

COTTON RESEARCH AND DEVELOPMENT CORPORATION

FINAL REPORT

**“Role of conventional and novel insecticides in Integrated
Pest Management in cotton.”**

DAN 105C

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Final Reports

Ensure you append the Cover Sheet to this report, and forward 3 copies to Cotton Research & Development Corporation

In addition to the cover sheet please address the following:

What was the **background** of the project?

Conventional insecticides continue to play a significant role in integrated pest management in the Australian cotton industry, for a number of reasons:

- a) transgenic cottons need protection from *Helicoverpa* spp. late season as plant efficacy declines.
- b) sucking pests (mirids, aphids, whitefly and mites) may become more important in transgenic crops as the moderating effect of early season heliothis sprays on these pests is reduced.
- c) there is a need to identify 'selective' spray options for supplemental control of *Helicoverpa* spp. and for control of sucking pests in transgenic cotton to prevent 'flaring' secondary pests such as mites.
- d) there is a need for backup technology if transgenic cottons go wrong (eg. if resistance develops sooner than we predict).
- e) there is a need for refugia crops to dilute potential Bt resistant individuals and one option will be sprayed non-transgenic cotton, which may comprise up to one third of the cotton area on each farm.
- f) some of the currently registered products in cotton are at risk due to increasing resistance problems (particularly thiodicarb) and/or environmental problems (eg. endosulfan, parathion).

Control of *H. armigera* in conventional cotton continues to rely heavily on several older insecticide groups (organochlorines, organophosphate, carbamates and pyrethroids). Australian field populations of *H. armigera* have developed resistance to members of all these groups and in recent seasons this has resulted in control failures particularly with with pyrethroids and carbamates. Resistance frequencies and factors are monitored in field populations of *H. armigera* each season, but the relationship between these data and field control is poorly understood.

Transgenic cotton expressing *Bacillus thuringiensis* (Bt) subsp. kurstaki Cry IAc delta endotoxin (Ingard®) for control of *Helicoverpa* spp. represented approximately 15% and 20% of the cotton area in the 1997-98 and 1998/99 seasons respectively. Uptake of Ingard® varieties has resulted in significant reductions (50%) of the numbers of applications of conventional insecticides, particularly in the first half of the season, when expression of the Cry IAc delta endotoxin is most robust. In the second half of the season Ingard® cotton requires supplemental insecticides to reduce *Helicoverpa* species below economic thresh-hold. This project aims to compare the efficacy of insecticides targeting *Helicoverpa* spp. in conventional cotton versus Ingard® cotton. There is a strong need for timely independent evaluation of the newer more selective and more environmentally benign insecticides under Australian conditions.

This project focuses on the role of both existing and new conventional insecticides for insect control in cotton. Research has been carried out on both synthetic chemical insecticides and biological control agents such as bacteria and viruses. Initial studies have been carried out on small-scale hand sprayed field plots on station (at the A.C.R.I.). For certain studies, commercially sprayed fields have also been used and this has provided the opportunity to study the impact of commercial scale spraying operations on field efficacy. Regular contact has been kept with researchers developing new insecticides for control of *Helicoverpa* species and new biochemical and molecular resistance assays so that these techniques can be tested in the field and calibrated against levels of field control.

What were the **Project Objectives** and to what extent were these achieved?

1) Calibrate thiodicarb laboratory discriminating dose data with levels of control of *Helicoverpa* in the field. Replicated field trials comparing the field efficacy of thiodicarb and methomyl were carried out during the 1997/98 and for the 1998/1999 seasons. *Helicoverpa* larvae were collected from treatment plots before and after field applications of methomyl or thiodicarb and transferred to the laboratory for bioassay. Larvae were topically treated with a discriminating dose of methomyl in order to determine the frequency of carbamate resistance. Both

carbamates effectively controlled *H. armigera* larvae in the field, despite measurable carbamate resistance before and after field applications. Both methomyl and thiodicarb selected for increases in the frequency of carbamate resistance however, thiodicarb selected for carbamate resistance more strongly than methomyl.

2) Calibrate synthetic pyrethroid and pyrethroid/synergist laboratory resistance data with levels of control of *Helicoverpa* in the field.

Using an established technique of topical bioassays of 30-40mg larvae, combinations of fenvalerate and a range of pyrethroid synergists have been evaluated. Laboratory results have confirmed metabolic resistance (due to both esterase and monooxygenase enzymes) in field populations of *H. armigera* from the Namoi valley. The implication of these results is that registered esterase synergists (certain organophosphates) and monooxygenase synergists (piperonyl butoxide and propargite) will improve the efficacy of pyrethroids against some resistant populations of *H. armigera* in the field. Importantly, neither group of enzymes appears to be wholly responsible for resistance. Pyrethroid resistance was not fully synergisable in any of the field strains tested in the laboratory. These results have been confirmed by field trials with pyrethroid mixtures on the Darling Downs in 1997/98 and Namoi Valley in 1998/99; no pyrethroid mixtures provided 100% control.

3) Evaluate new products for lepidopteran control and their impact on natural enemies.

Extensive replicated small plot trials have been conducted comparing the efficacy of a range of insecticides against *Helicoverpa* species and their impact on beneficial insect species in conventional and Ingard® cotton. These include a range of new insecticides (spinosad, chlorfenapyr, emamectin benzoate, indoxacarb, and methoxyfenozide), and biological insecticides (foliar Btks, NPV virus and Neem extract). The impact of repeated treatments of these insecticides on numbers of *Helicoverpa* species (eggs and larval stages), beneficial species and secondary pests (mites and aphids) has been assessed by field counts. No attempt has been made to rank the efficacy of new chemical groups against *Helicoverpa* species, however their impacts on beneficial species have been summarised the form of a table in the new IPM guidelines for cotton. Unforeseen (previously undocumented) impacts of several of the new insecticides on secondary pests have been noted, for example repeated applications of Tracer® (spinosad) have slightly flared mites compared with untreated controls.

Comparisons of the efficacy of insecticides in conventional versus Ingard® cotton indicate that additive mortality of *Helicoverpa* larvae (transgenic Bt plus insecticide) occurs with most supplemental insecticides throughout the season. Importantly, improved efficacy of several insecticides occurs in Ingard® cotton even at the end of the season when expression of Bt in the transgenic plants alone is insufficient to control *Helicoverpa* larvae. This work has continued in DAN141C and although the results of a third season of trials have not yet analysed they appear to agree with those of years 1 and 2, suggesting that efficacy of some of the new insecticides may be more robust in Ingard® cotton.

4) Evaluate new insecticides for sucking insect control and assess their impact on natural enemies.

1997/98 and 1998/99 field trials at the ACRI compared the field performance of trickle applied neem extract against a range of insect pest species in conventional and Ingard® cotton. The results of evaluations of neem extracts for sucking pest control are preliminary and are not presented in detail in this report.

5) Evaluate new biochemical and biotechnical resistance monitoring techniques.

A new method for monitoring insecticide resistance has been evaluated and modified for Australian species. An adult vial test developed by Dr. B. Plapp has been used extensively for monitoring resistance to conventional insecticides in *Helicoverpa* species in the USA. This assay has been re-calibrated with hatchling *H. armigera* larvae and the partial resistance breaking pyrethroid bifenthrin. Its value for pest management decision-making in Australian cotton is being evaluated.

6) Design and build a multi-treatment tractor mounted boom sprayer.

Hand booms and single treatment high clearance spray rigs have been used at the A.C.R.I. to apply insecticide treatments. Both application methods have significant draw-backs; use of hand booms necessitates hot and uncomfortable personal safety equipment, and the single treatment spray rigs are too heavy for transportation to trial sites off station. Both methods rely on each treatment being mixed and applied to each of the replicate plots and then the hand boom or spray rig returning to the chemical shed to be rinsed out before a second treatment can be applied. For small plot trials this process takes about 1 hour per treatment. Treatments that are applied at 6am are not necessarily given a fair comparison with those applied 5 or 6 hours later (in the middle of the day). This project aimed to design and construct a multi-treatment spray-rig.

