ACTIVITY OF AVERMECTIN IN THE LABORATORY AND THE FIELD AGAINST THE BOLL WEEVIL AND *HELIOTHIS* SPP. ON COTTON AND FLUE-CURED TOBACCO

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ABSTRACT

Based on LD_{50} values and confidence intervals, topical applications of avermectin (MK-936; a mixture of isomers B_1a_1, 80% and B_1a_2, 20%) and permethrin were ca. equally toxic to larvae of the tobacco budworm, *Heliothis virescens* (F.), but avermectin was somewhat less toxic to the bollworm, *H. zea* (Boddie). Avermectin was less toxic than azinphosmethyl when topically applied in acetone to the boll weevil, *Anthonomus grandis* Boheman, but its toxicity was greatly enhanced when it was diluted in dimethyl sulfoxide or cottonseed oil. Avermectin was equally toxic to boll weevils whether it was topically applied to the dorsum of the thorax, the tarsus of the right front leg, or the tip of the proboscis; however, it was significantly less toxic than azinphosmethyl in all the topical application tests.

In field tests at Brownsville, TX, applications of avermectin to cotton at the rate of 0.14 kg/ha at 2- to 4-day intervals significantly reduced the % of squares (flower buds) damaged by the boll weevil as compared to the check. Numbers of undamaged squares and bolls in plots treated with avermectin and azinphosmethyl were equal and significantly greater than those in the check. Yields of seed cotton from plots treated with these compounds were significantly greater than those from the untreated plots. In South Carolina, Georgia, and Florida, sprays of avermectin at the rates of 0.011-0.033 kg/ha caused significant reductions in larval populations and damage by larvae of the tobacco budworm on flue-cured tobacco.

INTRODUCTION

The natural insecticide avermectin (MK-936; a mixture of isomers B_1a_1, 80% and B_1a_2, 20%) was shown to have a wide spectrum of activity against a variety of arthropods (Putter et al. 1981). Wright (1984) reported avermectin to be effective against the boll weevil, *Anthonomus grandis* Boheman, in the laboratory, and against the bollworm, *Heliothis zea* (Boddie), and the tobacco budworm, *H. virescens* (F.), in a field trial with cotton.

Although the organophosphorus insecticide azinphosmethyl has been used successfully to control the boll weevil wherever it is of economic importance, and other insecticides such as acephate and methomyl have been effective against the tobacco budworm on tobacco, a serious situation might exist if these insects were to develop resistance to these compounds. In an effort to find an effective alternative insecticide, avermectin was tested in the laboratory and in the field at Brownsville, TX, for its efficacy against the boll weevil on cotton and against the bollworm and the tobacco budworm in the laboratory. It was also tested at Florence, SC; Tifton, GA; and Live Oak, FL, for control of the tobacco budworm on flue-cured tobacco.

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METHODS, MATERIALS, AND RESULTS

Laboratory Tests. At Brownsville, TX, in 1982 and/or 1983, technical grade avermectin (MK-936) was obtained from the manufacturer and applied topically to boll weevils of an ebony strain which originated in Mississippi and was reared for 5 yrs in Florence, SC; to tobacco budworm larvae of a Tucson, AZ, strain that had been reared about 10 yrs in the laboratory; and to bollworm larvae from from a wild strain collected near Brownsville, TX. These insects were considered to be susceptible to all insecticides.

Topical doses of acetone solutions of avermectin were applied to the dorsum of the thorax of 4-, 7-, and 10-day-old larvae of the tobacco budworm, and to 3rd-stage larvae (25±5 mg) of the tobacco budworm and the bollworm, using a standardized method (Anonymous 1970). Mortalities were recorded after 48 and 96 h.

At 48 h postreatment, the LD_{50} values for applications of avermectin to 7- and 10-day- old larvae were 35X and 100X greater, respectively, than the LD_{50} for 4-day-old larvae. However, it is important to note that the LD_{50} for even the late stage larvae was well under 1 µg/larva (Table 1).

TABLE 1. Toxicity of Avermectin Diluted in Acetone and Applied Topically to Larvae of Tobacco Budworm at Different Ages.

