DAN119.

# Cotton Research & Development Corporation

# "CONSERVATION AND UTILISATION OF BENEFICIAL INSECTS IN THE COTTON AGROECOSYSTEM FOR INTEGRATED PEST MANAGEMENT IN CONVENTIONAL AND TRANSGENIC COTTON II"

**(DAN 119 C ) (July 1998 to June 2001)**


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## NSW AGRICULTURE

*"A Final Report prepared for the Cotton Research and Development Corporation"*

A-2001

# January, August & Final Reports

## *Part 1 - Summary Details* **REPORTS**

*Please use your TAB key to complete part 1 & 2.*

**CRDC Project Number:** **DAN 119C**

| | | |
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| **January Report:** | ☐ | Due 29-Jan-01 |
| **August Report:** | ☐ | Due 03-Aug-01 |
| **Final Report:** | ☒ | Due within 3 months of project completion |

**Project Title:** Conservation and utilization of beneficial insects in the cotton agroecosystem for integrated pest management (IPM) program on transgenic and normal cotton II

**Project Commencement Date:** July 1998 **Project Completion Date:** June 2001

**Research Program:**

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NSW AGRICULTURE

# AUSTRALIAN COTTON RESEARCH INSTITUTE, MYALL VALE, NARRABRI, NSW 2390

## APPROVAL FOR SUBMISSION OF FINAL REPORT (DAN 119C) - DR Robert Mensah

Dr Robert Mensah has been granted approval to submit to Cotton Research and Development Corporation (CRDC) the attached final report " Conservation and Utilisation of Beneficial insects in the Cotton Agroecosystem for Integrated Pest Management in Conventional and Transgenic cotton II" (DAN 119C).

The report has been refereed by his peers and considered to be adequate.

Mr Dallas Gibb
(Program Leader, Plant Fibres)

Date: 15/10/01.

Dr Richard Spurway
Deputy Chief, Division of Plant Industries
NSW Agriculture, Orange, NSW

Date:

# DECLARATION

This report to the best of my knowledge contains no copy or paraphrase of materials previously published by any other person. The studies contained in this report were conducted by myself under the project Code DAN 119C funded by the Australian Cotton Research and Development Corporation (CRDC) and NSW Agriculture.

Dr Robert Mensah
(Senior Research Scientist)(Cotton Entomology, IPM)

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## *Plain English Summary*

Many beneficial insects have been recorded in Australian cotton. The potential value of these beneficial insects have not been widely exploited in cotton pest management due to lack of understanding of the efficacy of these beneficial insects, and lack of techniques to maximise both their abundance and effectiveness. Production systems based on monocultures also discriminate against and reduce the activity of beneficial insects because they lack ecological diversity. *Helicoverpa* spp. which are the major pests of cotton crops in Australia are highly migratory and can therefore rapidly infest cotton crops and lay their eggs and unless natural enemies are present and well established in high numbers before the pests arrive, they cannot respond rapidly enough to control them before damage is sustained. These have resulted in loss of confidence in these insects by growers who have opted instead to depend on synthetic insecticides to control the cotton pests. A major focus of the Australian cotton industry is to reduce their dependence on synthetic insecticides. One way this can be achieved is through the development and adoption of a true integrated pest management program which places much more emphasis on the role of beneficial insects.

The IPM program developed in this project utilised predatory insects as basic components of IPM by using techniques such as a lucerne/cotton interplant system and a supplementary food spray called Envirofeast®. The intergration of these two techniques with biological (NPV and Bt) and synthetic insecticides on cotton helped to achieve economic cotton yields and reduced the use of synthetic insecticides by 50 per cent without sacrificing cotton yield and profitability. In this study, the decision to use either biological or chemical insecticide to manage *Helicoverpa* spp. in cotton was based on predators to *Helicoverpa* spp. (pest) ratio of 0.5.

The study examined the effect of Ingard® cotton crops interplanted with lucerne and normal cotton crops. The study showed that interplanting lucerne as strips in Ingard® cotton crops did not affect the number of *Helicoverpa* spp. eggs and larvae laid on the Ingard® crop but it did reduce green mirid numbers and increased populations of predators on the Ingard® crop. The Ingard® crop with lucerne interplant also yielded higher than the Ingard® crop without lucerne interplant. Another alternative to use lucerne as a trap or refuge crop in cotton crops is to plant the lucerne crop in a centrally located block adjacent to cotton fields. This can manage green mirids and increase predator populations on adjacent cotton fields located 1- 50 metres away from the lucerne block.