7) To extend the results of the conventional insecticide programme to all the sections of the industry during and at the end of the season and help formulate each season's new IRM strategy.

This project provides data to help to allow informed decisions on the format for each new season's insecticide resistance management strategy. Results from this project have contributed to a number of changes to the Cotton Insecticide Resistance Management strategies.

What **methodology** was used, and a justification for the use of this methodology?

Insecticides

Products tested, their active ingredient, grade, formulation, common name, insecticide group and supplier are given in Table 1.

Insects

Reference strains of *Helicoverpa armigera* and *Helicoverpa punctigera* were used for laboratory work. These were reared on an artificial diet at $25 \pm 2^\circ\text{C}$ in constant temperature rooms at the A.C.R.I. using methods described by Forrester *et al.* 1993. Field strains of *Helicoverpa* species were collected from cotton and other host crops in the major cotton growing valleys and sent by overnight courier for testing.

Bioassay methods

Topical bioassays were performed with 30-40mg *Helicoverpa* larvae using methods and discriminating doses of carbamates, pyrethroids developed by Dr. Neil Forrester (Plate 1). Briefly, larvae weighing 30-40mg were topically dosed on the dorsal surface of the mid-thorax with 1 microlitre of acetone alone (controls) or acetone containing a discriminating dose of technical grade insecticide using a Hamilton syringe and repeating ratchet dispenser. The discriminating dose for each insecticide was the mean LC99.9 value for a range of susceptible strains (Forrester *et al.* 1993). Each discriminating dose bioassay was replicated a minimum of four times and included acetone treated larvae as controls. After dosing, individual larvae were maintained at $25 \pm 1^\circ\text{C}$ in constant light until mortality was assessed. Mortality at the discriminating concentration was corrected for control mortality (Abbot 1925), which did not exceed 10%. Probit regressions were computed on a PC using Probit 5 for Windows (Gillespie 1995). Probit regressions were calculated and LC50 and LC99.9 values estimated. Resistance factors were calculated by dividing the LC50 (99.9) of field collected strains by LC50 (99.9) of laboratory susceptible strain. The Adult Vial Test developed by Dr. Bill Plapp for monitoring insecticide resistance in *Heliothis virescens* and *Helicoverpa zea* in the United States (Plapp *et al.* 1990) was set up at the A.C.R.I. and modified for monitoring pyrethroid resistance in larval of *H. armigera*.

Field trial methods

These were developed during the project based on standard field trial designs for evaluation of insecticide efficacy (such as Replicated Complete Randomised Block and Split Plot designs) (Plate 2). Field trials were planted with Australian cotton varieties (Sicaia V2 and V2i). For insecticides tested and rates applied per hectare, see Table 1. Insecticides were applied using a hand boom or high clearance spray rig at commercial application volumes (100 or 150lt/Ha) hollow cone nozzles (TX4 or TX6), commercial application speeds and pressures (3bar). Visual counts of natural infestations of pest and beneficial insect species were made in each plot once every 3 days, and weekly counts were pooled. Sampling techniques were developed to be as close as possible to commercial checking practices (insects or damage per metre row) for pest and beneficial insects. Field trial data were recorded and analysed using the Pesticide Research Manager (PRM5) program (Gyling Data Management Inc. 1997). Field efficacy was corrected for control mortality and treatment differences were determined by ANOVA and Duncan's new Multiple Range Tests.

1) To calibrate thiodicarb laboratory discriminating dose data with levels of *Helicoverpa* field control.

Methods

- A replicated randomised complete block trial was undertaken in Sicala V2 cotton at the A.C.R.I. *Helicoverpa* larvae were collected from treatment plots before and after field applications of methomyl or thiodicarb and transferred to the laboratory for bioassay. Larvae were topically treated with a discriminating dose of methomyl in order to determine the frequency of resistance to carbamates before and after selection in the field.

Results

- Methomyl and thiodicarb effectively controlled *H. armigera* larvae in the field, despite measurable carbamate resistance before and after field applications.
- Both methomyl and thiodicarb selected for increases in the frequency of carbamate resistance (Figure 1 & 2).
- Thiodicarb selected for carbamate resistance more strongly than methomyl.

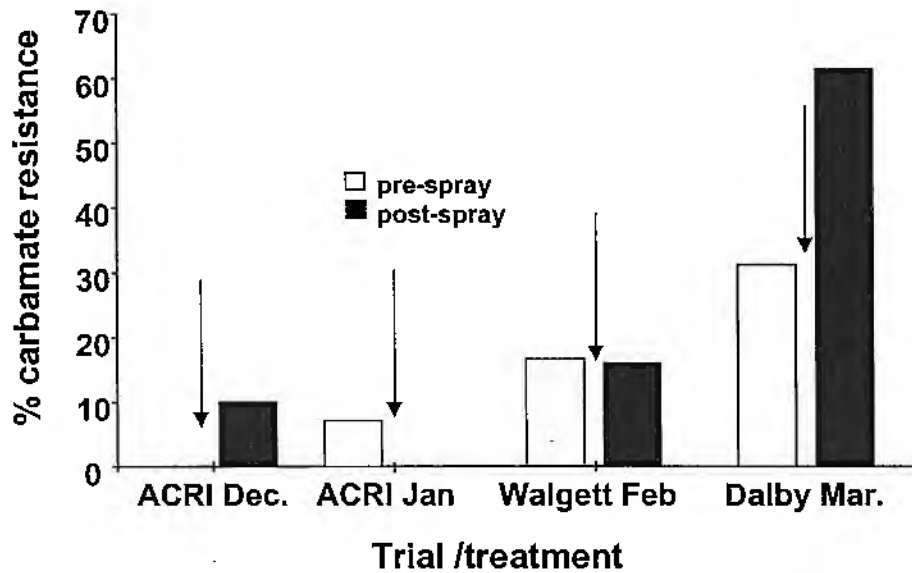


Figure 1. Carbamate resistance before and after field applications of thiodicarb. Vertical arrows represent foliar applications of insecticides.

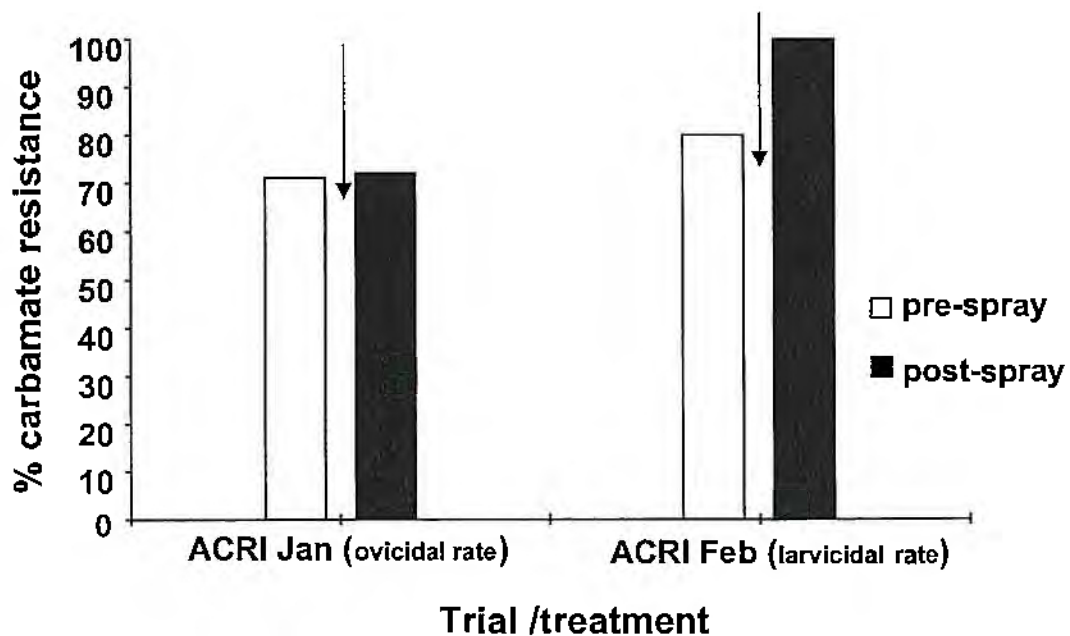


Figure 2. Carbamate resistance before and after field applications of methomyl. Vertical arrows represent foliar applications of insecticides.

