# FINAL REPORT

**The Testing of Hypotheses About the Evolution of Resistance to the Synthetic Pyrethroids in *Helicoverpa armigera.***

**DAN 36L**

---

## Summary

The use of pyrethroid insecticides on *Helicoverpa armigera* susceptible crops has been restricted to only 6 weeks each summer since 1983, when resistance to pyrethroids was diagnosed. The long term management of resistance in *H.armigera* is based on the hypothesis that after pyrethroid spraying ceases, resistance will decrease, partly due to dilution by susceptible immigrants from unsprayed refugia. The long term liability of the strategy will be favoured by the refugia remaining uncontaminated by resistant *H.armigera.* Sucess of the strategy will be enhanced if resistant individuals have a higher overwintering mortality than susceptibles.

Project DAN 36 L aimed to test these assumptions by determining the frequency of pyrethroid resistant *H.armigera* from areas where insecticide use was infrequent and to test the resistance status of the overwintering and spring populations of *H.armigera* . This project was a colaborative effort between researchers from NSW Agriculture & Fisheries and CSIRO Division of Entomology. Findings are summarised below.

The frequency of pyrethroid resistant *H.armigera* from unsprayed crops in NSW, some 300 - 400 km from the Namoi Valley, was monitored from 1983/84 - 1989/90 and showed a substantial rate of resistance contamination of the susceptible populations. Resistant individuals were distributed throughout the unsprayed populations sampled, apparently at little or no selective disadvantage. An unsprayed site at Inverell, which was 50 - 100 km from the intensively sprayed cotton areas, was also sampled and results indicated a declining effectiveness of the refugia as a source of susceptibles for the dilution of pyrethroid resistance.

Overwintering populations of *H.armigera* in the Namoi Valley had a high frequency of resistance to pyrethroids. But lower resistance frequencies were observed in spring populations, the spring populations appeared to be a result of populations from areas with lower levels of resistance than the Namoi Valley.

# COTTON RESEARCH AND DEVELOPMENT CORPORATION

---

**Final Report - Project DAN 36L**

# THE TESTING OF HYPOTHESES ABOUT THE EVOLUTION OF RESISTANCE TO SYNTHETIC PYRETHROIDS IN *HELICOVERPA ARMIGERA*

---

**Field of Research:** Crop and environment protection  Field Code: 1.1

**Organisation :** NSW Agriculture & Fisheries

Administrative Contact: Mr. G. Denney, Professional Officer (Industry Funds)

Telephone : 063-616119  Facsimile : 063-629059

Postal Address : PMB 21 Orange South, NSW. 2800

**Project Supervisor:** Dr. R.V. Gunning

Position in organisation : Senior Entomologist

Telephone : 067-641428  Fascimile : 067-679370

Postal Address : Agricultural Research Centre, RMB 944, Tamworth, NSW. 2340

**Research Staff:**

Dr. R.V. Gunning, B.A., B.Sc.(Hons.), Ph.D.
Agricultural Research Centre, RMB 944,
Tamworth, NSW. 2340

Mr. N.W. Forrester, B. Agr. Sci (Hons).
Agricultural Research Station, PMB Narrabri,
NSW. 2390.

Dr. J. Daly, B.Sc.(Hons)., Ph.D.
CSIRO, Division of Entomology,
PO Box 1700, Canberra ACT. 2601

# FINAL REPORT

**The Testing of Hypotheses About the Evolution of Resistance to the Synthetic Pyrethroids in *Helicoverpa armigera*.**

**DAN 36L**

**CONTENTS** **PAGE**

**The Testing of Hypotheses About the Evolution of Resistance to the Synthetic Pyrethroids in *Helicoverpa armigera.***

**DAN 36L**

---

## Introduction

The use of pyrethroid insecticides on *Helicoverpa armigera* susceptible crops has been restricted to only 6 weeks each summer since 1983, when resistance to pyrethroids was diagnosed. The long term management of resistance in *H.armigera* is based on the hypothesis that after pyrethroid spraying ceases, resistance will decrease, partly due to dilution by susceptible immigrants from unsprayed refugia. The long term liability of the strategy will be favoured by the refugia remaining uncontaminated by resistant *H.armigera.* Sucess of the strategy will be enhanced if resistant individuals have a higher overwintering mortality than susceptibles.

The aims of this project were then, to test these two assumptions:

1. To determine the frequency of pyrethroid resistant *H.armigera* from areas where insecticide use is infrequent. This study was undertaken by Dr. Gunning and Mr. Forrester

2. To determine the resistance status of overwintering moths and of the first spring generation in the Namoi Valley. This work was conducted by Dr. Daly and Dr Fitt.

# FINAL REPORT

**Pyrethroid resistance in *H.armigera* from unsprayed crops in New South Wales.**

(July 1987 - June 1990)

Dr Robin Gunning, NSW Agriculture & Fisheris, Tamworth, NSW.

**DAN 36 L**

---

## Staff

Dr. R.V. Gunning, B.A., B.Sc.(Hons.), Ph.D., Senior Entomologist.
Ms. M.E. Balfe, Assistant (Entomology).
Mr. R.V. Hall, Assistant (Entomology)
Miss N.A Coleman, Casual Assistant

## Introduction

*Helicoverpa armigera*, the cotton bollworm is a serious pest of cotton in Australia and insecticides are regularly used for its control. Pyrethroid insecticides were sucessfully used to control *H. armigera* on cotton from 1978 to 1982. In early 1983, following field failures at Emerald, pyrethroid resistance in *H. armigera* was diagnosed (Gunning *et al.* 1984). At this time resistance in was shown in *H. armigera* from summer crops sprayed with pyrethroids; however collections of non-sprayed *H. armigera* populations showed negliable resistance In response to this resistance problem, an insecticide resistance management strategy to restrict pyrethroid use on *H. armigera* was initiated.

