A THREE YEAR STUDY OF PYRETHROID RESISTANCE IN TOBACCO BUDWORM[1] IN LOUISIANA: RESISTANCE MANAGEMENT IMPLICATIONS

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ABSTRACT

Male tobacco budworm, Heliothis virescens (F.), moths were bioassayed from May through September of 1987, 1988, and 1989 using a discriminating dose (10 μg/vial) of cypermethrin. Examination of these data reveal that the frequency of pyrethroid resistance in tobacco budworm varied with location and date of bioassay. The frequency of resistant moths was low during May and June but increased dramatically during late July, August, and September when pyrethroids were being used extensively. Generally, the frequency of pyrethroid resistant moths in May and June of all three years was less than 15%. However, because much of the cotton crop matured later each year during this study (which resulted in greater use of pyrethroids in August and September), pyrethroid resistance levels during August and September of 1989 were much higher than the levels recorded during those same months of 1987 and 1988. Resistance levels were generally highest in areas of extensive cotton production (hence more extensive use of pyrethroids) and lowest in areas with little or no commercial cotton production.

INTRODUCTION

The photostable pyrethroid insecticides, which were introduced in the late 1970's (Elliott et al. 1973, 1974), gave unprecedented control of the tobacco budworm, Heliothis virescens (F.), and the bollworm, Heliocoverpa zea (Boddie). Both laboratory and field experiments demonstrated that the pyrethroids were more toxic to these cotton pests than either organophosphate or carbamate insecticides (Palazzo 1978, Pieters 1979, Twine and Reynolds 1980, Herzog and Ottens 1982, Martinez-Carrillo and Reynolds 1983). Elliott (1976) cautioned that overenthusiastic use of pyrethroids might lead to rapid development of resistant field species. Interestingly, some field populations of tobacco budworms were

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shown to have an increased tolerance to pyrethroids even before they become widely used on cotton (Davis et al. 1977, Harding et al. 1977, Crowder et al. 1979, Twine and Reynolds 1980, Plapp 1981). Additionally, Crowder et al. (1984) demonstrated in a laboratory selection experiment that the tobacco budworm could develop pyrethroid resistance in only a few generations.

In 1985, there were several instances where pyrethroids failed to control tobacco budworm in West Texas cotton fields. These failures were later confirmed in laboratory tests by Plapp and Campanhola (1986) to be due to resistance. During 1986, there were numerous cases where pyrethroids failed to control tobacco budworms in Arkansas, Louisiana, Mississippi,and Texas. Three different bioassay techniques indicated that elevated levels of pyrethroid resistance were present in tobacco budworms collected in problem fields (Allen et al. 1987, Leonard et al. 1987a, Roush and Luttrell 1987). Furthermore, Plapp et al. (1987) confirmed that pyrethroid resistant tobacco budworms were present in these four states.

Several researchers provided data indicating that the primary resistance mechanism in tobacco budworm was *kdr* (knockdown resistance), which apparently is incompletely recessive in nature (Campanhola and Plapp 1987, Roush and Luttrell 1987, Payne 1987). Because of it's recessive nature, this type of resistance mechanism (*kdr*) affords an excellent opportunity for resistance management.

In an effort to prolong the usefulness of the pyrethroids, a pyrethroid resistance management plan was developed for the Mid-South states of Arkansas, Louisiana, and Mississippi (Anonymous 1986). To determine if the pyrethroid resistance management plan was successful, widespread monitoring of male tobacco budworm for pyrethroid resistance was conducted in these states during 1987, 1988, and 1989 using Plapp's (1987) glass vial technique. Results of the pyrethroid resistance monitoring program in Louisiana are reported herein.

MATERIALS AND METHODS

Wire cone 75-50 traps (Hartstack et al. 1979) baited with sex pheromone (Hendricks et al. 1987) were used to collect male tobacco budworm moths from May through September of 1987-1989. Although males were collected from most cotton production areas, more intense sampling was conducted on or near the Dean Lee Research Station (Rapides Parish), the Northeast Research Station-St. Joseph Location (Tensas Parish), the Northeast Research Station-Macon Ridge Location (Franklin Parish), and the Red River Research Station (Bossier Parish).