Age of larvae (days)	LD_{50} as µg/larva at 48 h (95% confidence interval)
4	0.0031 (0.000094-0.01)
7	0.11 (0.071-0.16)
10	0.31 (0.19-0.5)

The LD_{50} values obtained from applications of avermectin to 3rd stage tobacco budworm and bollworm larvae were significantly different (Table 2). The mortality response of tobacco budworms at 96 h posttreatment with avermectin (LD_{50} 0.0053 µg/larva) was comparable to that obtained from topical treatments with permethrin (LD_{50} 0.0073 µg/larva) after 48 h (Wolfenbarger et al. 1977) but it was ca. 2X greater than the 96 h permethrin LD_{50} (0.0024 µg/larva) reported by Davis et al. (1975). The 48 h LD_{50} value (0.0275 µg/larva) reported by Davis et al. (1975) as a result of topical applications of permethrin to the bollworm was ca. 16x lower than that obtained with applications of avermectin at the same time posttreatment in this test.

TABLE 2. Toxicity of Avermectin Diluted in Acetone and Applied Topically to Larvae (5-6 Days Old) of the Bollworm and Tobacco Budworm.

	LD_{50} (µg/larva) at indicated h posttreatment (95% Confidence interval)	
Insect	48	96
Bollworm	0.43 (0.34-0.50)	0.31 (0.24-0.39)
Tobacco budworm	0.015 (0.0020-0.039)	0.0053 (0.00013-0.022)

In tests with adult boll weevils, topical applications of 1 μl of avermectin at various concentrations in dimethyl sulfoxide (DMSO), a twice-filtered cottonseed oil (CSO), or acetone were made to the dorsum of the thorax, the tarsus of the right front leg, or to the orifice of the proboscis according to standardized methods (Anonymous 1968). Mortalities were recorded after 72 h.

Dorsum applications of 20 μg of an acetone solution of avermectin killed only 10% of the weevils tested, but when avermectin was diluted in DMSO the LD_{50} was 1.26 μg/weevil. When avermectin was diluted in CSO and applied to the dorsum of the thorax, the tarsus, and the proboscis, the LD_{50} values were 1.2, 1.17, and 0.9 μg/weevil, respectively; These values did not differ statistically, as indicated by overlapping of their 95% confidence intervals, and they ranged from 22X to 31X greater than those that have been reported for azinphosmethyl, the lowest of which was 0.05 μg/weevil after 72 h (Anonymous 1968).

Field Tests. Cotton. Tests of the field efficacy of avermectin against the boll weevil were conducted during 1983 in cotton near Brownsville, TX. The cultivar Rio-875 was planted in river silt soil on March 7 (Julian date 66) in 12 plots, each consisting of twelve 67-m rows spaced 1 m apart. A randomized block design with 4 replications was used; plots were separated by corn plots of equal size.

Avermectin, formulated as an 18-g/L emulsifiable concentrate (EC), was provided by Merck, Sharp and Dohme Research Laboratories, Rahway, NJ. The 1% emulsified paraffinic crop spray oil Orchex-796® was included in the finished spray at a rate of 9.35 L/ha. Thirteen applications were made beginning June 13 (Julian date 164) at 2- to 4-day intervals. Because 16 cm of rain fell between July 11 and 19 (Julian dates 192 and 200), only two additional sprays were made on July 26 and 27 (Julian dates 207 and 208). The first five applications of avermectin were made at a rate of 0.017 kg AI/ha; however, since sampling indicated that this rate was not effective, subsequent applications were made at 0.14 kg AI/ha. Azinphosmethyl, formulated as a 240-g/L EC, was included as a control standard and was applied at a rate of 0.28 kg AI/ha. A high-clearance sprayer was used to apply 47 L/ha of finished sprays under a pressure of 2.5 kg/cm^2 from nozzles spaced 51 cm apart along the boom. All plots were irrigated in April, May, and July. The cotton was defoliated on July 28 (Julian date 209) and on August 9 (Julian date 221). Open bolls collected from 50 m of row in each plot were harvested and weighed August 24 and 28 (Julian dates 236 and 240).

Whole cotton plants (mean 10; range 5-15) were examined in each plot on six sampling dates for numbers of undamaged (by the boll weevil) pinhead squares (<0.5 cm in diameter at largest part), 1/3-grown squares (≥0.5-1.0 cm), full-grown squares (1.0 cm or larger); small bolls (red bloom to <2 cm in diameter at largest part), medium bolls (≥2-3 cm), large bolls (>3 cm or more in diameter), and open bolls (at least one harvestable lock). Boll weevil damaged squares and green bolls were also recorded to determine damage.