Conclusions

- More research is required to investigate the relationship between laboratory discriminating dose data and levels of *Helicoverpa* control in the field.
- Further work needs to be done to measure carbamate resistance frequencies of *Helicoverpa* larvae collected in the field before and after field applications of thiodicarb and methomyl. Although very preliminary these initial results suggest that restrictions in the use of larvicidal rates of thiodicarb should be more effective in managing resistance to carbamates than restrictions in the use of ovicidal rates of methomyl.

Extension

The results were presented at the Cotton Consultants of Australia annual meeting in Goodiwindi in 1998.

2) To calibrate pyrethroid laboratory discriminating dose data with levels of *Helicoverpa* field control.

Methods

- Field collected *Helicoverpa* larvae were topically treated with a discriminating dose of fenvalerate plus and minus a range of candidate pyrethroid synergists in order to determine the contribution of various forms of metabolic resistance (Plate 1).
- Replicated field trials were carried out in 1998 and 1999 to compare the efficacy of a range of pyrethroid mixtures against *Helicoverpa* species.

Results

- Topical bioassays of 30-40mg larvae with combinations of fenvalerate plus a range of synergist compounds confirmed metabolic resistance (due to both esterase and monooxygenase enzymes) in field populations of *H. armigera* (Figure 3).

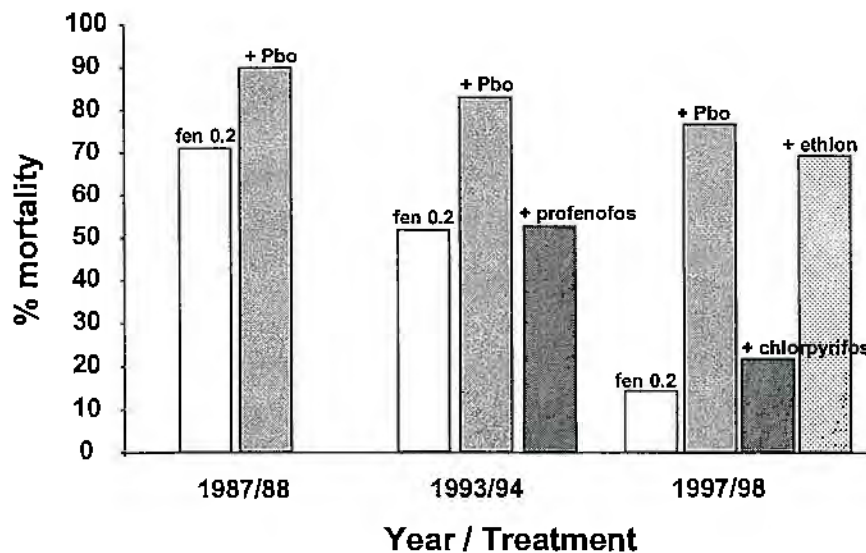


Figure 3. Laboratory bioassay of *H. armigera* larvae and a discriminating dose of fenvalerate ($0.2\mu\text{g/larva}$) with a range of candidate synergists; Pbo = piperonyl butoxide ($50\mu\text{g/larva}$), profenofos ($0.1\mu\text{g/larva}$), chlorpyrifos ($0.2\mu\text{g/larva}$) and Ethion ($8\mu\text{g/larva}$).

ii) Replicated field trials were carried out in 1998 and 1999 to compare the efficacy of a range of pyrethroid mixtures against *Helicoverpa armigera* see figures 4 and 5.

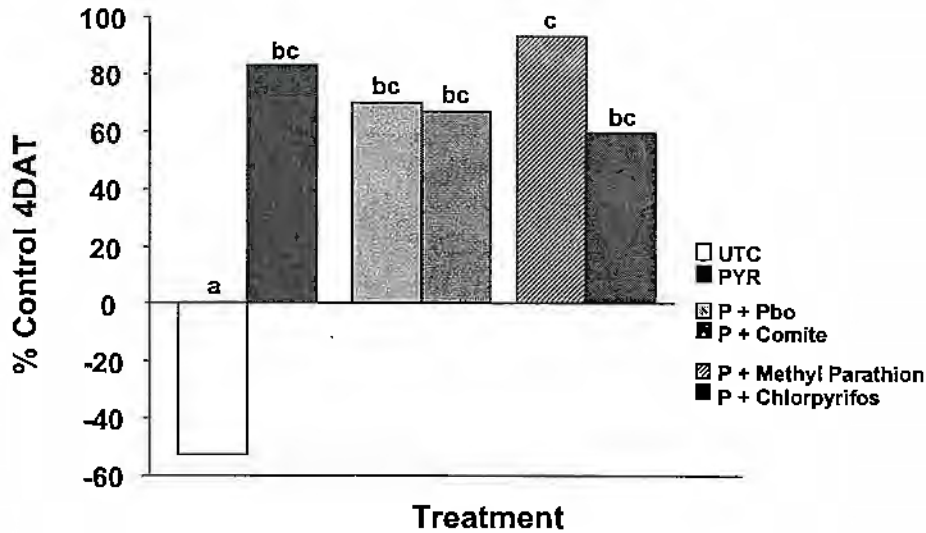


Figure 4. Replicated field trial (Darling Downs March 1998) assessing the efficacy of a betacyfluthrin in combination with a range of common mix partners against *H. armigera* larvae. For insecticides tested and rates applied per hectare see Table 1. Bars carrying the same letter are not significantly different ($P > 0.05$ Duncans New MRT).

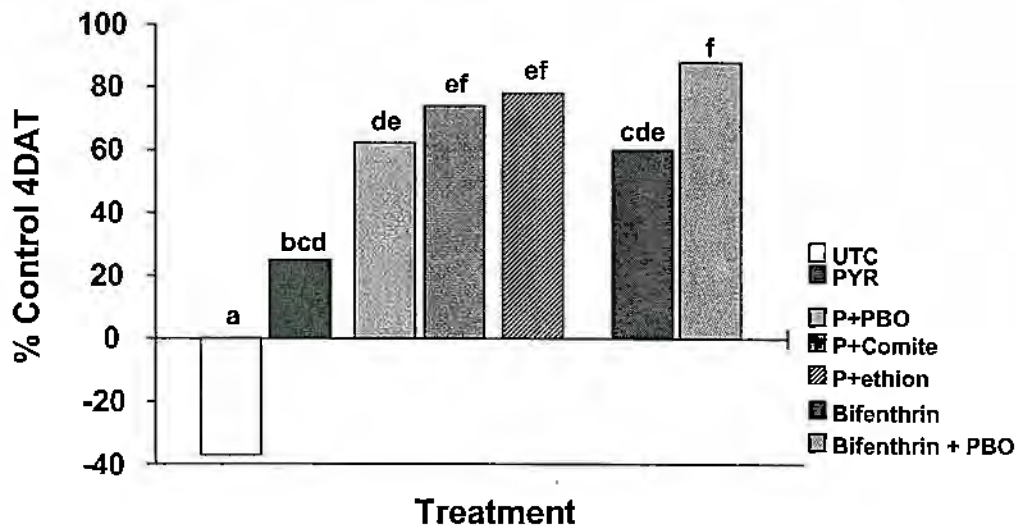


Figure 5. Replicated field trial (Namoi Valley March 1999) assessing the efficacy of a lambda-cyhalothin and bifenthrin in combination with a range of common mix partners against *H. armigera* larvae. For insecticides tested and rates applied per hectare see Table 1. Bars carrying the same letter are not significantly different ($P > 0.05$ Duncans New MRT). Legend PYR and P = lambda-cyhalothin, PBO = piperonyl butoxide.