The long term management of pyrethroid resistance in *H.armigera* is based on the assumption that each season, after pyrethroid spraying ceases, resistance levels will drop, because of dilution by immigration and, breeding with the majority of susceptible *H.armigera* in non sprayed populations. At the time of the initiation of the *Heliothis* resistance management strategy, there was a need to demonstrate, particularly as *H. armigera* have a confirmed capacity for long range movement, that any increase in resistance was limited to crops sprayed with pyrethroids. An increase in resistance in non-sprayed populations could eventually lead to a consistently high level of resistance in cotton areas. This report details the results of a pyrethroid resistance survey on *H. armigera* collected from unsprayed crops from 1983 to 1990 (Gunning and Easton,1989).

## Methods

Maize is very attractive to *H. armigera* and is grown in as cattle fodder in dairying areas of NSW remote from cotton growing. Maize used for this purpose is rarely, if ever, sprayed with insecticides and provides a source of unsprayed populations of *H. armigera.* Over the 7 seasons of this resistance survey, *H. armigera* were collected from maize sites in districts some 300-400 Km from the Namio Gwydir irrigation areas in NSW. The districts and sampling sites (Fig. 1) were: North Coast (Murwillumbah, Lismore, Tenterfield, McLean, Grafton), Central Coast (Bellingen, Kempsey, Port Macquarie, Taree), Central West (Merriwa, Mudgee, Dubbo) and New England (Armidale, Tamworth). Each district was visited during stages 1, 2 and 3 of the *Helicoverpa* resistance management season. Some 50-100 *H. armigera* were collected at each site and bred in the laboratory for the collections 1983 to 1986/87 . A rapid pyrethroid resistance screening method was used on the 1st lab generation. This method (Gunning *et al.* 1984) was based on a discriminating dose of 0.125 µg of fenvalerate on 30 - 40 mg larvae, which resulted in greater than 99% mortality of susceptibles. In 1987/88. 1988/89 and 1989/90, *H. armigera* eggs and small larvae only were collected. These field insects were directly bioassayed for pyrethroid resistance as described above. The percentage of pyrethroid resistant larvae for each *H. armigera* sample was calculated from the survival data. results were pooled across sites to produce the mean percent resistances for stages 1, 2 and 3 of each year.

## Results

The average levels of pyrethroid resistance in *H. armigera* collected from each stage and year of the survey are shown in Fig. 1 Initially, the resistance levels were low, during 1983/84 3 - 15% and in 1984/85 15 - 18% and some *H. armigera* populations were fully susceptible to pyrethroids. However in 1985/86 there followed a loss of susceptibility, pyrethroid resistance frequency increased considerably throughout the season to peak at 45% in stage 3. In the two following seasons (1986/87, 1987/88), resistance frequencies remained stable at approximately 40 % throught the seasons, suggesting some self regulation of resistance levels. However, data for 1988/89 and 1989/90, show evidence of further increasing resistance frequencies, (to over 50%).

There were no obvious anomalies between resistance frequencies derived from the $F_1$ lab generation of field collected material (1983/84 to 1986/87) and those derived directly from field *H. armigera.* Either collection technique is considered suitable for accurate resistance monitoring in *H. armigera,* producing comparable data.

## Discussion

The implications of the survey results for the long term management of pyrethroid resistance in *H. armigera* are serious, given the present rate of contamination of susceptible populations. For two years, following the introduction of the *Helicoverpa* resistance management strategy resistance frequencies of unsprayed insects were low, but since then there has been an inexorable loss of susceptibility.

The long term management of *H. armigera* resistance has been based on the assumption that limited insecticide use will preserve some susceptibity allowing some resistance dilution/reversion, which will allow levels to fall by the start of the next spraying season. Forrester has shown that this has occurred with fenvalerate resistance in sprayed *H.armigera* populations every year so far since the onset of the strategy, despite a continual loss of susceptibility (Fig.2). The yearly resistance dilution or reversion is probably not sufficient to last indefinitly because our data show that there is a high degree of pyrethroid, methomyl and endosulfan (CRC Final Report DAN 33L) resistance contamination in the refugia that we have sampled in NSW. Endosulfan, methomyl and pyrethroid resistants are distributed throught these unsprayed populations in NSW, apparently at little or no selective disadvantage.

Daly and Gregg, who studied genetic variation of *H. armigera* in Australia, concluded that individuals over regions formed a large common gene pool and that the effective size of the resultant populations was very large. Their data suggested that given suitable conditions, *H. armigera* could disperse over long distances, facilitating gene flow. Our data certainly showed that resistant individuals appeared to have dispersed widely.

If the present management practicies are maintained, there are several factors which will influence the ultimate resistance frequencies of *H. armigera.* Increasing resistance will depend on pyrethroid use and the relative fitness of resistant individuals. Resistant individuals are normally asumed to be at a selective disadvantage in the absence of pesticides, however from this study it seemed that pyrethroid resistant *H. armigera* are not disadvantaged relative to susceptibles.An agronomic factor which will limit the rate of increase of pyrethroid resistant *H. armigera* is the fact that growers will not use pyrethroid compounds unless effective control is guaranteed, thus limiting pyrethroid selection pressure.

