condor OF indicate the higher labeled rates of these products should be used if significant insecticidal activity is expected at 72 h post-treatment.

Green and Hutchins (1993) suggest the use of low rates of *B. thuringiensis* (0.15 to 0.58 L ha^{-1}) insecticides to manage tobacco budworm resistant to pyrethroid insecticides. In Texas, low rates have not been recommended to produce mortality but rather to slow development of tobacco budworm and expose them to natural mortality factors (Plapp, 1993; Karunaratne and Plapp, 1993). The data from the field trials in this study indicated that rates <1.17 L ha^{-1} generally did not provide significant control under the high infestation densities (25 to 30% tobacco budworm infested plant terminals) encountered in these trials. In Louisiana cotton production systems, natural mortality factors such as parasitoids and predators are likely to be destroyed by applications of chemical insecticides to control boll weevil, *Anthonomus grandis grandis* Boheman or tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Smith, 1989; Smith, 1994; Gaylor and Graham, 1991).

Successful tobacco budworm control with foliar applications of *B. thuringiensis* insecticides is highly dependent on population density, larval life stage, species composition, presence of natural enemies and conventional insecticide resistance levels in this pest. When moderate to high infestations of tobacco budworm occur, *B. thuringiensis* insecticides are generally not recommended. According to Johnson et al. (1993), foliar applications of *B. thuringiensis* may not provide satisfactory control under these conditions. This conclusion is also supported by the results of these field trials. Under heavy population densities of tobacco budworm, damage was significantly reduced below that in untreated plots with *B. thuringiensis* rates ≥ 1.17 L ha^{-1}. However, in most of these field trials, less than 40% control was obtained regardless of the rate. This level of control would not be sufficient for producing acceptable yields. When mixed populations of bollworm and tobacco budworm occur, *B. thuringiensis* insecticides are less likely to provide satisfactory control. *B. thuringiensis* insecticides as foliar treatments or in transgenic plants are not as efficacious against bollworm as compared with tobacco budworm (Ali and Young, 1993b; Leonard et al., 1997).

Furthermore, tobacco budworm has developed resistance to carbamate insecticides (Martin et al., 1992; Elzen et al., 1993; Graves et al., 1993). Results of laboratory studies reported herein indicate that mortality levels with thiodicarb decrease by an average of 12% at 2 h post-treatment and 25% at 72 h post-treatment for field-collected tobacco budworm compared with LSU-LAB tobacco budworm. Generally, commercial *B. thuringiensis* insecticides are not more efficacious against tobacco budworm than they have proven to be in the past. However, when foliar applications of *B. thuringiensis* insecticides are compared with chemical standards to which tobacco budworm has developed resistance, *B. thuringiensis* insecticides may appear to provide relatively better control, thus leading to false conclusions about their efficacy.

The use of *B. thuringiensis* insecticides and transgenic *B. thuringiensis* cotton cultivars is being expanded due to the development of resistant tobacco budworm populations. To reduce selection pressure on other classes of insecticides, applications of *B. thuringiensis* insecticides are recommended to control low to moderate infestations of tobacco budworm early in the cotton production season, primarily in June (Leonard et al., 1993; Leonard et al., 1994). Transgenic *B. thuringiensis* cotton cultivars are being used across the cotton belt in areas where insecticide resistant tobacco budworm populations are an annual problem. Results reported in these studies support current recommendations limiting *B. thuringiensis* insecticides to early season applications at rates of 1.17 to 2.34 L ha^{-1} to manage low to moderate infestations of tobacco budworm. Thus, exposure of tobacco budworm to other chemical insecticides will be reduced and the potential for successful control of later generations of tobacco budworm increased. In most of these tests, residual control (72 h post-treatment) with insecticides was negligible, and the common practice of adding an insecticide with ovicidal activity to improve control with these treatments is probably justified. The addition of an ovicide reduces egg hatch and limits the density of surviving larvae that the *B. thuringiensis* insecticide would otherwise need to control.

As the use of transgenic cultivars becomes more common, it is likely that producers will depend less on foliar applications of *B. thuringiensis* insecticides. The current insect resistant management guidelines for transgenic *B. thuringiensis* cotton prohibit the use of foliar *B. thuringiensis* insecticides on untreated refugia areas to reduce selection pressure on tobacco budworm populations. However, in those areas of the cotton belt that have sporadic annual tobacco budworm infestations and transgenic cultivars are not economically justified, foliar applications of *B. thuringiensis* insecticides may be justified, especially during the early season.

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