The study also showed that mixing Envirofeast® with NPV can increased the efficacy of NPV against *Helicoverpa* spp. neonate larvae.The optimum rate of Envirofeast/NPV mixture is 1.5kg Envirofeast per hectare. The optimum time to commence Envirofeast application in an IPM program is when the cotton crop is at a 4 true-leaf stage. Envirofeast® can be applied as a band spray (33-50 per cent band) or skip row spray (i.e. to every second row) to attract similar numbers of predators as when the product is applied as a solid spray (no banding) or to the entire crop (no skip row). Tailoring Envirofeast® treatment in this way will ultimately reduce the

quantity of product used, cost of the product and allow a multiple use pattern for the product.

Studies to examine *Helicoverpa* spp. pupae production under IPM and conventional insecticide regimes showed that, in terms of Ingard® refuge requirements, IPM managed cotton should be treated the same way as conventional insecticide managed cotton as both treatments can produce similar numbers of pupae during the cotton season.

Petroleum spray oils particularly Caltex oil (Canopy) with ultra-violet protectants applied at 2% v/v has significant effects against *Helicoverpa* spp. eggs, neonate larvae and aphids in commercial cotton field. The oil applied at a concentration of 2-10 % on irrigated cotton crops and 2-5% on dryland cotton crops was not phytotoxic to cotton plants. Addition of UV protected PSOs to biopesticides (NPV and Bt) may improve the efficacy and persistence of biopesticides against *Helicoverpa* spp. neonate larvae.

In conclusion, the results clearly indicate that a refined IPM approach such as the type developed in this project could have a distinctive advantages in terms of economic and environmental impacts on cotton production. The success of such an approach lies in a strict adherence to its methodology.

*Part 2*

## 1.0 Background to the project.

Many beneficial insects have been recorded in Australian cotton (Room (1979). These include generalist predators and specialist parasitoids which attack key pests. The potential value of these beneficial insects have not been widely exploited in cotton pest management due to lack of understanding of the efficacy of these beneficial insects, and lack of techniques to maximise both their abundance and effectiveness. Adoption of within field monocultures in the cotton production system also discriminate against and reduce the activity of beneficial insects because they lack ecological diversity (Hagen and Hale, 1974). *Helicoverpa* spp. which are the major pests of cotton crops in Australia are highly migratory and can therefore rapidly infest cotton crops and lay their eggs and unless the natural enemies are present and well established in high numbers before the pests arrive, they cannot respond rapidly enough to control them before damage is sustained (Fitt, 1989; Gregg *et al.*, 1993; Mensah and Harris, 1994, 1995). These have resulted in loss of confidence in these insects by growers who have opted instead to adopt chemical control.
A major focus of the Australian cotton industry is to reduce their dependence on synthetic insecticides. One way this can be achieved is through the development and adoption of a true integrated pest management program (IPM) which conserve and utilise beneficial insects as a base of the program.

CRDC funded projects DAN 68C and 98C have addressed some of these problems by developing Envirofeast and lucerne crop refugia technologies to conserve and enhance the activities of beneficial insects and utilise them as basic components of IPM programmes for cotton (Mensah, 1997). The Envirofeast® product when applied onto cotton crops attracts and augment beneficial insects from the lucerne crops and natural refugia onto cotton to feed on the pests. However, the feeding responses of the different species of predatory insects in the presence of Envirofeast® spray needed to be studied. It is crucial to know which of the predatory insect species switch from cotton pests to feed on Envirofeast® product when applied to cotton crops. Does Envirofeast spray affect the number of prey attacked by individual predator? Does Envirofeast spray affect their searching ability? The lucerne crop interplanted with cotton crops manages green mirids and conserves beneficial insects. The lucerne crop occupies 2 per cent of the total cotton crop area and most growers will prefer to use the whole crop area to grow cotton. The question is, if lucerne crop is planted in a block or field adjacent to cotton fields, can it manage green mirids and conserve beneficial insects which can subsequently be moved into cotton with Envirofeast® spray as lucerne planted as strips within cotton?
As in cotton growing regions worldwide, the cotton industry is currently at risk of losing insecticide products due to either increasing resistance and or environmental problems. In Australia, the development and introduction of transgenic cotton in 1996 was originally thought to be the answer to the industry's pest management problems, but the results of the large scale field trials during the 1996/97 cotton season has indicated the opposite and *Helicoverpa* spp. are more likely to develop

resistance to these crops. As a result much CRDC and CRC funded research are focussing on resistance management issues of transgenic cotton. In particular, the projects of Drs Neil Forrester and Gary Fitt are focussing on a resistant management plan such as pupae destruction, refuges to produce susceptible individuals to dilute the resistant population and the introduction of a double gene into the crop in an attempt to delay resistance on transgenic cotton crops. Despite this management plans, transgenic cotton will need to be managed in the context of a true IPM in order to delay resistance. What then is a true IPM? This is an IPM system that places much more emphasis on the role of beneficial insects. A true IPM system should have strategies put in place to conserve, augment and utilise beneficial insects as basic components. The current pest management strategy cannot be classified as an IPM despite the widespread use of pest thresholds and objective sampling because of the over reliance on insecticides. Truly integrated systems of pest management are now being developed for cotton that place much emphasis on the beneficial insects to control key pests (DAN 98C, Murray DAQ 58C). This IPM system is based on predator to prey ratio to make decisions on when to introduce a pest control tool. This enabled the full benefit of beneficial insects to be exploited and also reduces indiscriminate application of pesticides.