Figure 1. Sampling sites of non-sprayed *H. armigera*

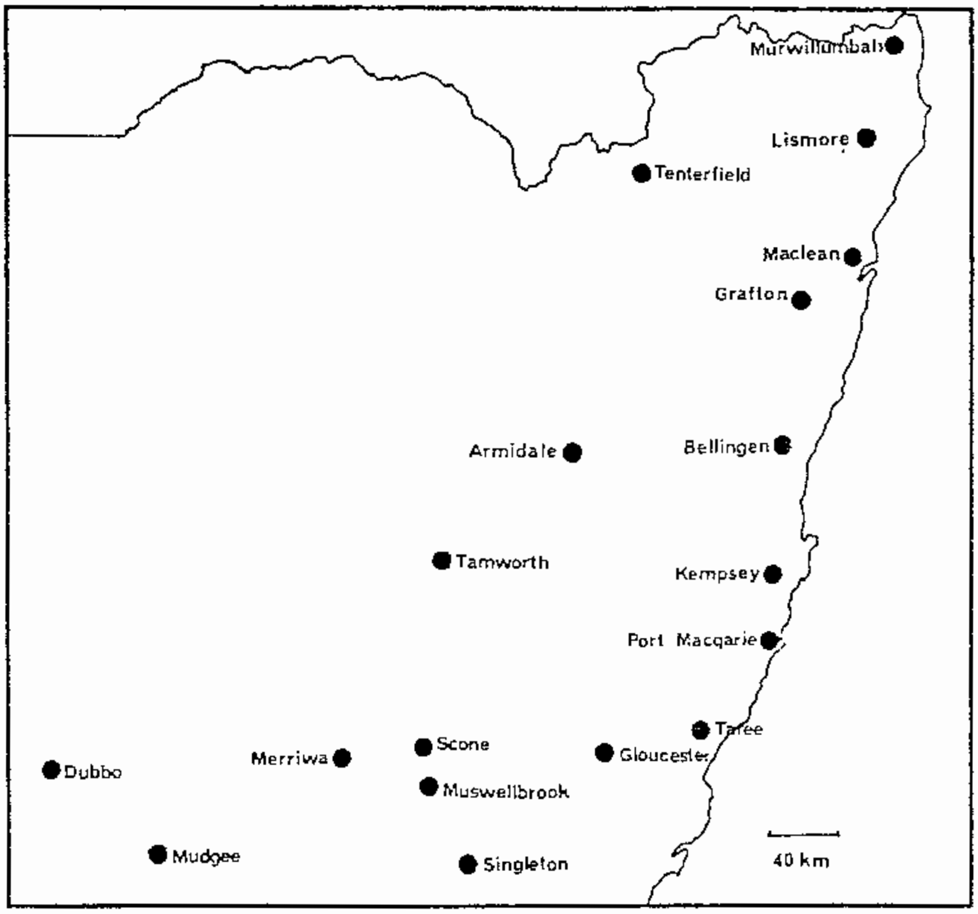
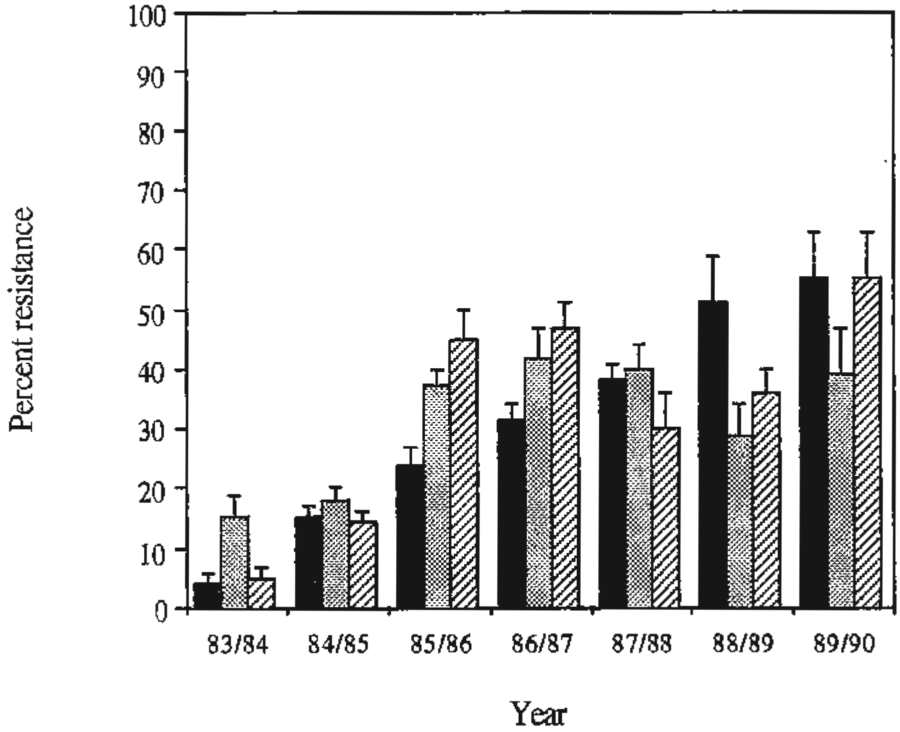


Fig. 2 - Pyrethroid resistance in *H. armigera* larvae collected from non-sprayed crops in NSW 1983 - 1990. Vertical bars represent standard errors. Pyrethroid resistance indicated by survival of a discriminating dose of 0.125 μg fenvalerate per 30-40 mg larva. Stage 1 ■ , Stage 2 ▒ Stage 3 ▨



## References

### Publications

Gunning, R.V., Easton, C.S., Greenup, L.R. and Edge, V.E. (1984) - Pyrethroid resistance in *Heliothis armigera* (Hubner) (Lepidoptera : Noctuidae) in Australia. *J. econ. Ent.* **77**: 1283-1287.

Gunning, R. V. and Easton, C.S. (1987) - Inheritance of resistance to fenvalerate in *Heliothis armigera* (Hubner) (Lepidoptera : Noctuidae). *J. Aust. ent. Soc.* **26**: 249-250.

Gunning, R.V. and Easton, C.S. (1989) - Pyrethroid resistance in *Heliothis armigera* (Hubner) collected from unsprayed maize crops in New South Wales 1983- 1987. *Journal of the Australian Entomological Society* **28**: 57-61.

Gunning, R.V., Forrester, N.W. Easton, C.S. and Greenup L.R. ( 1990) - Relationship between DDT and pyrethroid resistance in *Heliothis armigera* (Hubner) (Lepidoptera :Noctuidae) in Australia *Tropical Pest Management* **36**: 293-298.

### Conference proceedings

Gunning, R.V. (1988) - Pyrethroid resistance in *H. armigera* collected from unsprayed crops in NSW. *19 th Scientific Conference, Australian Entomological Society,* Brisbane, Q.

