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HISTORY AND DEFINITION OF RESISTANCE OF CYPERMETHRIN AND OTHER PYRETHROIDS AGAINST THE TOBACCO BUDWORM FROM FIELD EXPERIMENTS IN TEXAS

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Abstract

From 1974 to 1981 field tests in lower Rio Grande valley (LRGV) "island" of TX showed resistance to cyfluthrin [Baythroid], cypermethrin [Ammo] and tralomethrin [Scout] and susceptibility to deltamethrin [Decis] by the tobacco budworm, *Heliothis virescens* (F.), (TBW). Resistance was indicated when <80% control was determined. TBW was resistant to esfenvalerate [Asana], cypermethrin and cyfluthrin in 1985 in the trans-Pecos "island". TBW was resistant to *lambda* cyhalothrin [Karate] and cyfluthrin in 2000-2001 in the lower coastal bend "island". In 1989 and 1990, from field tests in the Brazos valley, cypermethrin controlled >85% of larval populations of TBW season long. Populations were susceptible. In 1986 and 2001 esfenvalerate showed >80% control of TBW in the LRGV and lower coastal bend "island", respectively; populations were susceptible. Resistance or susceptibility to pyrethroids in field experiments conducted from 1974-1999 are the historical aspects of resistance while tests conducted in 2000-2001 indicate the active aspects of resistance or susceptibility of the populations across TX today. This is because the inherited resistance patterns of TBW populations in the 2000s may be completely different from those determined in earlier y in the same or different "islands". Moths can disperse from one "island" to another. Pyrethroids should be evaluated each y in each "island" where high populations of TBW are found. From 1974 to 2001, when the last field test was conducted, cross resistance of TBW populations to the eight pyrethroids was not shown.

Introduction

In 2000 the Texas Agricultural Cooperative Extension Service and the Texas Agricultural Experiment Station of TX removed the eight pyrethroids from the list of suggested insecticides for use against the TBW on cotton (Norman and Sparks 2000). The suggested pyrethroid insecticides include bifenthrin [Capture], cyfluthrin, cypermethrin, deltamethrin, esfenvalerate, *lambda* cyhalothrin, tralomethrin and the old zeta cypermethrin [Fury]. TBW has been present in <2% of the cotton fields in the "islands" of TX each y for the past decade. For every 1000 fields <20 can have high populations of TBW. Fields, in subtropical and temperate climates, vary greatly in size and cotton production capabilities.

Documented information on the efficacy of each pyrethroid is necessary before they can be included or removed from the suggested list of insecticides. Since 1981 no information has been found from field tests on efficacy of TBW populations with bifenthrin, deltamethrin, permethrin (Pounce), tralomethrin and the old and new zeta cypermethrin (Mustang Max) against TBW in TX. From 1981 to 2001 field tests were conducted with cypermethrin in the LRGV, trans Pecos, and the Brazos valley (Wolfenbarger and Harding 1982, Allen et al. 1987 and Wolfenbarger et al. 1991), esfenvalerate in the trans Pecos, LRGV and lower coastal bend (Allen et al. 1987, Wolfenbarger et al. 1989 and Parker 2002), cyfluthrin in the trans Pecos (Allen et al. 1987 and Multer unpublished) and the lower coastal bend (Parker 2002) and *lambda* cyhalothrin in the lower coastal bend (Parker 2002) "island", respectively. Only four of the eight pyrethroids suggested for use have been evaluated in TX up to 1999.

The most widely accepted hypothesis for resistance by the TBW to pyrethroid insecticides is offered by Miller [1996). He suggests that resistance is exhibited first in scattered fields in each "island" across TX. This occurred in 1985 in the trans Pecos "island" (Allen et al. 1987). Fields with high populations of TBW and damage levels are supposed to have occurred to the late 1980s until the majority of the fields in the different "islands" exhibit economic damage. This has not been determined. Resistance cannot be shown in TX when field trials exhibit loss of control in only one or two "islands".

Cross resistance by strains to the suggested pyrethroids has not been shown in field tests in TX from 1974 to 2001. In my opinion removal of all the suggested pyrethroids was not justified because (1) cross resistance was not been shown by the eight pyrethroids in the "islands" across TX and (2) data for cypermethrin showed resistance (Allen et al. 1987) and susceptibility (Wolfenbarger et al. 1991) by the TBW. Efficacy of cypermethrin were determined in different "islands" and y. TBW can disperse from one "island" to another "island" within a y or between y.