The Australian cotton industry cannot afford to plant the total cotton area with transgenic crops because of resistance. This means, there will still be large areas of normal cotton planted in the industry. The normal cotton crops will still need protection against pests indicating a strong need for alternative pest control strategies to complement transgenic cotton crops and also manage pests on the normal cotton crops. Envirofeast® and lucerne refugia technology developed under CRDC funded projects DAN 68C and 98C have been used to develop IPM program for normal cotton. The Envirofeast® IPM program is currently being evaluated prior to commercialisation by Rhone-Poulenc (Rural) Australia Pty Ltd. Guidelines for use of this IPM program has been developed and distributed to co-operating growers within the industry. Twenty cotton growers and consultants have been selected across the cotton growing areas to use the IPM program during the 1997/98 season. Apart from this, studies have commenced under CRDC funded project (DAN 98C) to integrate the tools within the Envirofeast IPM with transgenic cotton. This study will not be completed when project DAN 98C ends in June 1998. In my view, however, research should continue to integrate Envirofeast IPM strategy with transgenic cotton. In integrating Envirofeast IPM especially Envirofeast/Gemstar virus mixture and Tracer on transagenic cotton one should consider the cost of such IPM. Further research is needed to determine the optimum rates of the tools within Envirofeast IPM to make it economical when integrated with transgenic cotton.

Also, the transgenic cotton resistance management plan proposed by the TIMS Commitee require that cotton growers plant either 10 ha unsprayed normal cotton or 100 ha conventionally managed normal cotton for every 100 ha of transgenic cotton planted to produce susceptible pupae to dilute any resistant individuals developed on the transgenic crop. The question is if a grower wanted to manage the normal cotton refuge with Envirofeast IPM instead of conventional insecticides, what size of Envirofeast IPM normal cotton refuge is required to satisfy the Ingard management plan? Currently this is not known. A better understanding of the pupae production under Envirofeast IPM system will enable the industry incorporate Envirofeast technology into the transgenic cotton management plan.

As in many IPM programmes developed for agricultural pests worldwide, Envirofeast IPM strategy will require additional research for more selective and enviromentally friendly pest management tools to be incorporated into the program. This will ensure continuous success of the IPM system in the field. One of the areas cotton research has not been focussed is the use of refined petroleum products and their effect on the survival of *Helicoverpa* spp. in cotton. Refined petroleum oils (PSOs) have been used since the 1860s for the control of phytophagous arthropod pests (Riehl, 1969). The efficacies of these PSOs as suffocants of traditional target pests are known to increase with increasing molecular weghts of their oil molecules but unfortunately the risk of PSO induced phytotoxicity have also been related to increasing molecular weight (Riehl, 1969). This has influenced the type of oils used for commercial foliar application on crops with most PSOs being manufactured as narrow-range oils with mean carbon number equivalents of C19, C21 and C23 (Furness et al. 1987). Mensah *et al.* (1995) reported of a reduced oviposition by *Helicoverpa* spp. on cotton crops treated with Caltex Lovis C21 oil. This oil did not show any phototoxic effect on the cotton plants and was less disruptive to natural enemies. The use of higher molecular weight C24 narrow range (Beattie, 1990) and broad-range PSOs was suspended in 1987 because of the risk of phytotoxicity (Beattie *et al.*, 1989), however, Ampol Research and Development Team has released a new "phytobland" broad-range C24 PSO (Ampol D-C Tron Plus) for use in foliar sprays. Additives in D-C-Tron Plus decrease ultraviolet oxidisation of oil molecules and reduce the risk of phytotoxicity to negligible levels (Hodgkinson *et al.* in press). Phototoxicity was also not detected when D-C-Tron Plus was used to control citrus leafminer, psylla and also *Helicoverpa* spp. on tomato (Beattie *et al.*, 1995 a,b; Rae *et al.*, 1996, 1997). It is therefore crucial to undertake preliminary studies to assess the efficacy of the newly developed PSOs on the survival of *Helicoverpa* spp. and their natural enemies for possible incorporation into the cotton industry's IPM strategy.