Conclusions

The implication of the bioassay and field trial results is that esterase synergists (certain organophosphates) and monooxygenase synergists (piperonyl butoxide and propargite) will improve the efficacy of pyrethroids against some resistant populations of *H. armigera* in the field. Importantly, neither group of enzymes appears to be wholly responsible for resistance. Pyrethroid resistance is not fully synergisable, by either esterase or monooxygenase blockers, in any of the strains tested in the laboratory. These results have been confirmed by field trials with pyrethroid mixtures on the Darling Downs in 1997/98 and Namoi Valley 1998/99; no pyrethroid mixtures have provided 100% control. In the experiment in the Darling Downs the pyrethroid alone effectively controlled *H. armigera* larvae in the field, despite measurable pyrethroid resistance before and after field applications. In contrast the experiment in the Namoi Valley showed a significant increase in control when synergists were added to the base

pyrethroid (*lambda-cyhalothin*). The contrasting results between these experiments strongly indicates that more research is required to investigate the relationship between laboratory discriminating dose data and levels of *Helicoverpa* control in the field.

Extension

Results of the laboratory and field-work were presented at the Cotton Consultants of Australia annual meeting in Goodiwindi in 1998 and in the paper 'Holloway J. W. and Forrester, N. W. (1998) Pyrethroid Resistance in Heliiothine pests of cotton: Mechanisms and Management' in Zaluki, M. P., Drew, R. A. I. and White, G. G. (Eds) Pest Management - future challenges. The University of Queensland Printery, Brisbane, Queensland, Australia pp. 172-180. These results have been summarised in a recent video commissioned by the C.C.A. 'Pyrethroid Resistance in Australian *Helicoverpa* spp. mechanism and management'.

3) Evaluate new products for lepidopteran control and their impact on natural enemies.

Methods

Replicated small plot trials have been conducted comparing the efficacy of a range of insecticides against *Helicoverpa* species and their impact on beneficial insect species in conventional and Ingard® cotton (Plate 2). These include a range of new insecticides (spinosad, chlorfenapyr, emamectin benzoate, indoxacarb, methoxyfenozide) and biological insecticides (foliar Btk and NPV virus) for control of *Helicoverpa* spp. The impact of repeated treatments of these insecticides on numbers of *Helicoverpa* species (eggs and all larval stages), beneficial species and secondary pests (mites and aphids) has been assessed by field counts.

Results

Only data for currently registered products are shown here. For a more complete set of results please refer to the proceedings of the XXI International Congress of Entomology. Data for spinosad (Tracer®) and chlorfenapyr (Intrepid®) are shown as an example (Figures 6 – 11).

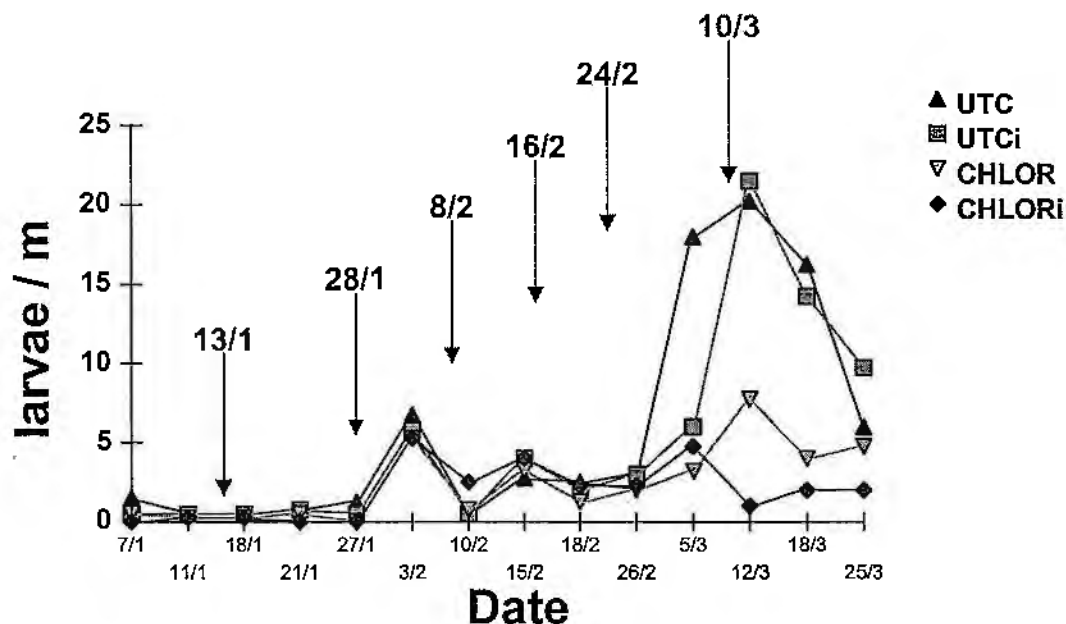


Figure 6. Replicated field trial (A.C.R.I. 1998/1999) assessing the efficacy of repeated applications of chlorfenapyr (1.1L/ha) against *Helicoverpa* larvae in conventional versus Ingard® cotton (i). Vertical arrows refer to application dates.

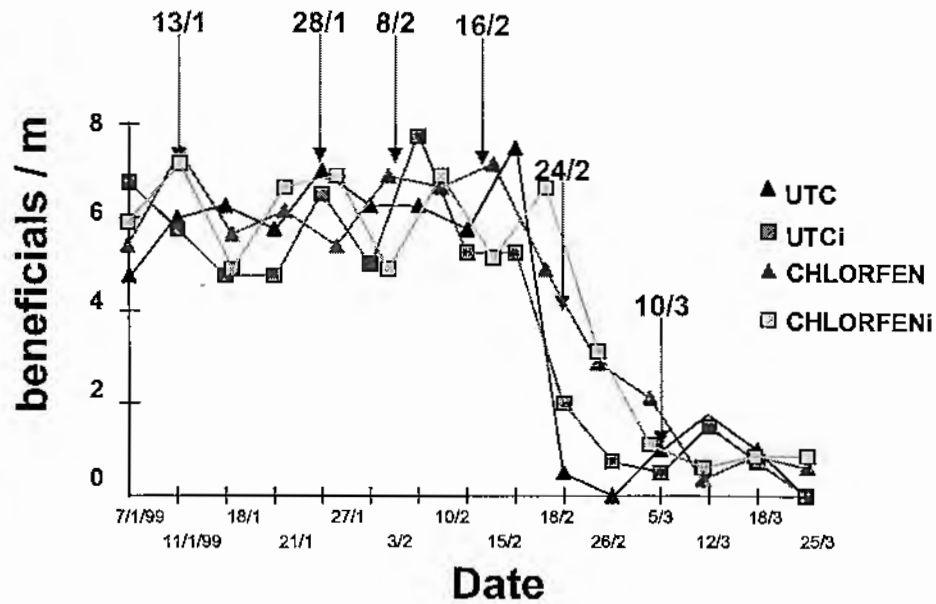


Figure 7. Replicated field trial (A.C.R.I. 1998/1999) assessing the impact of repeated applications of chlorfenapyr (1.1L/ha) on numbers of beneficial insects in conventional versus Ingard® cotton (i). Vertical arrows refer to application dates.