Field control failures were not considered to be a problem in the Brazos valley in 1988 and 1989 (Rogers et al. 1990). There may have been a reversion to susceptibility in those y compared to the resistance determined in the early 1980s. Resistance is supposed to have occurred in fields in the northern coastal plains "island" in 1986 and 1987, but the data to support this contention was not offered (Green and Hutchins 1993). They stated that the average number of applications of pyrethroid insecticides rose from 2-3 in 1986 to 5-8 at the highest labeled rates in 1987. Maybe the TBW populations in the fields were resistant or there were high populations of this insect. In 1992 the number of applications was about 10 and moth populations were predominately TBW all season (Green and Hutchins 1993). Again, field tests were not conducted against TBW showing that they survived applications of the pyrethroids in the northern coastal plains "island".

Cypermethrin was the standard pyrethroid designated by industry through PEG-US for use to monitor for resistance by TBW. In 1992 resistance to cypermethrin continued to be a consideration in the management of TBW in most "islands" (Plapp 1993). However, field tests were not part of the evaluation for resistance or susceptibility of TBW in the "islands" of TX.

Here, published and unpublished references on efficacy of pyrethroid insecticides against TBW in fields are summarized from 1974, the first y permethrin was evaluated, to 2001 when the last field test on efficacy was conducted in Texas. Tests conducted to 1999 were considered to be historical aspects, while those from 2000 indicate active aspects of resistance or susceptibility which could be present in the populations today. Some of the references used to remove the pyrethroids was obtained from C. C. Sansone, Area Extension Entomologist, Texas Agricultural Cooperative Extension Service, San Angelo, TX. These are identified by an asterisk in the references.

History of Field Control Tests Using Pyrethroids Against TBW Populations in TX ----1974 to 1999

Resistance is the inherited ability of populations of TBW to survive applications of a pyrethroid in a field. Resistance by the TBW to a pyrethroid in one field in one "island" does not mean there is resistance by field populations to all the other pyrethroids in the other "islands". The insecticides of the pyrethroid class were suggested for use from 1979, when permethrin was registered, to 2001 [Gage et al. 1991). Resistance is designated by control of damage to fruit or populations of TBW in cotton treated with a pyrethroid compared to populations in untreated cotton. Greater than 80% control was used as the resistance threshold to determine susceptible populations. Significant differences by statistical analysis was not considered.

In 1974 the mean percent control with permethrin at 0.2 kg{AI}/ha of larval feeding damage to fruit by TBW populations in two replicated field tests in the LRGV 'island' was 96% and 86%, respectively (Davis et al.1975]. The populations were susceptible. In 1975 control of 73% was achieved with permethrin following several applications at the same rate (Wolfenbarger et al. 1977). Populations were considered to be resistant.

In 1976 control of larval feeding damage for three tests with permethrin in the LRGV was 91% and 96% at Weslaco and 0% at Brownsville with 0.43, 0.43 and 0.11 kg (AI)/ha, respectively (Davis et al. 1977). For deltamethrin, in the same tests, control was 87%, and 0% at 0.022 and 0.011 kg (AI)/ha, respectively, to squares by populations which were >88% TBW. Resistance to permethrin and deltamethrin was determined for field populations from Brownsville, but not Weslaco, 60 km away, in the LRGV.

Percentage control of feeding damage to squares by populations of TBW with permethrin, at 0.056 kg (AI)/ha, were 48% and 42% in 1977 and 1978, respectively. At 0.11 kg (AI)/ha percent control with permethrin was 39%, 70%, 87% and 44% in 1977, 1978, 1979 and 1981, respectively (Wolfenbarger et al. 1982). Populations were susceptible in 1979, but resistant the other years. In 1977, in another test at Weslaco, permethrin and deltamethrin, at 0.11 and 0.022 kg (AI)/ha, respectively, showed 94% and 89% control, respectively, of damaged squares and bolls. In 1979 permethrin, at 0.11 kg (AI)/ha, showed 94% control of damaged squares and bolls at Weslaco (Wolfenbarger et al. 1982). Populations were susceptible to permethrin in these tests in 1977 and 1979. Populations of TBW were >80% in tests from 1977-1979 and 1981.

In 1981 cyfluthrin was tested at 0.014, 0.028 and 0.045 to 0.11 kg (AI)/ha and percentage control ranged from 44% to 47% in the LRGV (Wolfenbarger et al. 1982). All populations were resistant. That same y cypermethrIn was tested at 0.045, 0.067, 0.04 and 0.11 kg (AI)/ha; control was 48%, 61%, 73% and 69%, respectively and all the populations were resistant, Damaged squares were <70% in the untreated check. In 1977 and 1978 deltamethrin showed 81% control at 0.011 kg(AI)/ha and the populations were susceptible. In 1981 tralomethrin showed 47% and 60% control at 0.017 and 0.021 kg (AI)/ha. Populations were resistant. Damage by TBW infestations ranged from 88% to 100% in field plots in the LRGV from 1974 to 1981 (Davis et al. 1975 and 1977 and Wolfenbarger et al. 1982). One control value which indicates resistance by TBW in one field does not mean that resistance is present in all "islands".