The project was divided into four main parts. The first part was to improve understanding of predator feeding responses to prey, predator/prey interaction in relation to Envirofeast spray. The second part was to manage green mirids and conserve beneficial insects in cotton using lucerne crop planted in blocks adjacent to cotton fields instead of strips within cotton fields. The third part of the project was assessing the value of integrating food spray (Envirofeast) with other forms of control strategies to develop IPM program on transgenic and non-transgenic cotton. The fourth part of the project assessed phytotoxicity of PSOs to cotton plants and the efficacy of *Helicoverpa* spp. and their natural enemies to different rates and volume of application of PSOs to cotton crops.

**2. 0 Project objectives**

1. To assess the value of integrating Envirofeast® sprays, lucerne refugia, virus spray and synthetic insecticides for an IPM program on transgenic and normal cotton.

2. To determine levels of *Helicoverpa* spp. control on transgenic cotton with and without Envirofeast and lucerne strip refugia.

3. To determine the relative *Helicoverpa* spp. pupae production in transgenic and normal cotton under Envirofeast® IPM, conventional insecticide and organic (unsprayed) regimes (with Dr Gary Fitt).

4. To determine an optimum rate and time of application of Envirofeast/Gemstar virus mixture sprays on the survival of *Helicoverpa* spp. and their natural enemies on normal and transgenic cotton.

5. To evaluate and compare the feeding responses of adults and larvae of predatory beetles, bugs and lacewings to *Helicoverpa* spp. eggs and larvae in cotton systems in relation to Envirofeast sprays.

6. To investigate the utility of lucerne crop planted in a block adjacent to cotton fields rather than strips within cotton in the management and conservation of green mirids and beneficial insects.

7. To evaluate the newly developed petroleum spray oils (PSOs) on the survival of *Helicoverpa* spp. and their natural enemies in cotton (with Prof. GAC Beattie who is working in close association with manufacturer of the new PSOs).

## 3.0 Extent to which objectives has been achieved

3.1 The study of objective 1 showed that the integration of lucerne/cotton interplant system with supplementary food sprays retained and increased populations of predatory insects in cotton crop. The strategic use of biopesticides (Bt and NPV) within the IPM program reduced the use of synthetic insecticides by 50 per cent without sacrificing cotton yield and profitability.

3.2 The study of objective 2 showed that interplanting lucerne in Ingard® cotton crops did not reduce the number of *Helicoverpa* spp. eggs laid on the Ingard® crop. Thus the presence of lucerne strips did not affect egg lay. Similarly the number of *Helicoverpa* spp. neonate larvae recorded on Ingard® crops interplanted with lucerne crops was not significantly different from Ingard® crops interplanted with normal cotton crops. However, populations of predatory beetles, bugs, lacewings and spiders were significantly higher ($P<0.01$) on Ingard® cotton crops interplanted with lucerne than Ingard® crops interplanted with normal cotton crops. Both the Ingard® with lucerne and normal cotton strips received four synthetic insecticide sprays against *Helicoverpa* spp. during the season the Ingard® crop with lucerne interplant yielded 7.67 bales per ha whereas the Ingard® with normal cotton interplant yielded 7.17 bales per ha.

3.3 The study of objective 3 showed that the number of *Helicoverpa* spp. pupae per metre per sample date was significantly lower P<0.01) in Ingard® cotton crops than normal cotton under Envirofeast® IPM regimes and unsprayed cotton. The highest number of pupae per metre per sample date was recorded on the unsprayed cotton followed by Envirofeast® based IPM on normal cotton. There was no pupae recorded in the lucerne strips within the transgenic and normal cotton crops. In all, 90 per cent of the pupae recorded in all the treatments were *Helicoverpa armigera*, 5 per cent were *H. punctigera*. The other 5 per cent did not emerge. *H. punctigera* pupae occurred in December and early January whereas all pupae recorded from January until May were all *H. armigera*. All the pupae recorded under Ingard® was *H. armigera*.

3.4 In objective 4 the study determined Envirofeast® rate of 1.5kg/ha as the optimum rate required for Envirofeast® in combined mixture with NPV. At this rate and in commercial cotton field, the Envirofeast®/ NPV (Gemstar®) mixture caused 54.2 per cent mortality to *Helicoverpa* spp. neonates compared to 41.7 per cent mortality caused by NPV alone. The optimum time to apply Envirofeast®/NPV mixture is early in the morning or late in the afternoon when the sun goes down. Growers should avoid daytime sprays as NPV are destroyed by UV light and Envirofeast® has no UV filters to protect the virus.