The resistance monitoring technique developed by Plapp et al. (1987) was used to monitor the response of tobacco budworm male moths to cypermethrin. In this technique, the interiors of glass scintillation vials (20 ml) were coated with a residual film of cypermethrin (10 μg/vial). The 10 μg/vial dose is lethal to homozygous pyrethroid-susceptible moths as well as moths heterozygous for pyrethroid resistance (Plapp 1987). Since only homozygous pyrethroid-resistant moths survive this dose, it was used as a discriminating dose. Vials were stored in a dark area (to prevent photodegradation of cypermethrin) and used within one month after preparation.

Acetone-treated vials were used as controls for natural moth mortality, which was generally less than 10%.

Male moths were removed from the traps early in the morning to prevent dessication. Only those males that appeared to be young and healthy were used in these tests. One (1988 and 1989) or two (1987) males were placed in each vial and held at room temperature (ca. 27°C) for 24 h. Mortality was determined by removing the moths from the vials and tossing them into the air. Moths that were unable to fly or could only fly a short distance (< 3 meters) were recorded as dead. All data were corrected for control mortality using Abbott's (1925) formula.

RESULTS AND DISCUSSION

Responses of male tobacco budworm moths to a discriminating dose of 10 µg/vial of cypermethrin during the months of May, June, July, August, and September over the period 1987-1989 indicate that variations in the levels of pyrethroid resistance were associated with location, month, and year of bioassay (Table 1). Examining the bioassay data by location revealed that the frequency of pyrethroid resistant moths was generally higher in the northern Louisiana cotton production areas (i.e. Bossier, Caddo, Morehouse and Richland Parishes) than that observed in the southern areas (Rapides and Tensas Parishes). The portion of the total acreage that is devoted to cotton is less in the southern production areas and infestations of tobacco budworm generally appear to be lighter and receive less insecticide selection pressure. In an area where cotton is no longer commercially produced (East Baton Rouge Parish), the frequency of pyrethroid resistant moths was generally low.

Summarizing the bioassay data by month (life cycle of the tobacco budworm is about a month) indicates that the overall level of resistance in May, June, and July was similar for all three years (Table 2). These data suggest that the Mid-South Pyrethroid Resistance Management Plan recommended in Louisiana has been successful in maintaining the overall low level of pyrethroid resistance in early season. Avoiding the use of pyrethroids on cotton until July, a key component of this plan, allows the level of pyrethroid resistance to decrease as evidenced by the decrease in percent survival between seasons and during early season. Cotton producer compliance with the plan in Louisiana was estimated to about 95% in 1987 but only about 75% in 1988 and 1989.

The levels of resistance in August and September of 1989 were higher than that observed in 1987 (Table 2). The probable cause was that much of the 1988 and 1989 cotton crops did not mature until September or October whereas the majority of the 1987 crop matured in August. Thus, more pyrethroids were applied in August and September of 1988 and 1989.

In general, the occurrence of pyrethroid resistance followed a consistent pattern. High levels of resistance early in the year, probably due to emergence of overwintering resistant adults, were followed by a decrease in resistance levels during the time that the Mid-South Pyrethroid Resistance Management Plan recommended avoiding the use of pyrethroids. During the pyrethroid use period (from July to the end of the season), the level of pyrethroid resistance in tobacco budworms increased dramatically.

TABLE 1. Percent Survival[a] of Tobacco Budworm Male Moths at 10 µg of Cypermethrin per Vial by Location, Year, and Month (sample sizes are in parentheses).

Location (Parish)	Year	June	July	Aug.	Sept.
Bossier	1987	6(20)	31(320)	22(72)	19(430)
	1988	13(117)	36(87)	45(100)	40(40)
	1989	18(130)	40(68)	50(70)	45(20)
Caddo	1987	20(34)	9(100)	9(69)	--[b]
	1988	13(23)	15(40)	--	--
	1989	16(32)	38(50)	42(26)	--
E. Baton Rouge	1987	7(18)	0(38)	--	2(42)
	1988	--	--	4(25)	4(25)
	1989	--	--	0(6)	30(50)
Franklin	1987	17(104)	0(20)	11(196)	--
	1988	3(68)	7(70)	27(30)	27(20)
	1989	8(106)	9(106)	39(93)	55(65)
Morehouse	1987	--	--	--	16(40)
	1988	1(87)	17(208)	31(60)	30(20)
	1989	6(16)	30(27)	45(69)	--
Natchitoches	1987	--	--	9(48)	6(60)
	1988	2(59)	14(133)	34(80)	22(40)
	1989	10(62)	16(76)	45(66)	--
Rapides	1987	12(58)	5(55)	10(42)	4(55)
	1988	4(26)	3(60)	9(95)	25(20)
	1989	3(30)	24(50)	34(50)	19(16)
Richland	1987	16(60)	--	--	27(160)
	1988	0(14)	11(10)	--	47(20)
	1989	12(27)	15(20)	47(30)	--
Tensas	1987	3(60)	6(129)	15(244)	--
	1988	3(98)	8(196)	11(73)	20(20)
	1989	2(105)	7(362)	34(211)	35(20)

[a] Percent survival is an estimate of the percent homozygous pyrethoid-resistant males present.
[b] No tests were conducted.