Collections of egg-punctured squares from the check and the treated plots were made on June 16 and 29 (Julian dates 167 and 180) and egg-punctured bolls were collected on June 29 (Julian date 180). These squares and bolls (89-100/treatment or untreated control) were held in the laboratory and boll weevil emergence was recorded.

These and other field test data were analyzed using an analysis of variance and means were separated at the 5% level of probability using Duncan's multiple range test.

On at least two sampling dates, significantly less boll weevil damage was sustained by squares (>1 cm diam.) that had been treated with either avermectin or azinphosmethyl compared to the untreated control. The same was shown for the larger squares on the last sampling date; avermectin-treated squares received 88% less damage than the untreated squares (Table 3).

TABLE 3. Mean Boll Weevil Damage to Squares of Cotton (<1 cm and >1 cm in Size) in Treated and Untreated Plots Planted on March 7 (Julian Date 66).[a]

Treatment	$\bar{x}$ % squares (by size) damaged on indicated Julian date							
	160[b] - 167[c]		173		186[b] - 180[c]		210[b] - 206[c]	
	<1 cm	≥1 cm	<1 cm	≥1 cm	<1 cm	≥1 cm	<1 cm	≥1 cm
Azinphosmethyl	28 a	32 a	44 a	33 a	7 b	43 a	40 b	25 b
Avermectin[d]	33 a	37 a	41 a	0 a	12 b	29 a	47 b	11 b
Untreated control	23 a	25 a	27 b	25 a	39 a	25 a	83 a	91 a

[a] Means in vertical columns followed by the same letter are not significantly different at the P=0.05 level according to Duncan's multiple range test.
[b] Sampling date for untreated control.
[c] Sampling date for treated plots.
[d] Sprays at 0.017 kg AI/ha through Julian date 173; at 0.14 kg AI/ha thereafter. See Fig. 1 for dates of application.

On the first and second sampling dates (Table 4), bolls larger than 3 cm and bolls less than 3 cm in diameter, respectively, in treated plots received significantly less boll weevil damage than the untreated bolls. On June 29 (Julian date 180), the smaller bolls received significantly less damage than the bolls of equal size in the untreated control.

The cumulative numbers of undamaged squares and bolls/ha from six successive samplings in treated vs. untreated plots are shown in Figs. 1 and 2, respectively. Throughout the experiment the test materials were about equal in effectiveness, but the cumulative % increase in undamaged squares over the untreated control was 24 and 21 for azinphosmethyl and avermectin, respectively, on Julian date 213. Similarly for bolls, increases over the untreated control were 33% for azinphosmethyl and 29% for avermectin on Julian date 213. Significantly more open bolls were found in azinphosmethyl- and avermectin-treated plots (83% and 81%, respectively) than in the untreated control (Table 5).

Yields of seed cotton, picked on August 24 and 29 (Julian dates 236 and 241), as an average of the four replicated plots treated with avermectin and azinphosmethyl, were significantly greater (40% and 74%, respectively) than the average yield of 238 kg/ha from the four untreated control plots. More than 15 cm of rain fell during July and an additional 5 cm fell between the last open boll count and the harvest, causing many locks to fall and be buried in the soil. The very wet conditions reduced yields below those that might have been projected from the open boll counts.

The emergence of boll weevils from punctured squares or bolls that had been collected in plots treated with avermectin, azinphosmethyl, or in untreated plots was not significantly different (41%, 53%, and 29%, respectively).

Tobacco. In 1982, a test was conducted at the Pee Dee Research and Education Center, Florence, SC, with avermectin (formulated as a 3.6 g/L soluble liquid--SL) applied to flue-cured tobacco 'Coker 347' at rates of 0.011, 0.022, and 0.033 kg AI/ha. Acephate (75% soluble powder) applied at the rate of 0.8 kg AI/ha was used as the standard for comparison. The test was conducted in plots 4 rows wide (4.9 m) and 15.2 m long arranged in a randomized block design. Tobacco plants were transplanted on April 30 (Julian date 120) 56 cm apart on the rows, and normal cultural practices were followed. The insecticides were applied with a highboy-mounted sprayer with one nozzle (D3-35)/row at a pressure of 4.5 kg/cm^2 and at a rate of 187 L/ha of finished spray. The total number of live tobacco budworms found on 30 plants/plot was recorded on June 20 (Julian date 173) five days after the spray was applied.