3.4.1 Studies to determine the optimum time and placement of Envirofeast®, a supplementary food spray on the abundance of predatory insects on cotton showed that plots treated with Envirofeast® at 4-true leaf stage recorded the highest number of predatory beetles, bugs and lacewings per metre compared with plots treated at 8-true leaf stage and unsprayed (control) plots. The study also showed that the number of predators recorded in cotton crops treated with Envirofeast® as a band spray (33-50 per cent band) or skip row spray (i.e. to every second row) was not significantly different (P>0.05) from plots where the product was applied as a solid spray (no banding) to the entire crop (no skip row). Thus tailoring Envirofeast® treatment in this way will ultimately reduce the quantity of product used, cost of the product and allow cotton growers to adopt a multiple use pattern for the product to support integrated pest management programs in cotton.

3.5 The feeding responses of *Coccinella transversalis*, *Adalia bipunctata* and *Dicranolauis bellulus* have been studied in detail. These predatory beetles ate eggs and larvae of *Helicoverpa* spp. in the laboratory and did so in the field. Densities of prey and other predators can affect their consumption rate. Increasing the number of prey increased their consumption rate. The amount of prey they consumed increased their weight and this in turn affected the number of eggs they laid and their survival rate. The study also showed that factors such as temperature, rainfall, relative humidity, irrigation, food, competition, cultivation and synthetic insecticides can cause changes in the abundance of predatory insects in cotton farms. The study determined a predator to Helicoverpa spp. (pest) ratio as a threshold to incorporate the activity of the predators into pest management decisions. A predator to pest ratio of 0.5 or higher means the IPM system is functioning well.

3.6 In objective 6, the study showed that a lucerne crop planted in a block can manage green mirids on adjacent cotton fields located 50 metres away. The lucerne can serve as a trap crop for the green mirids. To achieve this, the lucerne crop should be kept attractive through the cotton growing season. The attractiveness of the lucerne can be maintained by slashing a quarter of the block at a time starting when the lucerne commence flowering. This will ensure that the lucerne block is always composed of older and younger lucerne growth. The lucerne crop planted in block served as a source of predators particularly predatory beetles, bugs and lacewings to adjacent cotton fields. However, given the abundance of food resources, shelter, mating, oviposition sites etc within the lucerne crop, higher numbers of the predators were not inclined to move from the lucerne block to forage the adjacent cotton crop. The movement was improved when Envirofeast® food spray was applied to the adjacent cotton crop or when part of the lucerne block was slashed.

3.7 Studies to evaluate Petroleum spray oils particularly Caltex oil (Canopy) as an IPM tool showed that Canopy oil with ultra-violet protectants applied at 2% v/v has significant effects against *Helicoverpa* spp. eggs, neonate larvae and aphids in commercial cotton field. The oil applied at a concentration of 2-10 % on irrigated cotton crops and 2-5% on dryland cotton crops was not phytotoxic to cotton plants. The use of PSOs against crop pests is advantageous over conventional insecticides because they are less disruptive to natural enemies of pests.The study also showed that the addition of UV protected PSOs to biopesticides (NPV and Bt) may improve the efficacy and persistence of biopesticides against *Helicoverpa* spp. neonate larvae.

## 4.0 How has your research addressed the Corporations three outputs: Sustainability, profitability and international competitiveness, and/or people and community?

The planting of lucerne within cotton crops and the use of food sprays to attract and conserve beneficial insects was developed in an earlier CRDC funded project DAN 68, 89 and 98C. This study has strategically integrated biopesticides Bt and NPV with lucerne cotton interplant system, food sprays and beneficial insects to develop an IPM program which has reduced the use of synthetic insecticide by 50 per cent without sacrificing yield. Petroleum spray oils (PSOs) have been evaluated for the first time in the cotton industry to complement IPM and which may in the near future reduce synthetic insecticide use in the cotton industry further. The conservation and use of beneficial insects to support IPM as addressed in this study, is a self-perpetuating solution to pest problems and can reduce crop losses and pest management costs to improve profitability, competitiveness and sustainability of the cotton industry. This research has therefore addressed all the Corporations three outputs and in addition set out to change the face of the Australian cotton industry in the eyes of the community.

## 5.0 Detail the methodology and justify the methodology used.

5.1 *To assess the value of integrating Envirofeast® sprays, lucerne refugia, virus spray and synthetic insecticides for an IPM program on transgenic and normal cotton.*

In this study, Envirofeast® sprays, lucerne/cotton interplants, biological pesticides, (NPV (Gemstar®), Bt and Tracer®), and synthetic insecticides were evaluated in large scale commercial cotton field at Norwood near Moree, Bellevue near Warren and Yarral near Narrabri in the 1998-99 season. These treatments were compared with transgenic and normal cotton crops managed with synthetic insecticides. The size of the trial at Norwood was 170 ha, Bellevue 132 ha and Yarral 50 ha. The cotton crops were interplanted with lucerne crops 12 m wide and placed 300 m apart across the field. The treatments evaluated at each site are summarised in the table below: All treatments were replicated 4 times at each study site in a randomised complete block design. The decision to apply each treatment was based on predator to pest (*Helicoverpa* spp.) ratio of 0.5 or higher (Mensah, 1999, 2000).