Gunning, R.V. (1988) - Pyrethroid resistance in *Heliothis armigera* from unsprayed crops in New South Wales 1983-1988. *Australian Cotton Conference,* Surfers Paradise, Q. pp. 55-60

## Pyrethroid resistance in *H.armigera* from unsprayed crops in Inverell.

Mr. Neil Forrester, NSW Agriculture & Fisheries, Narrabri, NSW.

**DAN 36L**

---

Pyrethroid and endosulfan resistance monitoring has been carried out at Inverell for the past three seasons (Table 1, Fig 3). Pyrethroid resistance levels at the start of the season (Stage 1) have increased to similar levels as those found in the sprayed Namoi/Gwydir cotton area. Stage II and III levels match fairly closely the same pattern as for the Namoi Gwydir but at a lower level. Endosulfan resistance at Inverell remains low and relatively constant throughout the season and does not reflect closely the increases recorded in the nearby Namoi/Gwydir study area. This may be because endosulfan is not considered to posess the irritant and repellent properties of the pyrethroid insecticides which promote effective dispersal of pyrethroid resistant moths.

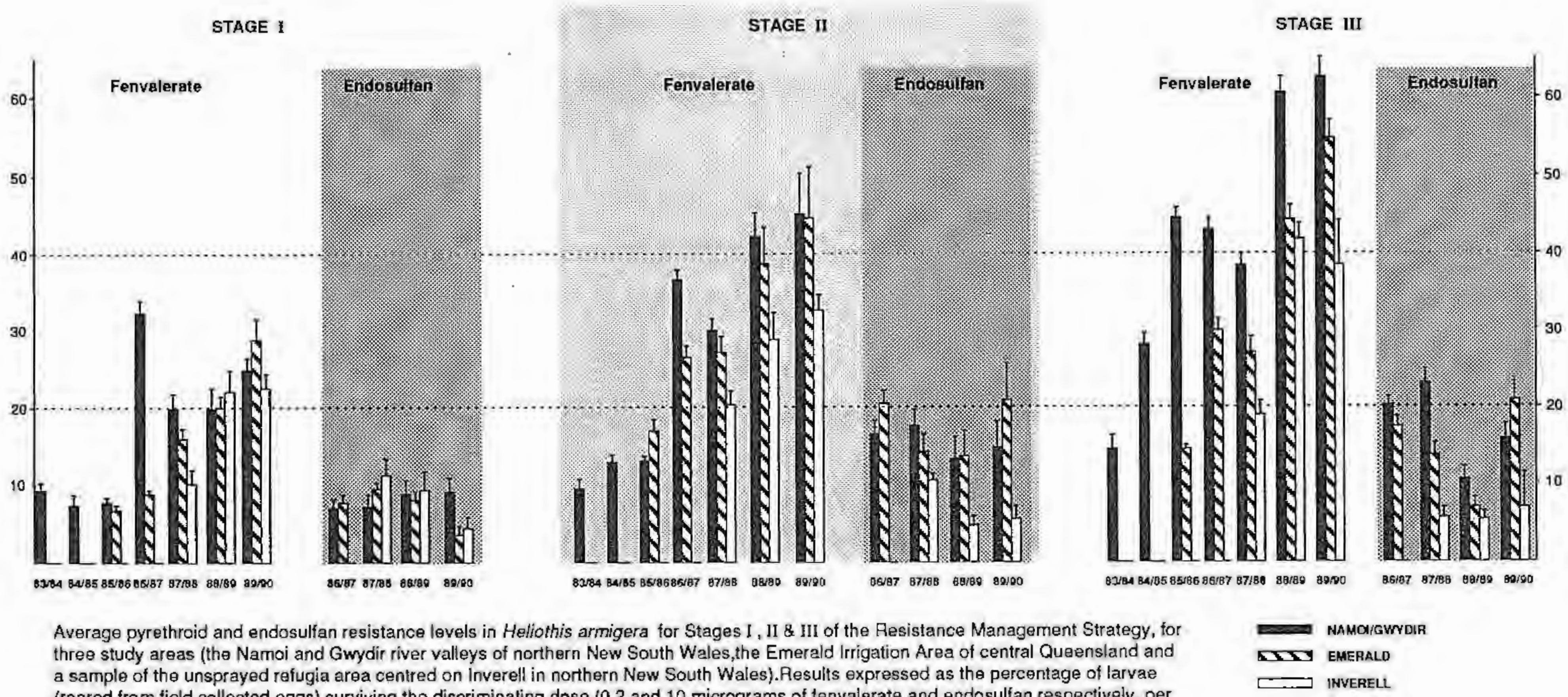
The unsprayed refugia at Inverell is relatively close to the intensively sprayed cotton areas (within 50 - 100 Km). As such, it would be expected that immigration of resistant moths from the sprayed areas should have contaminated the pool of susceptibles to some extent. This is quite clear for the pyrethroids and indicates a declining effectiveness of the refugia as a source of susceptibles for dilution of pyrethroid resistance. However, it would seem that the refugia still remains useful as a source for dilution of endosulfan resistance.