Survival at the 10 µg/vial discriminating dose often exceeded 30% during August and September of 1988 and 1989 (Table 1). Therefore, some moths were tested at 30 µg/vial and these data are presented in Table 3. It has been suggested that survival of moths at 30 µg/vial may be a better indicator of a possible field resistance problem than survival at the 10 µg/vial dose. During 1988, there was only one instance in which survival at 30 µg/vial exceeded 10%. However during 1989, seven of nine bioassays resulted in survival exceeding 10%. Numerous field problems in controlling tobacco budworm occurred in 1989 while only a few problems were reported in 1988. Two factors occurred in 1989 that complicated the interpretation of these data. Tobacco budworm populations appeared to be higher and chlordimeform (a pyrethroid synergist and ovicide), an integral part of the Mid-South Pyrethroid Resistance Management Plan, was not generally available.

The responses of tobacco budworm moths to tralomethrin were compared with their responses to cypermethrin at 1, 5,

TABLE 2. Monthly Summary of Cypermethrin Resistance Monitoring Data Obtained Using a Discriminating Dose of 10 μg/vial.

Month	Year	Number Tested	Percent Survival[a]
May	1987	93	20
June	1987	354	13
July	1987	674	18
August	1987	699	12
September	1987	787	15
May	1988	186	12
June	1988	485	5
July	1988	804	14
August	1988	458	26
September	1988	281	30
May	1989	167	11
June	1989	575	9
July	1989	827	19
August	1989	762	40
September	1989	442	36

[a] Percent alive is an estimate of the % homozygous pyrethroid-resistant males present.

10, and 30 μg/vial doses in five parishes during late August and September of 1988 (Table 4). The responses to both pyrethroids were quite similar. Survival at the higher doses was low in East Baton Rouge Parish where no commercial cotton is grown and where pyrethroid use is low. Data from this location serve as baseline responses of tobacco budworm to both pyrethroids. Moths from Bossier, East Carroll, Franklin, and Natchitoches Parishes that exhibited high levels of resistance to cypermethrin also exhibited high levels of resistance to tralomethrin. These findings support previous data (Leonard et al. 1987b) obtained using a different bioassay (topical application to larvae) that indicate resistance to a pyrethroid confers cross-resistance to other pyrethroids.

The Mid-South Pyrethroid Resistance Management Plan recommended by the Cooperative Extension Services of Arkansas, Louisiana and Mississippi was designed to delay development of resistance in tobacco budworms by: (1) avoiding the use of pyrethroids against any cotton pests until July; (2) using ovicides during periods of heavy oviposition by tobacco budworm and bollworm; and (3) using pyrethroid-synergist mixtures (Anonymous 1986). All of these approaches should conserve susceptibility to pyrethroids.

Almost unanimous adoption of the pyrethroid resistance management plan by Louisiana cotton producers during 1987 was successful in helping reduce the number of pyrethroid resistant tobacco budworms by at least 50% in comparison with 1986 data (Graves et al. 1988). Furthermore, there were no documented tobacco budworm control failures with pyrethroids during 1987. This is in contrast to numerous reports of control failures during 1986, several of which were documented by laboratory bioassays as being due to pyrethroid resistance

TABLE 3. Percent Survival of Tobacco Budworm Male Moths at 30 μg of Cypermethrin per Vial by Location, Year, and Moth (sample sizes are in parentheses).

Location (Parish)	Year	August	September
Bossier	1988	9(100)	21(58)
	1989	33(70)	15(20)
East Baton Rouge	1988	--[a]	0(5)
	1989	--	5(20)
Franklin	1988	5(20)	0(20)
	1989	6(50)	29(65)
Morehouse	1988	10(60)	10(20)
	1989	11(9)	--
Natchitoches	1988	8(40)	6(20)
	1989	12(50)	--
Richland	1988	--	5(20)
	1989	20(30)	--
Tensas	1988	0(35)	0(20)
	1989	4(103)	20(20)

[a] No tests were conducted.