*Helicoverpa* spp. eggs and larvae were assessed visually and predators were sampled using D-vac (Mensah, 1996, 1997). *Helicoverpa* pupae were sampled once every 4 weeks from each treatment until the end of the study. The number of insects were expressed as numbers per metre per sample date. At the end of the season, insecticide spray records were compared between the treatments. Cotton crops were harvested and lint yields (bales/ha) and gross margins from each treatment were compared. The gross margin was based on lint yields, total insecticide spray costs, cost of seeds and licence fee in the case of transgenic (Ingard®) cotton. All other agronomic inputs were the same for all treatments.

Treatments compared at Yarral, Norwood and Bellevue in 1998-1999 season.

| Treatments | Features |
|---|---|
| 1. Sicala V2 + Lucerne strips + Envirofeast® + Envirofeast/Gemstar virus + insecticides | Normal leaf cotton with lucerne and managed with predator food attractant, Gemstar virus and synthetic insecticides. |
| 2. Sicala V2 (transgenic) + Lucerne strips + Envirofeast®+ Envirofeast/virus + synthetic insecticides | Normal leaf (transgenic) cotton with lucerne strips and managed with predator food attractant, Gemstar virus and insecticides. |
| 3. Sicala V2 + Conventional insecticides | Normal leaf cotton managed with conventional insecticides |
| 4. Sicala V2 (transgenic) + insecticides | Normal leaf (transgenic) cotton managed with conventional insecticides. |

5.2 *To determine levels of Helicoverpa spp. control on transgenic cotton with and without lucerne strip refugia.*

The goal of the study was to determine whether interplanting lucerne or normal cotton crops as strips within commercial Ingard® cotton crops can conserve predatory insects and manage green mirids in the Ingard® crops. Four treatments (1) Ingard® cotton interplanted with lucerne strips (2) Ingard® cotton interplanted with normal cotton strips, (3) Lucerne strips alone and (4) normal cotton strips alone were evaluated.

The lucerne and normal cotton strips were 12 m (or rows) wide and 100 m long. For every 300 rows of Ingard® cotton, one strip of either lucerne or normal cotton crop was planted; this was repeated four times across the field. The lucerne were planted 4 weeks before the cotton and was irrigated at the same time as cotton, depending on the soil moisture level. Alternate 6 m wide bands of each lucerne strip were slashed every 4 weeks. The 4 week slashings sequence stimulates new growth and prevents the lucerne from haying or drying off before the end of the study (Mensah, 1999; Mensah and Khan, 1997).

Predatory insects and green mirids were sampled weekly by taking a 20 m row vacuum sample from lucerne and cotton plants. After each sampling, the contents of the D-vac were transferred to a plastic bag, chilled, taken to the laboratory, and frozen until the contents were counted and identified. The predators were separated into predatory beetles, bugs, lacewings and spiders. The numbers of both mirids and predators were expressed as numbers per metre.

At the end of the study, cotton crops in each treatment were harvested and lint yields (bales/ha) were compared. All other agronomic inputs were the same for all treatments.

5.3 *To determine an optimum rate and time of application of Envirofeast/Gemstar virus mixture sprays on the survival of Helicoverpa spp. and their natural enemies on normal and transgenic cotton.*

Two studies were conducted under this objective. The first study was to determine the optimum rate of Envirofeast/NPV mixture and the other study was to determine the optimum timing and method placement of Evirofeast® spray to reduce cost and improve efficacy.

5.3.1 *Effect of Envirofeast®/Gemstar mixture on the survival of Helicoverpa spp. larvae*

The treatments evaluated were (1) 1.0 kg Evirofeast®/750 ml Gemstar, (2) 1.5 kg Envirofeast®/750 ml Gemstar®, (3) 2.0 kg Envirofeast®/750 ml Gemstar, (4) 2.5 kg Envirofeast®/ 750 ml Gemstar® mixture in 100 litres of water (5) Gemstar® alone and (6) unsprayed (control). Plots were arranged in randomized complete block design with 4 replicates with the size of each replicate measuring one hectare. A 40 m wide buffer separated each treatment and control plot.