## % SURVIVING DISCRIMINATING DOSE

| STUDY AREA | SEASON | FENVALERATE I av | ± s.e. | n | FENVALERATE II av | ± s.e. | n | FENVALERATE III av | ± s.e. | n | ENDOSULFAN I av | ± s.e. | n | ENDOSULFAN II av | ± s.e. | n | ENDOSULFAN III av | ± s.e. | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Namoi/Gwydir | 1983/84 | 9.3 | 1.1 | 1,207 | 9.5 | 1.3 | 842 | 14.6 | 1.8 | 567 | - | - | - | - | - | - | - | - | - |
| | 84/85 | 7.5 | 1.2 | 732 | 12.9 | 1.0 | 2,175 | 27.9 | 1.6 | 2,948 | - | - | - | - | - | - | - | - | - |
| | 85/86 | 7.8 | 0.6 | 1,769 | 13.0 | 0.6 | 4,104 | 44.5 | 1.4 | 5,266 | - | - | - | - | - | - | - | - | - |
| | 86/87 | 32.2 | 1.6 | 1,765 | 36.7 | 1.2 | 3,003 | 42.9 | 1.7 | 4,333 | 7.1 | 1.1 | 895 | 16.7 | 1.5 | 867 | 20.1 | 1.1 | 2,616 |
| | 87/88 | 19.8 | 1.9 | 904 | 30.1 | 1.5 | 1,725 | 38.4 | 1.5 | 2,035 | 7.3 | 1.4 | 229 | 17.6 | 2.2 | 507 | 23.0 | 1.8 | 1,107 |
| | 88/89 | 19.6 | 2.8 | 440 | 42.4 | 3.1 | 434 | 60.7 | 2.0 | 1,055 | 8.8 | 1.8 | 214 | 13.2 | 3.0 | 145 | 10.6 | 1.7 | 667 |
| | 89/90 | 24.7 | 1.6 | 619 | 45.3 | 5.3 | 357 | 62.5 | 2.4 | 690 | 9.2 | 1.9 | 478 | 14.8 | 3.5 | 272 | 15.9 | 1.8 | 589 |
| Emerald | 1985/86 | 6.8 | 0.6 | 7,269 | 17.1 | 1.3 | 2,728 | 14.4 | 0.6 | 5,871 | - | - | - | - | - | - | - | - | - |
| | 86/87 | 8.8 | 0.6 | 2,831 | 26.5 | 1.6 | 1,646 | 29.8 | 1.5 | 3,423 | 7.7 | 1.0 | 1,114 | 20.6 | 1.6 | 1,091 | 17.3 | 1.3 | 2,910 |
| | 87/88 | 15.9 | 1.4 | 2,027 | 27.1 | 2.1 | 838 | 27.0 | 2.1 | 1,975 | 9.5 | 0.9 | 1,036 | 14.3 | 2.3 | 475 | 13.7 | 1.6 | 1,593 |
| | 88/89 | 19.8 | 1.5 | 1,255 | 38.7 | 4.9 | 358 | 44.3 | 1.9 | 1,354 | 8.1 | 1.1 | 1,013 | 13.6 | 3.5 | 259 | 7.1 | 1.1 | 848 |
| | 89/90 | 27.9 | 3.1 | 274 | 44.6 | 7.0 | 77 | 54.6 | 2.3 | 565 | 3.1 | 1.0 | 127 | 21.0 | 5.2 | 42 | 20.9 | 2.6 | 523 |
| Inverell | 1987/88 | 10.2 | 1.8 | 408 | 20.4 | 1.8 | 670 | 19.0 | 1.8 | 481 | 11.3 | 2.1 | 229 | 10.5 | 1.0 | 558 | 5.8 | 1.1 | 292 |
| | 88/89 | 21.9 | 2.8 | 291 | 28.9 | 3.4 | 509 | 41.7 | 2.1 | 720 | 9.4 | 2.4 | 157 | 4.8 | 1.2 | 373 | 5.4 | 1.2 | 615 |
| | 89/90 | 22.1 | 1.8 | 269 | 32.7 | 2.1 | 476 | 38.2 | 6.0 | 97 | 4.0 | 1.3 | 243 | 5.2 | 1.9 | 347 | 7.1 | 5.3 | 78 |

Average pyrethroid and endosulfan resistance levels in *Heliothis armigera* for each Stage( I, II & III ) of the Resistance Management Strategy, for three study areas (the Namoi and Gwydir valleys of northern NSW, the Emerald Irrigation Area of central Queensland and a sample of the unsprayed refugia area centred on Inverell in northern NSW). Results expressed as the percentage of larvae (reared from field collected eggs) surviving the discriminating dose(0.2 and 10 micrograms of fenvalerate and endosulfan respectively, per 30-40 mg larva) ± the standard error of the mean. n = the total number of larvae tested in each Stage.

# % Larvae Surviving Discriminating Dose {+ Standard Error}




Average pyrethroid and endosulfan resistance levels in *Heliothis armigera* for Stages I, II & III of the Resistance Management Strategy, for three study areas (the Namoi and Gwydir river valleys of northern New South Wales, the Emerald Irrigation Area of central Queensland and a sample of the unsprayed refugia area centred on Inverell in northern New South Wales). Results expressed as the percentage of larvae (reared from field collected eggs) surviving the discriminating dose (0.2 and 10 micrograms of fenvalerate and endosulfan respectively, per 30-40 mg larva) + the standard error of the mean.

DAN 36L

## Resistance frequencies in Overwintering Pupae and in Spring Populations of *Helicoverpa armigera* in Northern New South Wales.

Dr Joanne Daly, CSIRO Division of Entomology, Canberra ACT
Dr Gary Fitt, CSIRO Division of Entomology, Narrabri, NSW.

**AIM: To determine which factors were important in the annual decline in resistance frequencies from autumn to spring.**

BACKGROUND: The frequency of resistance to synthetic pyrethroids fluctuates cyclically. This project examined two possible causes of the decline in resistance frequencies from the high levels observed in late summer/autumn to the low levels in spring: immigration of susceptible moths in springtime or the selective mortality of resistant individuals during diapause. During these seasons, populations of *H. armigera* are not exposed to chemical control with pyrethroids. Dr Fitt was responsible for collecting field samples and for determining the relative distribution and abundance of *H. armigera.* Dr Daly reared the samples and then determined the resistance status of the moths or other causes of death. The funds from this grant were used to employ a technical assistant to collect the pupae and larvae each winter and spring. Other financial support was provided from other grants to the investigators.