In 1986, in the LRGV, damage by TBW to squares and bolls was reduced >80% with applications of esfenvalerate (Shell Development 43775) at 0.075 kg (AI)/ha (Wolfenbarger et al. 1989). Populations were susceptible and damage was controlled by this resolved isomer pyrethroid.

In the trans-Pecos "island" in west Texas in1985, Allen et al. (1987) showed 32%, 44% and 24% control of TBW with cypermethrin at 0.084 kg (AI)/ha, esfenvalerate at 0.028 kg (AI)/ha and cyfluthrin at 0.024 kg (AI)/ha, respectively; populations were >90% TBW during the test period. Populations were resistant and cross resistance to these three pyrethroids was indicated. In 1985 counties in the "islands" of cotton across TX showed "poorer than normal" and "control failures" with cypermethrin when control was <50% [Allen et al. 1987). In 1988 *lambda* cyhalothrin killed 92% of neonate larvae of TBW compared to the untreated check (Allen et al. 1989). These populations were susceptible.

Control of three d + older larvae of TBW with cypermethrin was 54%; control of larvae hatching 3-5 d after application was 94% (Multer unpublished). These results clearly show control of hatching larvae. This is an important result.

In 1985 Allen et al. [unpublished) showed 80 small larvae, 44 medium larvae and 101 large larvae in pretreatment counts in the check. Four d following the application of cypermethrin small larvae, medium larvae and large larvae were reduced 13%, 0% and 76%, respectively. Resistance was indicated.

In 1988 a management plan for pyrethroid resistance against TBW in a cotton field in the Brazos valley was evaluated (Bagwell et al. 1989). Experimental design included dividing the cotton growing season into early, mid and late season with different insecticides applied to the plots three times during the season. One treatment was cypermethrin alone which was applied all season. Cypermethrin was the only insecticide applied in mid-season. The population size of TBW was unknown in this test because no untreated check was used during the three parts of the season.

The field data offered by Bagwell et al. (1989) on pyrethroids did not define a resistance management plan against TBW in TX, but it was a first attempt (Wolfenbarger et al. 1991b). A plan for TX needs to be developed. No experimental design will define an effective management plan in the field unless immigration and emigration of moth populations, genetic and abiotic factors are taken into account (Wolfenbarger et al. 1991b). The definition of field resistance and an appropriate sampling scheme to access the efficacy of each pyrethroid with a resistance management system deserves more research.

In 1988-1989 control of TBW with cypermethrin was evident in the Brazos valley (Wolfenbarger et al.1991a). Populations of TBW throughout the test were 92%. Only susceptibility was shown. Control with cypermethrin was >80% of feeding damage by neonate through second instar larvae.

An examination of the timing of each of the applications indicates that they were made during periods of oviposition and hatch. The long residual life of cypermethrin killed the larvae as they eclosed. Control of TBW was enhanced when applications were made to neonate larvae [Allen et al. 1989, Gage et al. 1991 and Wolfenbarger et al.1991a). Based on this data both the author and Allen et al. (1987) suggest that cypermethrin and cyfluthrin can be used to control neonate larvae. No reference on field control tests in TX was shown from 1991 to 1999.

<u>Field Tests for Resistance and Susceptibility of TBW Populations with Pyrethroids in TX---2000 to Present</u>

Damage to squares by predominately TBW populations was reduced 43% and 82% two and five d following applications of *lambda* cyhalothrin and esfenvalerate at >0.036 kg (AI)/ha in 2000 and 2001, respectively, in the lower coastal bend "island" (Parker 2002). Resistance by the TBW to *lambda* cyhalothrin was evident in 2000 and cyfluthrin, in combination with imidacloprid, in 2000 and 2001. Esfenvalerate provided control of the TBW in 2001. Cross resistance by esfenvalerate, *lambda* cyhalothrin and cyfluthrin in the lower coastal bend "island" is not shown because 67% of the pyrethroids tested were determined to be resistant. This is the last field test with pyrethroids conducted in TX. Author suggests that all previous field tests in TX are only the history of resistance by pyrethroids. Since 2000 it is unknown what the resistance levels are in the other "islands".

Resistance to the eight pyrethroids listed as suggested insecticides against the TBW is not an all or none phenomena in the "islands" of TX. Certain pyrethroids are more effective against larvae in one "island" than to larvae in another "island". The pyrethroids that are the most toxic, based on doses for 50% mortality, have the greatest capability to control larvae of the different strains in TX. This means that resistance among the strains of TBW in cotton fields across TX is variable and even larvae of each strain do not react similarly to each pyrethroid.