Foliar application of each treatment were applied on 23 December 1998 when *Helicoverpa* spp. were predominantly neonates and numbers were 2 per metre. Three days after treatment application, 24 larvae were collected from each treatment and placed in 24 plastic well plates containing artificial diets. Larvae were kept one to a well to avoid cross-infection of the virus. The number of dead larvae were counted and recorded daily until all the surviving larvae had pupated. The per centage mortality for each treatment was calculated relative to the control plot.

### 5.3.2 *Responses of predatory insects to Envirofeast® spray applied to cotton crops with varying numbers of true leaves*

The experiment was conducted on a 50 ha commercial irrigated cotton field at Yarral near Narrabri in New South Wales. The treatments evaluated were application of Envirofeast® product to cotton plants at (1) 2-true-leaf stage, (2) 4-true-leaf stage, (3) 6-true-leaf stage (4) 8 true-leaf stage and (5) unsprayed (control). Plots were arranged in a randomized complete block design with 4 replicates with each replicate measuring 3 ha. The conventional insecticide treated plots were selected from other cotton fields located 400 m away from the trial site to avoid spray drift. A 40 m wide buffer separated food sprayed and unsprayed (control) plots.

Pre-treatment counts of insects were made 24 hours before treatment application and then approximately every 7 days until the end of the study. Foliar applications of each treatment were made on 29th October 1998 and thereafter at 10-day intervals until the end of study. On each occassion treatments were applied using 120 L water/ha. In all, 10 applications of Envirofeast® were made during the season. The control plot was left unsprayed and the synthetic insecticide treated standard plot received 10 applications according to local practice.

Predators of *Helicoverpa* spp. were sampled weekly using D-vac (Mensah and Harris, 1995; Mensah, 1996, 1997). On each sampling occasion, the D-vac sample was collected from a single pass of the tube of the vacuum sampler along the tops of the plants in 20 m of row. After each sampling, contents of the D-vac were transferred to a plastic bag, taken to the laboratory and counted. Predators were separated into predatory beetles, bugs, lacewings and spiders and the data were expressed as numbers per per metre for each treatment.

### 5.3.3 *Responses of predatory insects to Envirofeast® product applied as a "band" or "skip row" spray*

The experiment was conducted on an 80 ha commercial irrigated cotton field at Yarral near Narrabri in New South Wales. The cotton crops were interplanted with 3 lucerne strips each 8 rows wide and 300 metres apart across the field. The lucerne strips covered 2.5 per cent of the whole field. The methodology for the establishment of the lucerne/cotton interplants has been reported elsewhere (see Mensah, 1999). The goal of the study was to determine whether applying Envirofeast® (food) product as a "band" or "skip row" spray on cotton crops interplanted with lucerne (Mensah, 1999) could conserve and maximise the abundance of predatory insects on cotton.

The treatments evaluated were (1) Envirofeast® product applied as a "skip row' (i.e. spraying every second row crops) until first flower (2) Envirofeast® product applied at 30-50 per cent band until first flower (3) Envirofeast® product applied to all rows (solid/no band spray) and (4) unsprayed (control). All the treaments were applied using a ground rig. The Envirofeast® treated and the unsprayed plots were arranged in a randomized complete block design with 4 replicates with each replicate measuring 3.0 ha.

Pre-treatment counts of insects were made 24 h before treatment application and then all plots approximately every 7 d until the end of the study. Envirofeast® treatments were made on 9 November to 21 December 1999 at 14-day intervals. On each occassion the treatments were applied using 100 L water/ha. In all, 3 applications were made on the Envirofeast® treated plots during the season the early cotton season.

Predatory insect counts were made on cotton plants using a D-vac. Predators were separated into predatory beetles, bugs, lacewings and spiders and the data were expressed as numbers per metre for each treatment.

5.5 *To evaluate and compare the feeding responses of adults and larvae of predatory beetles, bugs and lacewings to Helicoverpa spp. eggs and larvae in cotton systems in relation to Envirofeast sprays.*

5.5.1 *Functional response of Coccinella transversalis* to *Helicoverpa* spp. *eggs* and larvae.

The consumption rate of *Coccinella transversalis* and *Dicranolauis bellulus* adults were assessed in the laboratory on *Helicoverpa* spp. eggs and larvae. Adult predators were starved for 24 hours and then exposed to different densities of eggs and larvae. The number of eggs consumed per day at different prey densities were calculated and a functional response curve was derived from the data.

5.5.2 *Effect of Envirofeast® on the consumption rate of C. transversalis adults.*

*C. traversalis* adults were introduced to *Helicoverpa* spp. eggs on cotton leaves treated with (1) Envirofeast®, (2) Sugar solution, (3) Water. The number of eggs consumed daily over 7 days were calculated.