METHODS: During winter, diapausing pupae were collected in cropping areas within, and adjacent to, the cotton growing areas of the Namoi and Gwydir Valleys. Deaths from parasitism were recorded. Diapause was broken in the laboratory and the adult moths were tested for their resistance status using a treated vial test, modified for *H. armigera* (Daly and Fitt 1990b). In spring, larvae and eggs were collected from weeds, and crops in northern New South Wales. Individuals were tested as adults, as above.

RESULTS: The majority of the viable overwintering pupae in the Namoi/Gwydir region were in the soil under cotton stubble (99% of pupae in 1987; 50% in 1988). These populations had the highest frequencies of resistance (53-87%) compared with those observed in populations located under other crop stubble, such as sunflower or maize (23-55%). Rates of parasitism were very low in cotton populations (19-46%) compared with those observed elsewhere (33-100%). However, significant source populations with low resistance frequencies could not be found in the cropping areas.

There was a small but detectable decline in the frequency of resistance in an overwintering population of pupae. It is possible that resistant diapausing pupae had higher mortality rates than did susceptible ones, but such difference was small (ca. 10%) and was insufficient to account for all the decline in resistance frequencies from autumn to spring (Daly and Fitt 1990a).

In early spring, populations with high levels of resistance could be observed (ca. 60%). These *H. armigera* were presumed to have been of local origin as their appearance coincided with local emergence of *H. armigera.* Most spring populations, however, had lower resistance frequencies (23-53%). Trapping data from Fitt and Daly (1990) indicate that these populations were a mixture of local and immigrant moths. The immigrants were presumed to be from areas in which resistance to pyrethroids was at relatively lower levels (Daly and Fitt 1990a) to that in the cotton growing areas.

CONCLUSIONS: Populations of *Helicoverpa armigera* overwinter in the Namoi/Gwydir Valley in large numbers, mostly under cotton stubble. These populations have a high frequency of resistance to synthetic pyrethroids. The lower resistance frequencies observed in spring populations appear to be a result of dilution by immigration of populations from source areas with relatively lower levels of resistance. Selective mortality of resistant moths in the absent of insecticides appeared to be of only minor importance.

PUBLICATIONS AND CONFERENCE PROCEEDINGS:

Daly, J.C. and G.P. Fitt. 1990a. Resistance frequencies in overwintering pupae and the spring generation of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in northern New South Wales, Australia: selective mortality and gene flow. J. Econ. Entomol. 83: 1682-1688.

Fitt, G.P. and J.C. Daly. 1990. Abundance of overwintering pupae and the spring generation of *Helicoverpa* spp. (Lepidoptera: Noctuidae) in northern New South Wales, Australia: implications for pest management. J. Econ. Entomol. 83:1827-1836.

Daly, J.C. and G.P. Fitt. 1990a. Monitoring for pyrethroid resistance in relation to body weight in adult *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). J. Econ. Entomol. 83: 705-709.

Daly, J., S. Trowell and A. Hobbs. 1990. Ecological genetics of *Heliothis.* pp 259-266. Australian Cotton Growers Research Conference, Broadbeach, QLD, August 1990.

Fitt, G.P. and J.C. Daly. 1988. The overwintering foe. Australian Cotton Growers Research Conference, Surfers Paradise, August 1988.

Daly, J.C., G.P. Fitt and J.H. Fisk. 1988. Pyrethroid resistance in pupae and adult *Heliothis armigera.* Australian Cotton Growers Research Conference, Surters Paradise, August 1988.

# Relationship between DDT and pyrethroid resistance in *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) in Australia

(*Keywords: Heliothis armigera*, resistance, DDT, pyrethroids)

R. V. GUNNING, N. W. FORRESTER, C. S. EASTON and L. R. GREENUP

*New South Wales Agriculture and Fisheries, RMB 944, Tamworth, NSW 2340, Australia*

**Abstract.** From 1974 to 1978 field populations of *Heliothis armigera* in Australia were strongly (up to 500-fold) resistant to DDT, but fully susceptible to pyrethroids. Following the introduction of pyrethroids for bollworm control in 1979, resistance to DDT dropped very markedly, but it reappeared in 1983 when *H. armigera* became resistant to pyrethroids. The evidence indicates that the initial strong DDT resistance was caused by DDT-dehydrochlorinase, which was subsequently replaced by kdr (nerve insensitivity) which confers resistance to both DDT and the pyrethroids.

## Introduction

*Heliothis armigera* (Hubner) is a major pest in field crops in Australia, attacking cereals, oil seeds, grain legumes, tobacco, cotton and a wide range of vegetables and ornementals. Insecticides are widely used for its control especially in cotton. DDT resistance in *H. armigera* was discovered in the Ord River irrigation area of Western Australia in 1972 (Wilson, 1974), and was soon reported in Queensland and New South Wales (Twine and Kay, 1973; Goodyer *et al.*, 1975; Goodyer and Greenup, 1980). DDT resistance levels exceeding 500-fold were reported by these workers. In 1983 resistance to pyrethroid insecticides was detected in *H. armigera* (Gunning *et al.*, 1984). Subsequently it was found to be widespread in eastern Australia. DDT resistance has been found to confer cross-resistance to pyrethroids in several insect species (for review see Sawicki, 1982). It has been suggested that the development of pyrethroid resistance in *H. armigera* was due to residual DDT cross-resistance (Anon., 1983; Miller, 1984; Twina, 1984).

In this paper we present data to elucidate the relationship between DDT resistance and the development of pyrethroid resistance in *H. armigera*.

## Materials and methods

From 1975 to 1982, *H. armigera* larvae and adults were collected in New South Wales at many sites from crops or by light trapping (Table 1). At least 50 *H. armigera* from each site (Table 1) were used to establish laboratory cultures (Gunning *et al.*, 1984). Their progeny and subsequent insecticide-selected generations were tested with insecticides using a topical application bioassay procedure similar to that recommended by the Entomological Society of America (Anon., 1970).