TABLE 4. Responses of Tobacco Budworm Male Moths Collected During 1988 to Tralomethrin and Cypermethrin.

Location (Parish)	Date	Percent Survival[a]			
		1	5	10	30
		(Dose in μg/vial)			
			Tralomethrin		
Natchitoches	8/30	74	37	37	--[b]
E. Baton Rouge	9/1	35	6	0	0
Bossier	9/15	90	50	40	5
	9/21	80	35	15	20
Franklin	9/23	42	32	21	0
East Carroll	9/23	65	35	20	0
Bossier	9/28	58	26	21	5
			Cypermethrin		
Natchitoches	8/30	80	75	34	8
E. Baton Rouge	8/30	69	13	4	--
Bossier	9/15	85	45	40	15
	9/21	85	30	40	33
Franklin	9/22	80	47	27	0
East Carroll	9/23	78	56	44	6
Bossier	9/28	81	31	12	12

[a] Twenty moths per dose on each date.
[b] No tests were conducted.

(Leonard et al. 1987a). However, it must be noted that tobacco budworm infestation levels in cotton during 1987 were much lower than in 1986, particularly during the critical months of July and August.

A later maturing cotton crop in 1988 in comparison with

1987 resulted in much greater use of pyrethroids in August and September of 1988. The consequence was that the level of pyrethroid resistance in August and September of 1988 increased above the level observed in 1987.

During 1989, inclement weather during the planting season resulted in part of the cotton crop being planted in late May. As a result, pyrethroids were again used during late August and September. Higher populations of tobacco budworms in late July and early August required extensive use of pyrethroids. Less than satisfactory control was observed in many fields, but in only a few fields was control unacceptable. Mixing organophosphates, carbamates or formamidines with pyrethroids improved efficacy. In some instances, cotton producers used larvicidal rates of organophosphates or carbamates rather than pyrethroids. The higher levels of pyrethroid resistance observed in July, August and September of 1989 as compared with 1987 and 1988, in conjunction with the numerous field control problems experienced in 1989, suggest that more restrictions should be placed on use of pyrethroids if their efficacy against tobacco budworm is to be maintained. In response to these alarming developments, the Mid-South Pyrethroid Resistance Management Plan was modified for 1990 to recommend that pyrethroids be used only during the period from 1 July to 15 August. Alternatives to pyrethroids include acephate, profenofos, sulprofos and thiodicarb. Hopefully, avoiding the use of pyrethroids late in the season as well as early season will prolong the usefulness of these chemicals.

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LITERATURE CITED

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18:265-267.

Allen, C. T., W. L. Mueter, R. R. Minzemayer, and J. S. Armstrong. 1987. Development of pyrethroid resistance in Heliothis populations in cotton in Texas, pp. 332-335. In: Proc. Beltwide Cotton Prod. Res. Conf. Nat. Cotton Council, Memphis, Tenn.

Anonymous. 1986. Cotton entomologists seek to delay pyrethroid resistance in insects. MAFES Res. Highlights. 49(12):8.

Campanhola, C., and F. W. Plapp, Jr. 1987. Toxicity of pyrethroids and other insecticides against susceptible and resistant tobacco budworm larvae and synergism by