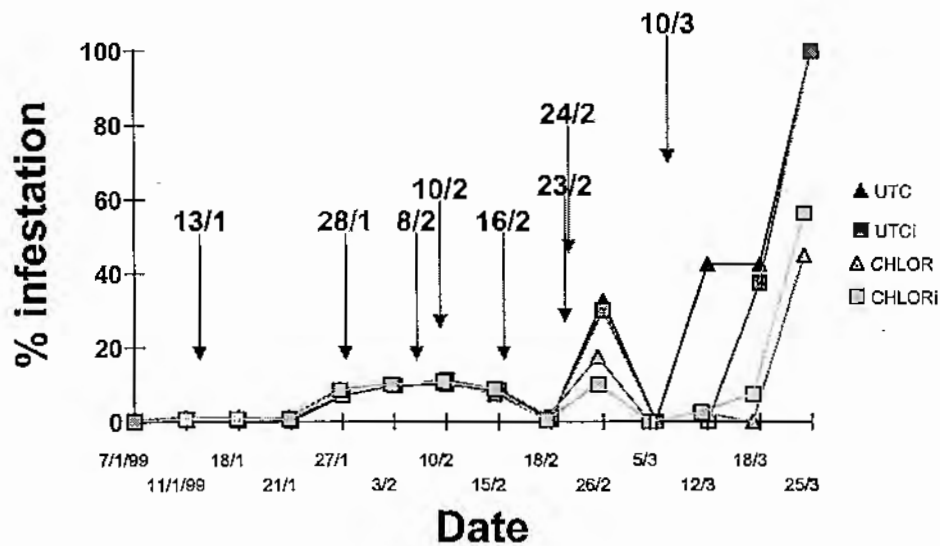


Figure 8. Replicated field trial (A.C.R.I. 1998/1999) assessing the impact of repeated applications of chlorfenapyr (1.1L/ha) on infestations of *Tetranychus* spp. in conventional versus Ingard® cotton (i). Vertical arrows refer to application dates. Arrows on 10/2 and 23/2 refer to supplemental applications of miticide (0.6L/ha diafenthiuron) to all plots.

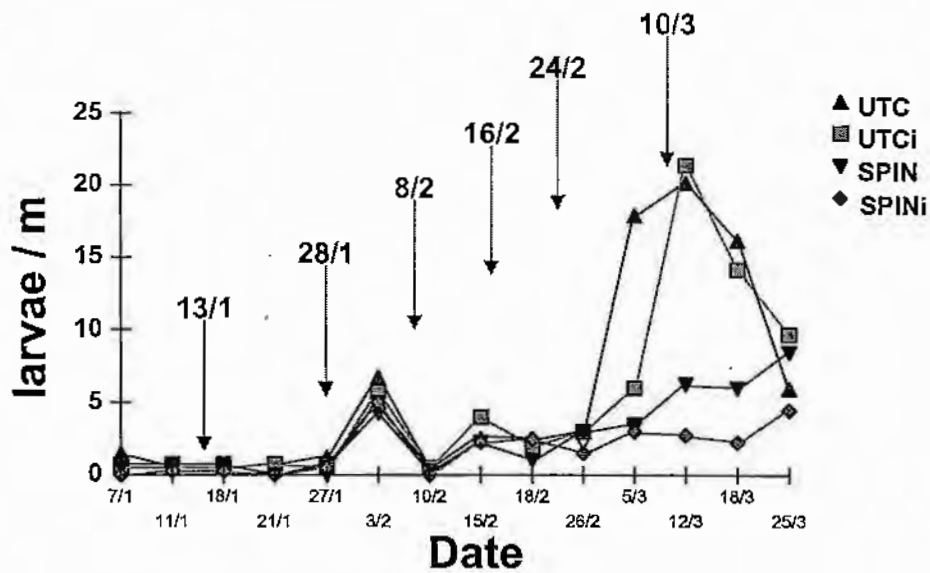


Figure 9. Replicated field trial (A.C.R.I. 1998/1999) assessing the efficacy of repeated applications of spinosad (0.2L/ha) against *Helicoverpa* larvae in conventional versus Ingard® (i) cotton. Vertical arrows refer to application dates.

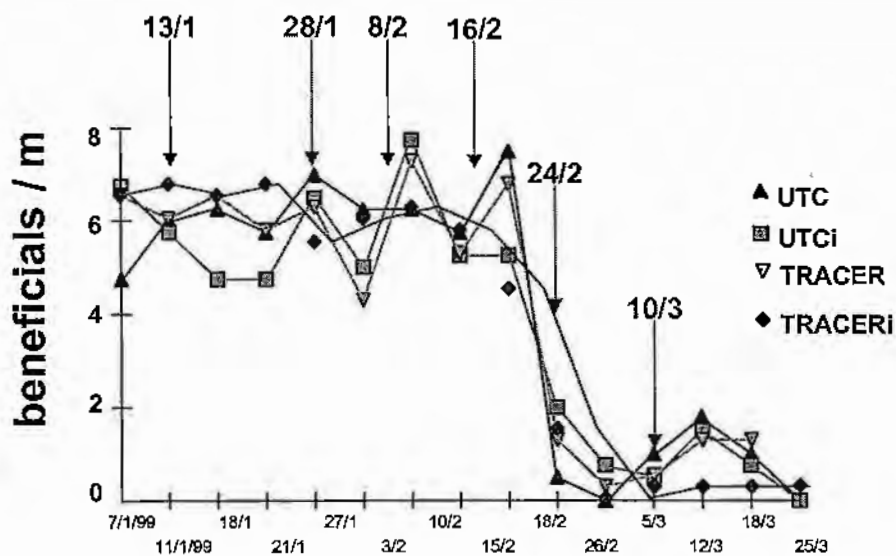


Figure 10. Replicated field trial (A.C.R.I. 1998/1999) assessing the impact of repeated applications of spinosad (0.2L/ha) on numbers of beneficial insects in conventional versus Ingard® (i) cotton. Vertical arrows refer to application dates.

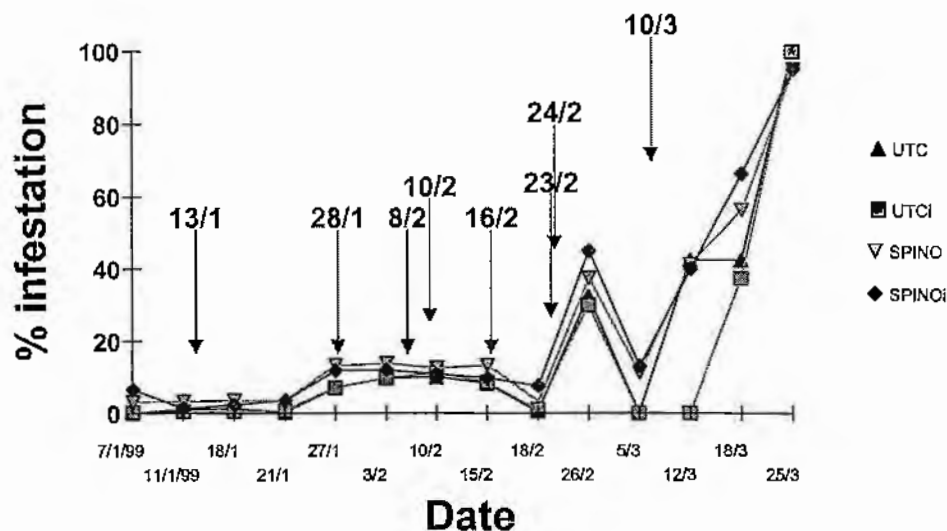


Figure 11. Replicated field trial (A.C.R.I. 1998/1999) assessing the impact of repeated applications of spinosad (0.2L/ha) on infestations of *Tetranychus* spp. in conventional versus Ingard® cotton (i). Vertical arrows refer to application dates. Arrows on 10/2 and 23/2 refer to supplemental applications of miticide (0.6L/ha diafenthiuron) to all plots.

Conclusions

No attempt has been made to rank the efficacy new chemical groups against *Helicoverpa* species, this work aims to help to identify each products strongest and weakest fit during the cotton season. The impacts of repeated applications of new insecticides on numbers of beneficial species have been summarised the form of a table in the new IPM guidelines for cotton. Relative to the broad-spectrum insecticide groups such as pyrethroids and organophosphates, minimal negative effects of the new insecticides on total numbers of beneficial insects have. However the total beneficial numbers presented here are a very crude measure of a particular treatment's impact on beneficial species. Although generally softer than older groups, each new insecticide tested may have a strong negative effect on a particular beneficial group or species, which requires more detailed study. In addition to their activity against *Helicoverpa* species, several of the new insecticides (chlorfenapyr, abamectin and emamectin benzoate) either suppress or control mites. This activity on mites will help to influence selection of these products in situations were *Helicoverpa* and mites are present in cotton crops. Other (previously undocumented) effects of several of the new insecticides on secondary pests have been noted, for example in plots treated with multiple applications of Tracer® (spinosad) infestations of mites have increased slightly more rapidly than in untreated control plots.