The overall response to DDT and the pyrethroids of these populations was investigated further using a representative strain (Narrabri/1978) collected from cotton at Narrabri in 1978. After testing on receipt with DDT, fenvalerate and permethrin this strain selected with DDT (50 $\mu$g/larva), and its progeny was subsequently tested with DDT and the pyrethroids.

In 1983, three pyrethroid-resistant strains of *H. armigera*, collected at Emerald (Queensland), Moree (New South Wales) and Kingaroy (Queensland) were tested on receipt and after selection for one or more generations with DDT (50 $\mu$g/larva) or fenvalerate 0·25 $\mu$g/larva equivalent to twice $LD_{99}$ They were tested to establish whether they differed in cross-resistance from the populations collected previously. The insecticides used were: DDT, 73·5%

*Table 1. Toxicity of DDT due to* Heliothis armigera *collected from New South Wales, 1975–1982*

| Year | Location | Crop | $LD_{50}$ ($\mu$g/larva) | Fiducial limits 95% | Slope | R.F.† |
|---|---|---|---|---|---|---|
| 1974–75 | Wee Waa | Cotton | 61 | 35–105 | 2·2 | 183 |
| | Narrabri | Sorghum | 53 | 28–97 | 1·8 | 159 |
| | Wee Waa | Cotton | 79 | 35–179 | 1·4 | 238 |
| 1976–77 | Moore Ck | Tobacco | 60 | 30–117 | 1·3 | 180 |
| | Narrabri | Maize | 44 | 12–163 | 0·7 | 131 |
| 1977–78 | Narrabri | Light | 51 | 33–78 | 2·2 | 152 |
| | Narrabri | Light | >166 | — | 0·7 | >500 |
| | Wee Waa | Cotton | >166 | — | 1·1 | >500 |
| | Narrabri | Maize | 61 | 23–152 | 0·9 | 182 |
| 1978–79 | Tamworth | Cabbage | 0·8 | 0·5–1·3 | 1·6 | 2·5 |
| 1979–80 | Wee Waa | Cotton | 0·8 | 0·4–1·4 | 1·4 | 2·5 |
| 1980–81 | Narrabri | Light | 3·6 | 2·5–5·2 | 1·3 | 10·6 |
| 1981–82 | Wee Waa | Maize | 0·6 | 0·4–0·8 | 2·1 | 1·8 |
| | Narrabri | Light | 0·8 | 0·6–1·0 | 2·1 | 2·4 |

†R.F. (Resistance factor) = ratio of $LD_{50}$ resistant strain/$LD_{50}$ susceptible strain (0·3 $\mu$g/larva derived from Goodyer *et al.*, 1975).

0143-6147/90 $3.00 

(Bayer); permethrin, 89·7%, 40:60 cis/trans ratio (ICI); and fenvalerate, 95·5% (Shell). Three replicates of 20 larvae were treated at five insecticide concentrations; controls were treated with acetone only. The larvae were then placed in individual containers and supplied with food. Mortality was assessed 48 h (permethrin and fenvalerate) and 72 h (DDT) after treatment. Data were analysed by probit analysis (Finney, 1971).

## Results

Between 1975 and 1977/78, *H. armigera* populetions from New South Wales (NSW) were strongly resistent to DDT, up to 238-fold (Table 1), but in 1979 DDT resistance dropped dramatically and stayed low until 1983. High levels of resistance were no longer detected and DDT resistance ranged between 1·8 and 10·6-fold (Table 1). However, in 1983 the progenies of pyrethroid-resistant strains from Queensland and NSW again demonstrated very strong resistence to DDT (Table 2) whilst the laboratory-reared DDT-resistant Narrabri strain had remained fully susceptible to pyrethroids (Table 2). Clearly pyrethroids had selected in the field DDT resistance that was dissimilar to the one present in 1975–78 DDT-resistant populations.

## Discussion

From 1975 to 1978 populations of *H. armigera* in NSW were strongly resistant to DDT but not to pyrethroids. Their DDT resistance dropped very sharply after the introduction of pyrethroids to control DDT-resistant *H. armigera*, but it reappeared once *H. armigera* became resistant to pyrethroids (Gunning *et al.*, 1984). This had already been noted in many other arthropods, viz. the buffalo fly; various mosquito species; some ticks; the diamond back moth; and the tentiform leaf miner (Whitehead 1959; Plapp and Hoyer 1968; Nolan *et al.* 1977; Qmer *et al.*, 1980; Liu *et al.*, 1982; Schnitzerling *et al.*, 1982; Pree *et al.*, 1986) which all gained strong DDT resistance on becoming resistant to pyrethroids.

This cross-resistance (reviewed by Sawicki, 1982) is probably due to the resistance mechanism referred to as knockdown resistance (kdr) (Busvine, 1958) which is thought to reduce the rate of closing of tha activation gate of the sodium channels (Vijverber *et al.*, 1982) by both DDT and pyrethroids.

It is very likely that, during the 1970s, *H. armigera* resisted DDT solely through having the enzyme DDT-dehydrochlorinase (Sucksoong, 1979) which detoxifies only DDT. Because of this, in the late 1970s, bollworms did not resist pyrethroids; the subsequent reduced use of DDT resulted in decreased selection for DDTase and the concomitant drop in DDT resistance. The reappearance of DDT resistance was caused by the selection by pyrethroids of 'kdr', decreased nerve insensitivity (Gunning, to be published) which conferred resistance to DDT and pyrethroids.

## References


ANON. 1970. Standard method for detection of insecticide resistance in *Heliothis zea* (Boddie) and *H. virescens* F. *Bulletin of the Entomological Society of America* **16**, 147–153.

ANON. 1983. *Heliothis* develops resistance to pyrethroids. *The Australian Cotton Grower* 4 (2), 19–19.

BUSVINE, J. R. 1958. Insecticide resistance in bed-bugs. *Bulletin of the World Health Organisation* 19, 1042–1052.

FINNEY, D. J. 1971. *Probit Analysis*. London: Cambridge University Press.