It is unknown what populations of TBW are resistant or susceptible to the old or new zeta cypermethrin, esfenvalerate and deltamethrin in the LRGV, southern coastal bend, the Brazos valley, the trans Pecos and the winter garden "islands" since 2000. These five "islands" probably have the greatest populations of TBW each y in TX. These pyrethroids are probably the most effective of the eight suggested for use against the TBW.

<u>Discussion</u>

What level of field control is needed to estimate resistance or susceptibility of a pyrethroid to TBW in each "island"? Should field control for each pyrethroid be >80% for larval populations or damage levels following each application, as proposed by Sansone (personal communication). Yes, it should. An untreated check with species identification should always be used in the experimental design of a field control test. Resistance is indicated if <80% control is determined following two to five applications of a pyrethroid. Population size or damage level should be high in the experimental area. Does the percent of fruit damaged or larval populations reflect control better than any other criteria? Both can be used to determine whether the population is resistant or susceptible. Field control experiments should be conducted against the TBW in most "islands" of TX with each pyrethroid before this class of insecticides is removed from usage. Larval populations or damage levels of fruit need to be high enough and last long enough in cotton fields to give a true evaluation of larval response.

In TX if TBW larvae were collected in a field, bioassayed immediately 10 µg/new zeta cypermethrin, esfenvalerate or deltamethrin all died before 72 h, the population would be susceptible. These results could serve as guidelines to identify resistance or susceptibility by TBW populations in the "islands" of TX.

Based on DNA analysis >51% of the TBW moths are more similar within an 8 km radius compared to those outside the radius (Korman et al. 1993). This means that 49% of the moths could disperse from one "island" to another and can carry genes for resistance. Author suggests that most of the populations of TBW in most fields across TX are susceptible to the three pyrethroids listed above. The population of TBW may vary in each field in any "island" depending on temperatures and wind movements.

TBW appeared in large numbers in 75% of the years that "El Nino" winds were over the LRGV [Norman et al. 1993). Populations of TBW in the LRGV "island" were high in 1977, 1987 and 1992 when "El Nino" was present In 1983, "El Nino" was present, but the populations were light (Norman et al. 1993).

Field tests have to be the cornerstone to indicate resistance by larvae of the TBW to each pyrethroid in each of the "island" (Wolfenbarger et al. 1991b). Pretreatment counts or high damage to squares before the first application will reflect the size of the populations (Allen et al. 1987). Replicated plots do not need to exceed two rows of cotton 15 m in length but they do have to have high populations of eggs and larvae must be present for three to five weeks. If populations of three sizes of larvae are taken two to three times following each application an estimate of control or lack of control can be determined [Allen et al. 1987).

The most practical way to prevent resistance to pyrethroids in the field is to make no applications until absolutely necessary [Mallet and Luttrell 1991). This is the correct philosophy but it requires sampling eggs and neonate larval populations in each field at 2 to 5 d intervals season long.

It is often difficult to really determine whether there is or is not a field control failure of TBW in any population in every field and "island" (Huffman et al. 1995). Producers need to know the egg hatch and relative size of larvae in each of their fields. The count would reflect sizes of populations 24 h pre and post d of each application. This sampling would determine a declining or increasing population.

A complex set of ecological or biological factors affect control or failure to control TBW in the field whether resistance is present or not (Huffman et al. 1995). Effective control in a given field may be obtained when there are populations of susceptible insects or low populations of resistant TBW. Alternately, field control failures may occur when there are high or persistent populations of resistant TBW, predominately large instars of larvae or low use rates of the pyrethroid. The results of field efficacy tests in TX from 2000-2001 on response of TBW are similar to those determined from 1974 to the 1990s. There is great variation for response to the different pyrethroids in fields in each "island". One generation of TBW requires about 30 d so different levels of resistance and susceptibility can change in each field each y.

Conclusion

Field tests with all the pyrethroid insecticides need to be conducted against TBW each y in as many "islands" as possible to determine their resistance and susceptibility. Neonate or first stage larvae should be the target stage to control. Field tests in the LRGV from 1974 to 2001 show both resistance and susceptibility by populations of TBW to bifenthrin, cypermethrin, cyfluthrin, deltamethrin, *lambda* cyhalothrin, permethrin and tralomethrin. Cross resistance to pyrethroids by field populations of TBW in the "islands" has not been shown.

Any insecticide or class of insecticides should be thoroughly tested and evaluated before being placed on the list of insecticides suggested for use in TX. An insecticide or class of insecticides should not be dropped from the suggested list without a valid reason and adequate data to support the decision.

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