Comparisons of the efficacy of insecticides in conventional versus Ingard® cotton indicate that improved efficacy of several insecticides occurs in Ingard® cotton even at the end of the season when expression of Bt in the transgenic plants alone is insufficient to control *Helicoverpa* larvae. These observations require further data but suggest that foliar applications of some insecticides for supplemental control of *Helicoverpa* spp. may have more robust efficacy in Ingard® cotton than in conventional cotton. Late in the season, sub-lethal effects of transgenic Bt may alter the growth, development, feeding, movement and distribution of *Helicoverpa* larvae in Ingard® cotton relative to conventional cotton in a way that effects their exposure to, uptake of and susceptibility to foliar applied insecticides.

Extension

These results have been presented at regional field days (the 2000 Goondiwindi and Lower Namoi 2000 field days), and are due to be presented later this year at the and the 2000 CCA winter meetings XXI Congress of Entomology in Brazil.

4) Evaluate new insecticides for sucking insect control and assess their impact on natural enemies.

A replicated small plot trial was carried out during the 1997/98 season to compare the field performance of foliar and trickle applied neem extract against sucking pests in conventional and Ingard® cotton. Preliminary results

suggested that the field efficacy of trickle applied neem extract was poor. Foliar applications of neem extract had no significant effects on numbers of thrips, mirids or on numbers of *Helicoverpa* eggs or larvae. No significant treatment differences were recorded in cotton damage or yield compared with untreated controls. Laboratory bioassays of terminal leaves of cotton plants treated with foliar applications of neem extract showed more promising efficacy of neem for suppressing the development of *Helicoverpa* larvae. These results are preliminary and are not presented in detail in this report, but suggest the potential for further work with neem based products.

Extension

These results were presented at the Namoi Valley Cotton Growers Association annual field day in June 1998 and in the paper 'Holloway, J. W., Kerr, D., Bird, L. J. and Forrester, N. W. (1998) Investigation of foliar and systemic applied neem in Australian cotton'. In Proc. Second World Cotton Conference, 'New Frontiers in Cotton Research' Athens, Greece pp. 198.

5) Evaluate new biochemical and biotechnical resistance monitoring techniques and calibrate these against levels of field control.

Methods

Eight collaborating consultants from across the Australian cotton belt were supplied with larval vial test kits in 1998/1999 and in 1999/2000 containing vials with an internal coating of a specific dose of bifenthrin (Talstar®) (Plate 3). The kits are prepared at the A.C.R.I., used in the field and then returned to the laboratory for re-cycling. 20 vials per dose of a range of doses of bifenthrin are supplied in each kit with each dose colour coded (red, blue etc.). Consultants infest each vial with a hatchling larvae using a paint brush and score mortality after 6 and 24hrs. Mortality at each of the colour coded doses is recorded on a score sheet provided in the kit, and faxed back to the A.C.R.I. Results are presented in Figure 12 & 13.

Results

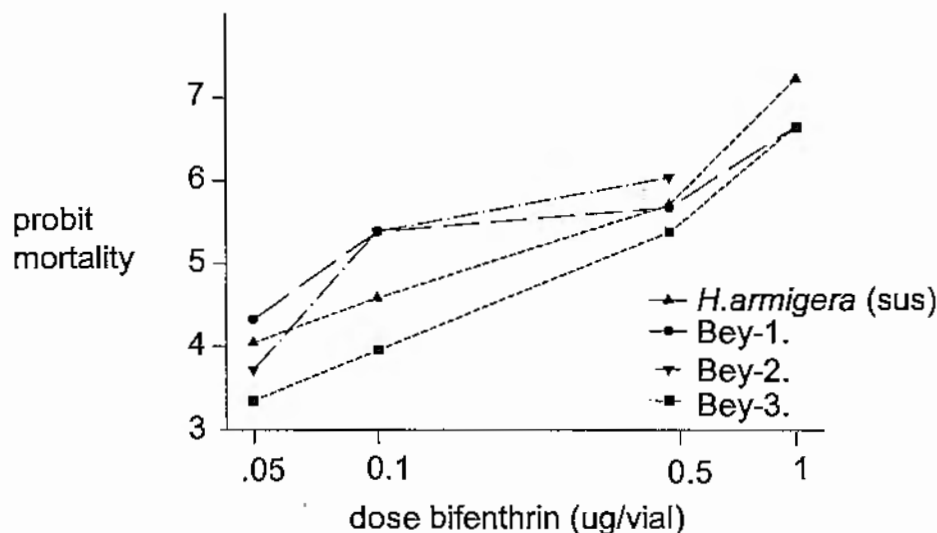


Figure 12. Larval vial test assessing the efficacy of a bifenthrin against neonate *H. armigera* larvae collected early (Bey1), mid (Bey2) and late (Bey3) in the 1998/99 cotton season.

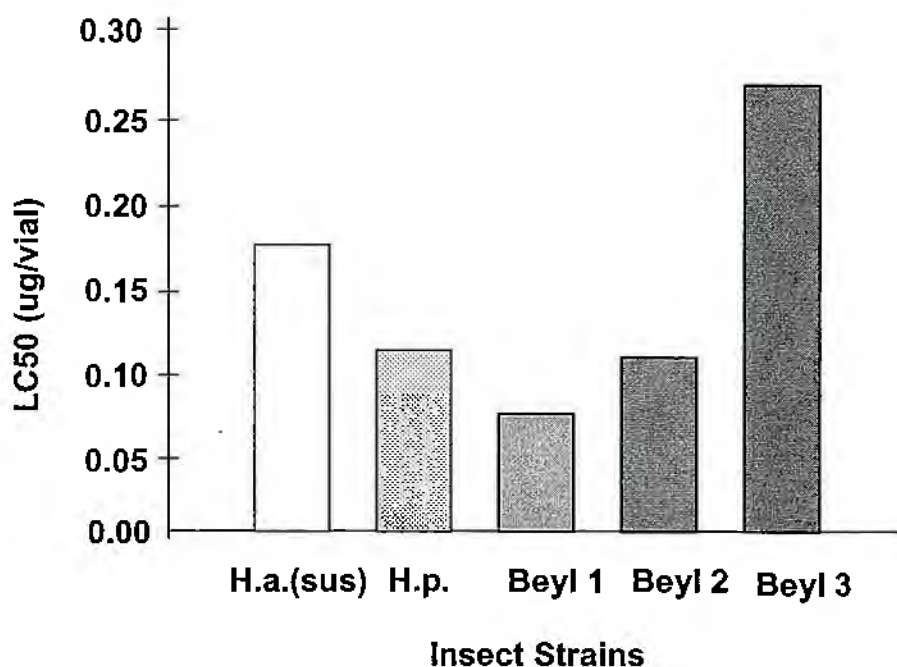


Figure 13. Larval vial test LC_{50} s of bifenthrin and neonate larvae from susceptible laboratory strains of *H. armigera* and *H. punctigera* versus neonate larvae from field strains of *H. armigera* collected early (Bey1), mid (Bey2) and late (Bey3) in the 1998/99 cotton season.

Conclusions

With further validation this simple cost-effective resistance monitoring technique could provide predictive data to assist spray decisions against *H. armigera* in Australia. Continued development of a larval vial test could provide a useful tool for cotton growers and consultants to make their own measurements of resistance before making spray decisions. This approach would be useful for management of *Helicoverpa* spp in other Australian field crops (for example grain legumes) where control relies more heavily on older chemical groups (pyrethroids and carbamates). Laboratory work is underway to continue to develop larval vial tests for bifenthrin and to develop test kits for other insecticides (fenvalerate and methomyl).

6) Design and build a multi-treatment tractor mounted boom sprayer.

Methods

Dr. Roger Leonard at Louisiana State University Experimental Station designed and built a tractor-mounted, multi-treatment spray-boom. He provided details and photographs of that design, which we modified to fit a high clearance, lightweight vehicle, suitable for use in irrigated cotton. A self-propelled, high-clearance, centrally articulated, lightweight vehicle, designed for spraying in cotton is produced by the West Texas Lee Company in Idalou, Texas. The basic frame of a West Texas Lee unit was purchased by Dr John Triantafyllis at the A.C.R.I. in 1996 and modified for soil conductivity work. Local engineers (Armor Industries in Gunnedah) were contacted to determine if cost savings could be made by having a similar unit constructed in Australia. The decision was then made to proceed with a local manufacturer.