In 1983, three tests were conducted with avermectin (18-g/L EC)

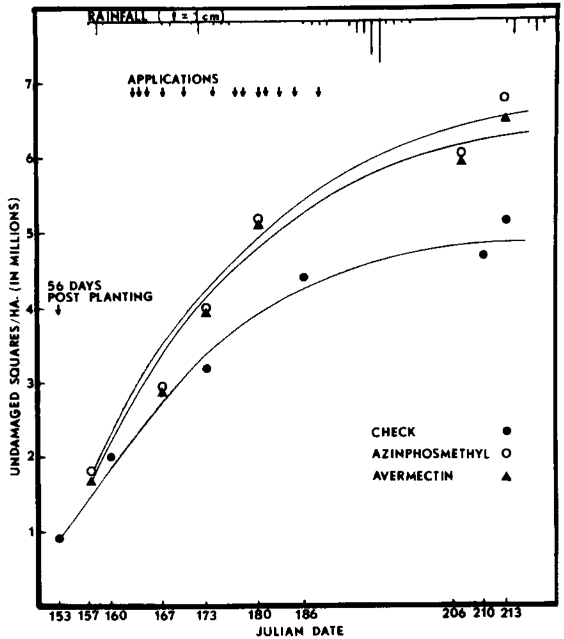

FIG. 1. Undamaged squares of cotton (cumulated from six successive samplings)/ha in untreated plots vs. plots treated with 0.017 or 0.14 kg AI/ha of avermectin or 0.28 kg AI/ha of azinphosmethyl for boll weevil control, Brownsville, TX, 1983.

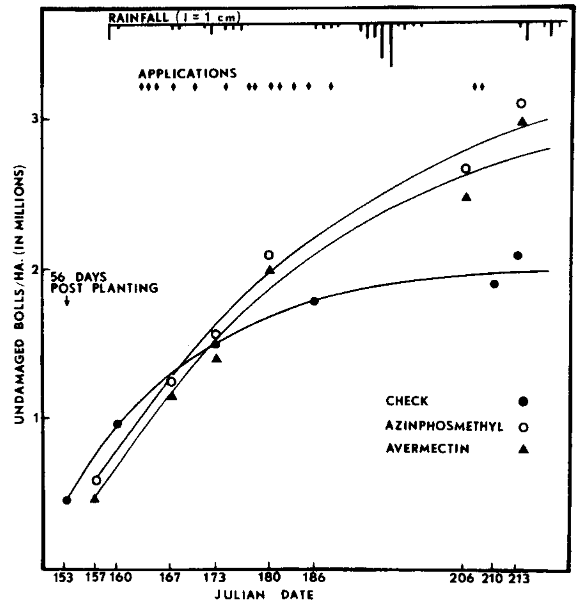

FIG. 2. Undamaged bolls of cotton (cumulated from six successive samplings)/ha in untreated plots vs. plots treated with 0.017 or 0.14 kg AI/ha of avermectin or 0.28 kg AI/ha of azinphosmethyl for boll weevil control, Brownsville, TX, 1983.

TABLE 4. Mean Boll Weevil Damage to Small and Medium Size Bolls (<3 cm and ≥3cm in Diameter at Widest Point) in Treated and Untreated Cottons.[a]

	$\bar{x}$ % bolls (by size) damaged on indicated Julian date					
	173[b/c]		186[b]	180[c]	210[b]	206[c]
Treatment	<3 cm	≥3 cm	<3 cm	≥3 cm	<3 cm	≥3 cm
Azinphosmethyl	49 a	2 b	27 b	4 b	32 a	21 a
Avermectin[d]	51 a	0 b	23 b	23 ab	28 a	22 a
Untreated control	32 a	46 a	65 a	54 a	63 a	26 a

[a] Means in vertical columns followed by the same letter are not significantly different at the P=0.05 level according to Duncan's multiple range test.
[b] Sampling date for untreated control.
[c] Sampling date for treated plots.
[d] See Fig. 1 for dates of application.

TABLE 5. Mean Number of Open Bolls in Treated and Untreated Cotton.