chlordimeform. pp. 326-329. In: Proc. Beltwide Cotton Prod. Res. Conf. Nat. Cotton Council, Memphis, Tenn.
Crowder, L. A., M. S. Toellfson, and T. F. Watson. 1979. Dosage-mortality studies of synthetic pyrethroids and methyl-parathion on the tobacco budworm in Central Arizona. J. Econ. Entomol. 72:1-3.
Crowder, L. A., M. P. Jensen, and T. F. Watson. 1984. Permethrin resistance in the tobacco budworm, Heliothis virescens. pp. 229-231. In: Proc. Beltwide Cotton Prod. Res. Conf. Nat. Cotton Council, Memphis, Tenn.
Davis, J. W., D. A. Wolfenbarger, and J. A. Harding. 1977. Activity of several synthetic pyrethroids against the boll weevil and Heliothis spp. Southwest. Entomol. 2:164-169.
Elliott, M., A. W. Farnham, N. F. James, P. H. Needham, D. A. Pulman, and J. H. Stevenson. 1973. A photostable pyrethroid. Nature. 246:169-170.
Elliott, M., A. W. Farnham, N. F. James, P. H. Needham, and D. A. Pulman. 1974. Synthetic insecticide with a new order of activity. Nature. 248:710-711.
Elliott, M. 1976. Properties and applications of pyrethroids. Environ. Health Perspectives. 14:3-13.
Graves, J. B., B. R. Leonard, A. M. Pavloff, G. Burris, K. Ratchford, and S. Micinski. 1988. Monitoring pyrethroid resistance in tobacco budworm in Louisiana during 1987: resistance management implications. J. Agric. Entomol. 5:109-115.
Harding, J. A., F. R. Huffman, D. A. Wolfenbarger, and J. W. Davis. 1977. Insecticidal activity of alpha-cyano-3-phenoxybenzyl pyrethroids against the boll weevil and tobacco budworm. Southwest. Entomol. 2:42-45.
Hartstack, A. W., J. A. Witz, and D. R. Buck. 1979. Moth traps for the tobacco budworm. J. Econ. Entomol. 72:519-522.
Hendricks, D. E., T. N. Shaver, and J. L. Goodenough. 1987. Development of bioassay of molded polyvinyl chloride substrates for dispensing tobacco budworm (Lepidoptera: Noctuidae) sex pheromone bait formulations. Environ. Entomol. 16:605-613.
Herzog, G. A., and R. J. Ottens. 1982. Dosage-response analysis for methyl parathion, methomyl and permethrin on the tobacco budworm and bollworm (Lepidoptera: Noctuidae) in Georgia. J. Econ. Entomol. 75:961-963.
Leonard, B. R., J. B. Graves, T. C. Sparks, and A. M. Pavloff. 1987a. Susceptibility of bollworm and tobacco budworm larvae to pyrethroid and organophosphate insecticides. pp. 320-324. In: Proc. Beltwide Cotton Prod. Res. Conf. Nat. Cotton Council, Memphis, Tenn.
Leonard, B. R., T. C. Sparks, and J. B. Graves. 1987b. Insecticide cross-resistance in pyrethroid-resistant strains of tobacco budworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 81:1529-1535.
Martinez-Carrillo, J. L., and H. T. Reynolds. 1983. Dosage mortality studies with pyrethroids and other insecticides on the tobacco budworm (Lepidoptera: Noctuidae) from the Imperial Valley, California. J. Econ. Entomol. 76:983-986.
Palazzo, R. J. 1978. Comparison of the responses of adults and larvae of five lepidopteran species to seven

insecticides. M.S. Thesis. Louisiana State Univ., Baton Rouge. 81 pp.

Payne, G. T. 1987. Inheritance and mechanisms of permethrin resistance in the tobacco budworm, Heliothis virescens (Lepidoptera: Noctuidae). Ph.D. Dissertation, Clemson Univ., 103 pp.

Pieters, E. P. 1979. Effectiveness of new insecticides against cotton pests, especially Heliothis spp. p. 118. In: Proc. Beltwide Cotton Prod. Res. Conf. Nat. Cotton Council, Memphis, Tenn.

Plapp, F. W. 1981. Toxicity of synthetic pyrethroids to laboratory and field populations of the tobacco budworm in central Texas. J. Econ. Entomol. 74:207-209.

Plapp, F. W. 1987. Managing resistance to synthetic pyrethroids in the tobacco budworm. pp. 224-226. In: Proc. Beltwide Cotton Prod. Res. Conf. Nat. Cotton Council, Memphis, Tenn.

Plapp, F. W., and C. Campanhola. 1986. Synergism of pyrethroids by chlordimeform against susceptible and resistant Heliothis. pp. 167-169. In: Proc. Beltwide Cotton Res. Conf. Nat. Cotton Council, Memphis, Tenn.

Plapp, F. W., G. M. McWhorter, and W. H. Vance. 1987. Monitoring for pyrethroid resistance in the tobacco budworm. pp. 324-326. In: Proc. Beltwide Cotton Prod. Res. Conf. Nat. Cotton Council, Memphis, Tenn.

Roush, R. T., and R, G. Luttrell. 1987. The phenotypic expression of pyrethroid resistance in Heliothis and implications for resistance management. pp. 220-224. In: Proc. Beltwide Cotton Prod. Res. Conf. Nat. Cotton Council, Memphis, Tenn.

Twine, P. H., and H. T. Reynolds. 1980. Relative susceptibility and resistance of the tobacco budworm to methyl parathion and synthetic pyrethroids in Southern California. J. Econ. Entomol. 58:525-526.