Eight removable (20lt) aluminium post-mix spray tanks mounted on the sprayer contain the different insecticide treatments. Each spray tank is pressurised using an air compressor, independently plumbed to an eight-metre boom, each with a pressure gauge and regulator. Treatments are activated from a solenoid controller box inside the cab and since the spraying lines are not shared, this alleviates the need for flushing between treatments. All treatment lines can be connected to a 350lt water-tank for flushing at the end of a trial and the aluminium tanks can be removed for triple rinsing. The spray rig has a carbon filtered, air-conditioned cab, which minimises exposure to insecticide treatments and improves the comfort of the operator. The spray-rig was manufactured for a total cost of

A list of publications arising from the research project

- Forrester, N. W. and Holloway, J. W. (1999) Strategies for prevention of development of pesticide resistance. In Proc. International Cotton Advisory Committee Regional Consultation on Insecticide Resistance Management in Cotton, Multan, Pakistan (in press)
- Holloway, J. W., Leonard, B. R. and Forrester, N. W. (1999) New Insecticide Chemistry for Cotton IPM. In Proc. Beltwide Cotton Production Research Conference, National Cotton Council, Memphis, TN pp. 1086-1089.
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Plain English Summary

Helicoverpa armigera remains the most important pest species in Australian cotton. In the 1999/2000 cotton-season, transgenic Ingard® cotton accounted for approximately 30% of the cotton planted in Australia. Significant savings in the numbers of insecticide applications in Ingard® crops have reported, particularly early in the growing season. However 70% of the Australian crop is planted to conventional varieties, and relies on foliar applied insecticides for protection against insect pests. Current transgenic cotton varieties still require supplemental control of *Helicoverpa* species later in the cotton season. Control of *Helicoverpa* spp. has traditionally relied on applications of organochlorine, pyrethroid, carbamate and organophosphate insecticides. Overuse of some of these groups has lead to environmental, residue and resistance problems. This project aims to evaluate the effects of resistance on field efficacy of some of the older insecticide groups, as well as to provide an independent assessment of the efficacy of new insecticides for control of *Helicoverpa* species. This information will assist in the update of Insecticide Resistance Management strategies for Australian cotton.

A\$47,000 and has completed more than 160hrs of spraying in the field so far, without major difficulties (Plate 4).

Results

The design and construction of a high clearance multi-treatment spray-rig has improved the accuracy, efficiency and safety of insecticide application at the A.C.R.I. The Australian cotton industry will benefit from improved data quality (the time to conduct experiments has been significantly reduced and multiple treatments can be applied over a shorter time span). The rig is lightweight (less than 2.75 tonnes) and mobile (on a tandem axle trailer towed behind a Toyota Land-Cruiser). Researchers from the QDPI (Dr. Dave Murray, Peter Hughes and Hugh Brier) are currently seeking funds to construct a rig of the same basic design for insecticide trials in QLD.

7) To extend the results of the conventional insecticide programme to all the sections of the industry during and at the end of the season and help formulate each season's new IRM strategy.

This project provides data to assist in informed decisions on the format for each new season's insecticide resistance management strategy. Results from this project have contributed to a number of changes to the Cotton Insecticide Resistance Management strategies:

1 Colour-coding the different insecticide groups on IRM strategy cards.

This facilitates grower, consultant and agronomist understanding of how insecticides are related in terms of mode of action and resistance status. Colour coding the strategy cards provides a straight-forward guide to the rotation and alternation of different insecticide groups.

2 Removing the restriction of the use of Foliar Bt's in Ingard crops.

The resistance management strategy for transgenic Bt cotton aims to delay an increase in frequency of genes for resistance to Bt in *Helicoverpa* species. This is a 'high dose' strategy with several basic assumptions, one of which is that the transgenic cotton plants express a high dose of Bt throughout the cotton season. The high dose of Bt should control not only susceptible *Helicoverpa* larvae, but also any heterozygous resistant insects (making resistance to Bt functionally recessive in the field). Commercial experience has shown that the efficacy of transgenic cotton declines during the cotton season and that supplemental control of *Helicoverpa* species is required. Foliar Bt's can be used as a top up for Ingard crops (*but not on Ingard refuges*) without jeopardising the tenets of the IRM strategy. This provides a cost effective and IPM compatible management tool for *Helicoverpa* species in Ingard® crops, particularly in environmentally sensitive areas where Foliar Bt's can be used in preference to products such as endosulfan.

3 Removing pyrethroids from Stage 1 and from the end of Stage 3

The status of pyrethroid resistance continues to worsen in the Australian cotton industry, in terms of increasing resistance frequencies and factors in most cotton growing valleys and reduced field efficacy of pyrethroids alone and in mixtures. Even the efficacy of elite partial resistance breaking pyrethroids (such as bifenthrin) has declined in the field in the last couple of seasons. The original 1983/84 cotton IRM strategy was set up to preserve the efficacy of pyrethroids and endosulfan by limiting their use to strict windows (corresponding with peaks of *Helicoverpa* generations) during the cotton season. By 1995/96 the efficacy of the pyrethroid group had continued to decline and restrictions on pyrethroid use were relaxed to allow pyrethroid use in all stages of the cotton season. In the 1998/99 season the use of pyrethroids in Stage 1 was again restricted in an effort to prevent season long selection with pyrethroids and halt or reverse the continuing deterioration in pyrethroid efficacy. In 1999/2000 pyrethroid use was further restricted at the end of stage 3 to tighten the pyrethroid use window.

4 Recommending further alternation of the different insecticide groups

As the efficacy of single products from the pyrethroid, carbamate and organophosphate groups has declined against field populations of *Helicoverpa armigera*, growers and consultants have come to rely more and more heavily on insecticide mixtures. This project has provided some much-needed replicated field trial data on the efficacy of mixtures and has led to the development of guide-lines for their use. Recommendations have been added to the IRM strategies and the Cotton Pest Management Guide to encourage more effective alternation and rotation of the different insecticide groups.

5 Including newly registered products (Abamectin®, Intrepid® and Tracer®)

Newly registered products such as Abamectin®, Intrepid® (chlorfenapyr) and Tracer® (spinosad) have been added to the cotton IRM strategies. Independent evaluation of these and other new conventional insecticides as part of this project will assist in determining their initial suggested fit alongside existing management tools

Table 1. Insecticides tested in replicated small plot trials.

Trade Name	Common Name	Chemical Group	Form	Supplier	Rate/Ha
Marlin	methomyl	carbamate	LC	Rhone Poulenc	0.5L
Larvin	thiodicarb	carbamate	SC	Rhone Poulenc	2.5L
Parathion methyl	methyl parathion	organophosphate	EC	Crop Care	2L
Predator	chlorpyrifos ethyl	organophosphate	EC	DowAgrosciences	4L
Bulldock	betacyfluthrin	pyrethroid	EC	Bayer	0.8L
Decis Forte	deltamethrin	pyrethroid	EC	AgrEvo	0.7L
Talstar	bifenthrin	pyrethroid	EC	FMC	0.8L
Zeta-cypermethrin	Zeta-cypermethrin	pyrethroid	EC	FMC	0.5L
Pbo	piperonyl butoxide	MDP synergist	EC	Crop Care	0.435L
Ethion	ethion	OP synergist	EC	FMC	1.875L
Tracer	spinosad	naturaiyte	SC	DowAgrosciences	0.2L
Intrepid	chlorfenapyr	pyrole	SC	Cyanamid	1.1L
Affirm	emamamectin benzoate	avermectin	EC	Novartis	0.65L
Steward	indoxacarb	indoxadiazine	SC	Dupont	0.65L
Prodigy	methoxyfenozide	insect growth regulator	SC	Bayer	1.66L
Costar	foliar Btk	<i>Bacillus thuringiensis</i>	SC	Novartis	0.9L
Gemstar	NPvirus	baculovirus	LC	Rhone Poulenc	0.5L
MVP2	foliar Btk	<i>Bacillus thuringiensis</i>	SC	Cyanamid	1L

LC = liquid concentrate SC = suspension concentrate, EC = emulsifiable concentrate, and WP = wettable powder.