	$\bar{x}$ No. bolls/ha on indicated Julian date[a]		
Treatment	186	206	213
Azinphosmethyl		74,000 a	281,515 b
Avermectin	3,300	59,225 a	258,651 b
Untreated control			49,076 a

[a] Means in vertical columns followed by the same letter are not significantly different at the P=0.05 level according to Duncan's multiple range test.

applied to flue-cured tobacco 'Clemson PD-4' at the rates of 0.022, 0.011, and 0.0056 kg AI/ha. Acephate was included as a control using the same rates as in 1982. The test design was the same as it was in 1982 except that plots were 2 rows wide (2.44 m) and 22.9 m long (12.2 m long in the second test only). The plants were transplanted on June 7 (Julian date 158) and the insecticides were applied using the same methods as in 1982. In Test 1, the tobacco was treated on July 29 (Julian date 210), and in Tests 2 and 3 it was treated on August 15 (Julian date 227). The total number of live budworms found on 30 infested plants/plot (40 plants in Test 3) was recorded 4 days after treatment in Test 1 and 5 days after treatment in Tests 2 and 3.

Based on tests in 1982, avermectin appeared promising for control of the tobacco budworm on tobacco. Within 5 days after treatment, avermectin significantly reduced numbers of live tobacco budworm larvae compared to the untreated control (Table 6). In 1983, similar results were obtained following applications of avermectin or acephate whether the counts of larvae on plants were made 4 or 5 days posttreatment. In both yrs, the efficacy of avermectin was equal to that of acephate.

In tests at Tifton, GA, flue-cured tobacco ('Hicks') was transplanted on April 12, 1982 (Julian date 102) and April 27, 1983 (Julian date 117), with plants spaced 61 cm and 46 cm apart on the rows in the respective years. In each

TABLE 6. Efficacy of Two Insecticides Against the Tobacco Budworm on Flue-Cured Tobacco, Florence, SC, 1982-1983.

Treatment	Rate (kg AI/ha)	$\bar{x}$ no. live larvae/plot at indicated days posttreatment[a/] 4	5	$\bar{x}$ % Control
		1982 Test 1[b/]		
Acephate	0.8		5.3 a	65
Avermectin	0.033		1.2 a	92
Avermectin	0.022		2.2 a	85
Avermectin	0.011		2.1 a	86
Untreated control	-		15.0 b	-
		1983 Test 1[b/]		
Acephate	0.8	4.0 a		81
Avermectin	0.0056	9.8 a		52
Avermectin	0.011	6.0 a		71
Avermectin	0.022	2.8 a		86
Untreated control	-	20.5 b		-
		Test 2[b/]		
Acephate	0.8		13.3 a	80
Avermectin	0.056		19.7 a	71
Avermectin	0.012		17.0 a	75
Avermectin	0.022		12.0 a	82
Untreated control	-		67.3 b	-
		Test 3[b/]		
Acephate	0.8		28.0 a	69
Avermectin	0.056		25.2 bc	72
Avermectin	0.011		16.8 ab	81
Avermectin	0.022		11.5 a	87
Untreated control	-		88.8 d	-

[a/] Means in vertical columns followed by the same letter are not significantly different at the P=0.05 level according to Duncan's multiple range test.
[b/] 30 plants.
[c/] 40 plants.

yr, the plot size was 1 row wide and 9.14 m long; the row spacing was 0.91 m in 1982 and 0.84m in 1983, and plots were arranged in a randomized complete block design with four replications for each treatment and the untreated control.

The insecticides tested were avermectin (formulated as a 3.6-g/L SL in 1982 and as an 18-g/L EC in 1983) and methomyl (formulated as a 216-g/L SL). A CO_2-powered back-pack sprayer equipped with three TX-12 hollow cone nozzles/row was used to apply the insecticides. The sprayer, carried at a speed of 4.8 km/h was calibrated to deliver a total finished spray volume of 140.3 L/ha in 1982 and 234 L/ha in 1983 at a pressure of 4.2 kg/cm^2.

Data were obtained from weekly whole-plant examinations of each plant in a plot. In 1982, records were made of numbers of plants infested with larvae of the tobacco budworm; in 1982 and 1983, % damaged plants and damage ratings were recorded. Also in each yr, ratings of 0 through 7 were assigned to each plant depending upon the severity of damage incurred. These ratings were then divided into 3 classes; 0 = no damage; 1-3 = damage estimated to be of no economic importance; and 4-7 = damage regarded as unacceptable. Ratings were made on June 23 (Julian date 174) in 1982 and on July 11 (Julian date 192) in 1983.