GOODYER, G. J. and GREENUP, L. R. 1980. A survey of insecticide in the cotton bollworm *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) in New South Wales. *General and Applied Entomology* 12, 37–39.

GOODYER, G. J., WILSON, A. G. L., ATTIA, F. J. and CLIFT, A. D. 1975. Insecticide resistance in *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) in the Namoi Valley of New South Wales, Australia. *Journal of the Australian Entomological Society* 14, 171–173.


*Table 2. Differences in cross-resistance to DDT and two pyrethroids between a DDT-resistant (Narrabri/1978) and three pyrethroid-resistant strains of* Heliothis armigera

| Collection (site/date) | Laboratory generation | Selection | $LD_{50}$ (μg/larva) | Slope | R.F.† |
|---|---|---|---|---|---|
| *DDT* | | | | | |
| Narrabri/1978 | 1 | — | 53 | 2·2 | 177 |
| Narrabri/1978 | 2 | DDT | 1000 | 0·75 | 3000 |
| Emerald/1983 | 2 | Fenvalerate | ≫100 | — | > 500 |
| Moree/1983 | 2 | Fenvalerate | >100 | — | > 500 |
| Kingaroy/1983 | 2 | Fenvalerate | >100 | — | > 500 |
| *Fenvalerate* | | | | | |
| Narrabri/1978 | 1 | — | 0·04 | 3·2 | 1 |
| Narrabri/1978 | 2 | DDT | 0·02 | 3·3 | 1 |
| Emerald/1983 | 2 | Fenvalerate | 1·5 | 1·6 | 50 |
| Emerald/1983 | 2 | DDT | 1·7 | 1·6 | 57 |
| Moree/1983 | 2 | DDT | 1·5 | 1·5 | 50 |
| Kingaroy/1983 | 2 | DDT | 1·4 | 1·6 | 52 |
| *Permethrin* | | | | | |
| Narrabri/1978 | 1 | — | 0·04 | 3·7 | 1 |
| Narrabri/1978 | 2 | DDT | 0·04 | 3·2 | 1 |

†Resistance factors calculated from a ratio of $LD_{50}$s, resistant strain/susceptible strain.

The susceptible strains were defined as follows: DDT, 0·3 μg/larva (Goodyer *et al.*, 1975); fenvalerate, 0·03 μg/larva (Gunning *et al.*, 1984); permethrin, 0·04 μg/larva (Gunning *et al.* 1984).

NING, R. V., EASTON, C. S., GREENUP, L. R. and EDGE, V. E. 1984. Pyrethroid resistance in *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidiae) in Australia. *Journal of Economic Entomology* 77, 1283–1287.

KAY, I. R., GREENUP, L. R. and EASTON, C. S. 1983. Monitoring *Heliothis armigera* (Hubner) strains from Queenslend for insecticide resistance. *Queensland Journal of Agricultural and Animal Sciences* **40**, 23–26.

LIU, M. Y., SUN, C. N. and HUANG, S. W. 1982. Absence of synergism of DDT by piperonyl butoxide and DMC in the larvae of the diamond back moth (Lepidoptera: Yponomeutidae). *Journal of Economic Entomology* **75**, 964–965.

MILLER, T. 1984. The pyrethroid strategy: Why it should work. *The Australian Cotton Grower* **5** (1), 4–5.

NOLAN, J., ROULSTON, W. J. and WHARTON, R. H. 1977. Resistance to synthetic pyrethroids in a DDT resistant strain of *Boophilus microplus*. *Pesticide Science* **8**, 484–486.

OMER, S. M., GEORGHIOU, G. P. and IRVING, S. N. 1980. DDT/pyrethroid resistance inter-relationships in *Anopheles stephensi*. *Mosquito News* **40**, 200–209.

PLAPP, F. J. and HOYER, R. F. 1968. Possible pleiotropism of a gene conferring resistance to DDT, DDT analogues and pyrethrins in the housefly and *Culex tarsalis*. *Journal of Economic Entomology* **61**, 781–765.

PREE, D. J., MARSHALL, D. B. and ARCHIBALD, D. E. 1986. Resistance to pyrethroid insecticide in the spotted tentiform leafminer *Phyllonorycter blancardella* (Lepidoptera: Gracillaridae) in southern Ontario. *Journal of Economic Entomology* **79**, 318–322.

SAWICKI, R. M. 1982. Resistance aux pyrethrinoides chez les arthropods. *Comite pour les Applications des Insecticides dans les Locaux et al protection des Denrees Alimentaires* **13**, 16–57.

SCHNITZERLING, H. J., NOBLE, P. J., MACQUEEN, A. and DUNHAM, R. J. 1982. Resistance of the buffalo fly, *Haemotobia irritans exigua* (De Meijera) to two synthetic pyrethroids. *Journal of the Australian Entomological Society* **21**, 77–80.

SUCKSOONG, V. 1979. Toxicology of three juvenile hormone analogues and DDT to *Heliothis* spp. and metabolism of DDT and hydroprene in these species. PhD. thesis, University of Queensland, Brisbane, Australia.

TWINE, P. H. 1984. Containing resistance, pp. 97–102. In *Australian Cotton Conference*, Australian Cotton Growers Research Association, Toowoomba, Queensland.

TWINE, P. H. and KAY, I. R. 1973. *Heliothis* species and DDT resistance. *Queensland Agricultural Journal* **99**, 520–523.

VIJVERBERG, H. P. M., VAN DER ZALM, and VAN DEN BERCKEN, 1982. Similar mode of action of pyrethroids and DDT on sodium channel gating in meylinated nerves. *Nature* **295** 601–603.

WHITEHEAD, G. B. 1959. Pyrethrum resistance conferred by resistance to DDT in the blue tick. *Nature* **184**, 378–379.

WILSON, A. G. L. 1974. Resistance of *Heliothis armigera* to insecticides in the Ord River irrigation area, north western Australia. *Journal of Economic Entomology* **67**, 256–258.