Plate 1. Topical bioassay of 30-40mg *H. armigera* larvae – application of 0.2 $\mu\text{g}/\mu\text{l}$ fenvalerate using a Hamilton micro-syringe.

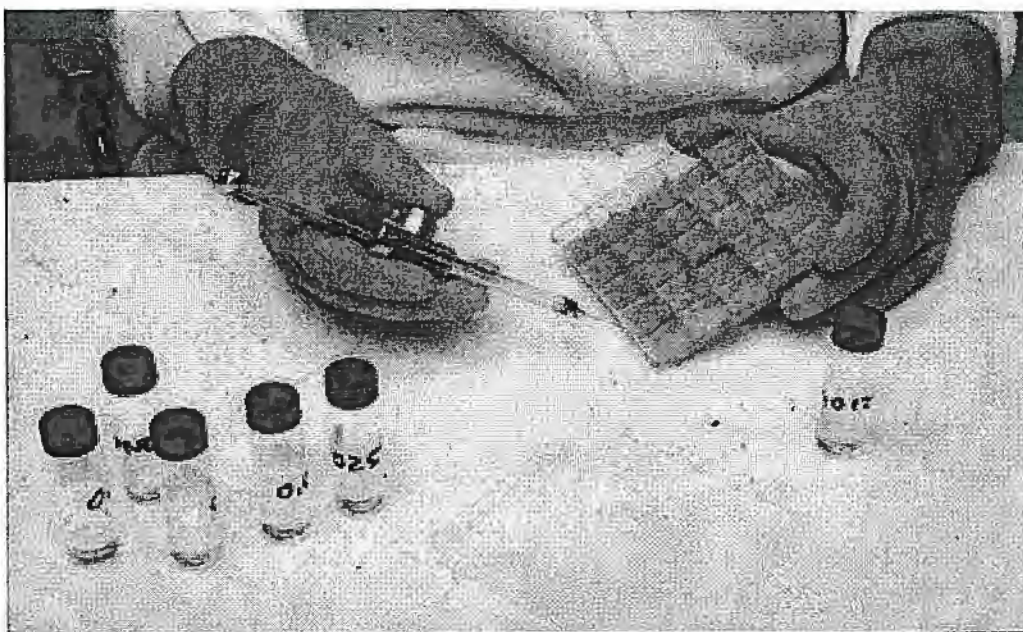


Plate 2. Replicated Small plot trials of new conventional insecticides at the A.C.R.I. Treated plots (foreground) and untreated control plots (centre) at the end of the 1998/99 season.

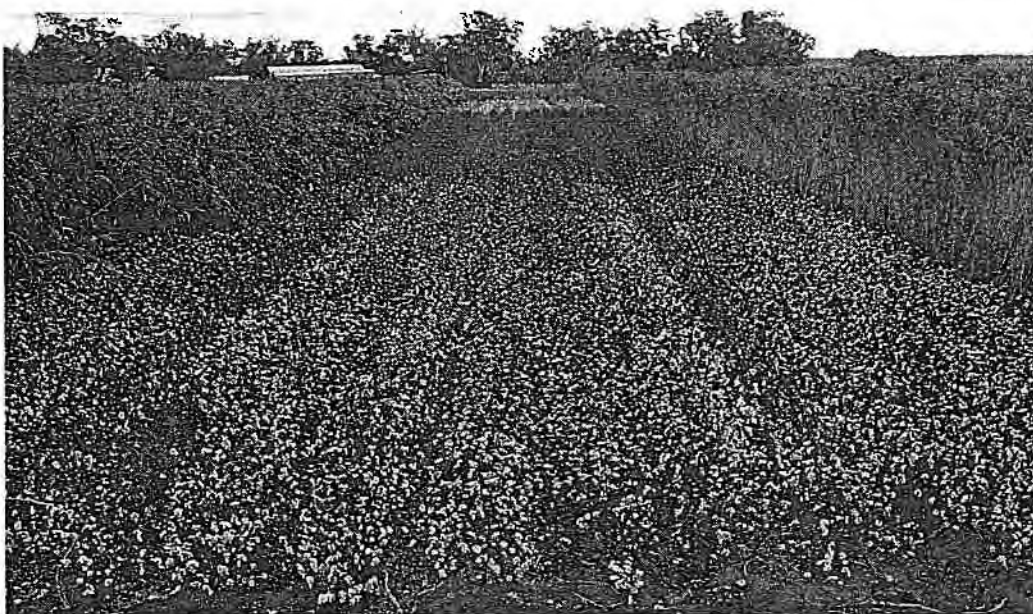


Plate 3 Larval Vial Test assessing the efficacy of bifenthrin against neonate *H. armigera* larvae.

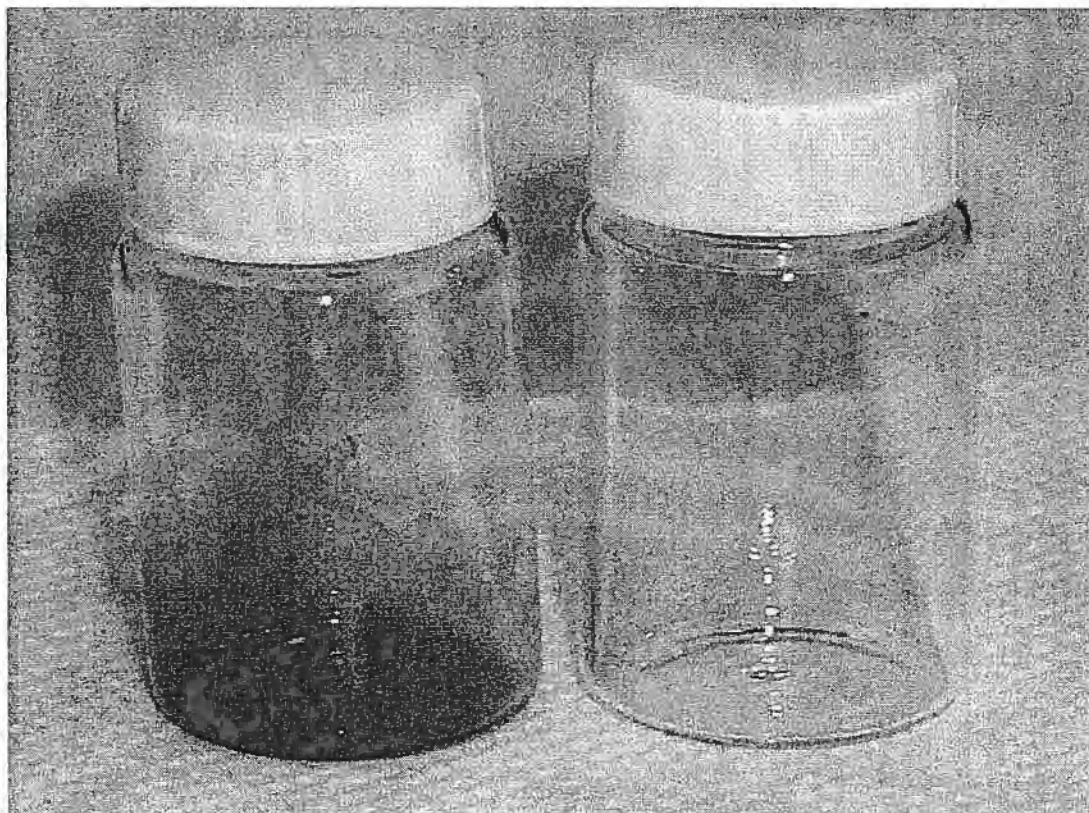


Plate 4. Purpose designed and built multi-treatment spray rig at the ACRI.



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