TABLE 7. Efficacy of Two Insecticides Against the Tobacco Budworm on Flue-Cured Tobacco, Tifton GA, 1982-1983.[a]

Treatment	Rate (kg AI/ha)	$\bar{x}$ % of plants infested with larvae: Small (<1.9 cm)	Large (>1.9 cm)	$\bar{x}$ % damaged plants	Seasonal $\bar{x}$ % infested plants	$\bar{x}$ damage rating (0-7)[b]	$\bar{x}$ % of plants with damage rating of: 0	1-3	4
1982									
Avermectin	0.011	14.7 a	5.6 a	31.7 a		1.5 b			
	0.022	8.3 a	1.4 a	17.0 a		0.8 a			
	0.033	10.6 a	0.0 a	19.3 a		0.3 a			
Methomyl	0.50	15.0 a	7.4 a	24.8 a		1.2 a			
Untreated control	-	33.2 b	26.1 b	68.8 b		4.4 c			
1983									
Avermectin	0.00056				12.0 a	0.5 a	78.8 a	16.7 a	4.4 a
	0.011				6.5 a	0.4 a	83.2 a	14.8 a	1.9 a
	0.022				4.5 a	0.2 a	87.6 a	12.3 a	0.0 a
Methomyl	0.50				7.8 a	0.8 a	66.2 a	26.1 a	7.5 a
Untreated control	-				25.0 b	1.9 b	38.3 b	33.0 a	28.6 b

a/ Means in vertical columns followed by the same letter are not significantly different (P=0.05) according to Duncan's multiple range test.
b/ 0 = no damage; 7 = unacceptable damage.

Results of studies conducted in 1982 indicated that applications of avermectin, at the concentrations of 0.022 and 0.033 kg AI/ha, were as effective against tobacco budworm larvae as methomyl applied at a much higher (0.50 kg AI/ha) concentration (Table 7). Damage in all insecticide-treated plots was significantly less than in the treated control. Again in 1983, the two insecticides proved to be significantly effective regardless of the method of evaluation.

At Live Oak, FL, in 1983, the usual cultural practices for preparing the test area for planting were performed and flue-cured tobacco plants ('NC/79') were transplanted on March 8 (Julian date 67) and handtopped on June 2 (Julian date 153). A sucker control material (Royal Tac 85®) was applied at the recommended rate in 18.7 L of finished spray/ha on June 6 and 15 (Julian dates 157 and 166). Beginning May 4, six applications of avermectin at rates of 0.0067 and 0.019 kg AI/ha and methomyl at 0.80 kg AI/ha were made biweekly with a tractor-mounted CO_2-pressurized sprayer equipped with three Tee Jet D3-25 hollowcone nozzles arranged to cover the top and both sides of the row. The spray was delivered at a rate of 243 L/ha at a pressure of 4.22 kg/cm^2 and a speed of 6.4 km/h.

TABLE 8. Efficacy of Avermectin Against the Tobacco Budworm on Flue-Cured Tobacco, Live Oak, FL, 1983.

Treatment	Rate (kg AI/ha)	$\bar{x}$ % tobacco budworm-damaged plants/sampling date (Julian)[a/] 138	152	166[b/]	180
Avermectin	0.0067	86 b	62 a	28 a	32 a
	0.019	57 a	55 a	29 a	31 a
Methomyl	0.80	57 a	73 a	26 a	29 a
Untreated control	--	99 c	99 b	53 b	68 b

[a/] Counts made on 150 to 158 plants/treatment/sampling date. Means in vertical columns followed by the same letter are not significantly different at the P=0.05 level according to Duncan's multiple range test.
[b/] A decline in number of damaged plants in all treatments resulted from hand topping on June 2 (Julian date 153).

Applications of avermectin and methomyl, at the rates tested, caused significant reductions in numbers of tobacco budworm-infested plants compared to the untreated control (Table 8). However, the dose at which methomyl was applied was over 40 times greater than the greatest concentration of avermectin tested. Populations of the tobacco budworm were the largest observed in 28 yrs, and sprays of avermectin or methomyl at 14-day intervals failed to hold the damaged-plant level to 25% which is considered to be the least conservative estimate of the economic threshold for tobacco budworm damage to flue-cured tobacco in Florida (Baumhover and Herzog 1979). Whether applications of these insecticides at shorter intervals would suppress populations to economically acceptable levels under the pressure of unusually heavy infestations is not known.

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