5.5.3 *Determination of predator to pest (Helicoverpa spp.) ratio required to manage Helicoverpa spp. in cotton crops*

This study was conducted in irrigated cotton fields at Bellevue (31° 48'S, 147° 59'E) near Warren in New south Wales. The size of the cotton field at Norwood was 53 ha and at Bellevue 70 ha. The fields used for this trial were treated with food sprays (Envirofeast®) and biological insecticides (NPV and foliar Bt), from October until the first week in January to avoid disruption to the activity of predatory insects. Thereafter fields were treated with synthetic insecticides when *Helicoverpa* spp. numbers exceeded 2 (1st-3rd stage) larvae per metre of row of cotton (recommended pest threshold). Foliar application of Envirofeast® was commenced when the cotton crop was at the 4-true leaf stage and thereafter at 14 day intervals until the completion of the experiments.

Visual counts of *Helicoverpa* spp. eggs, larvae and predatory insects were made on cotton plants in 10 randomly selected one metre lengths of row i.e. 10 metres per field. Data for *Helicoverpa* spp. were expressed as numbers of eggs (E), very small plus small larvae (VS+S) and medium plus large larvae (M+L) per metre as in experiment 2.1. The survival rates of *Helicoverpa* spp eggs to very small and small larvae and medium and large larvae per metre were calculated from the field data.

The predatory insects were separated into predatory beetles, bugs, lacewings and spiders. In calculating the predator to pest ratio, all the predators were grouped as one unit (total predators). The predator to pest ratio per metre was calculated for each sample date by dividing the total number of the predators per metre by the number of *Helicoverpa* spp. eggs plus very small and small larvae per metre (i.e Total predators ÷ *Helicoverpa* spp. (E + VS+S). Numbers of medium and large larvae were not included in the calculation as at that stage they were too big for the predators to effectively capture as food.

A comparison was made between the predator to pest ratio and *Helicoverpa* spp. larval survival rate and density per metre by plotting the predator to pest ratio per metre per sample date at a minimum with larval survival rate and densities of eggs and larvae per metre per sampling date. This enabled the determination of the minimum ratio at which *Helicoverpa* spp. larvae can survive to reach, exceed or remain under the threshold of 2 larvae per metre in the study sites.

### 5.6 *To investigate the utility of lucerne crop planted in a block adjacent to cotton fields in the management of green mirids and and conservation of beneficial insects.*

Lucerne crop planted in a centrally located block surrounded by 3 adjacent irrigated cotton fields was used for the trial. The cotton field 1 was 20 metres , field 2 was 50 metres and field 3 was 100 metres away from the lucerne block.

Green mirids, predatory beetles, bugs, lacewings and spiders were sampled weekly from the lucerne block and the adjacent cotton fields using a D-vac. Data were expressed as numbers per metre.

### 5.7 *To evaluate the newly developed petroleum spray oils (PSOs) on the survival of Helicoverpa spp. and their natural enemies in cotton*

Experiments were conducted in the laboratory and field on irrigated cotton between 1999 and 2001.

#### 5.7.1 ***Laboratory experiments:***

Two experiments were conducted. In all experiments, *H. armigera* eggs and first instar larvae were used.

5.7.1.1 *Efficacy of Caltex Petroleum spray oil against H. armigera eggs*

Separate trials were conducted using 5 different concentrations of Caltex C24 oil on newly laid (white) eggs and 2-day old (brown) eggs. The oil concentrations evaluated on white eggs were 0.75%, 1.0%, 1.2%, 1.5% and 2.0% v/v, and on brown eggs were 1.0%, 1.5% and 2.0%. Plants sprayed with water were used as controls. Each treatment used 4 eggs stuck on a cotton plant, sprayed to run-off and then placed in a petri dish. Each treatment was replicated 5 times (n=20 eggs). The number of eggs that hatched and the number of larvae that died before moulting to second instar larvae were recorded. The percentage eggs that hatched and the percentage of eggs surviving to end of the first instar stage were calculated for each treatment.

5.7.1.2 *Efficacy of Caltex Petroleum spray oil against H. armigera first instar larvae*

The oil concentrations evaluated were 0.75%, 1.0%, 1.2%, 1.5% and 2.0% v/v. Water was used as control. For each concentration, I sprayed a total of 12 first instar larvae on cotton leaves until run-off. After spray application, larvae from each treatment were transferred and kept separately in 35-ml clear plastic containers containing artificial diet. Each treatment was replicated 5 times. The number of dead larvae were counted and recorded daily until all the live larvae had pupated, and the percentage mortality was calculated relative to the control.

5.7.1.3 *Efficacy of Caltex Canopy® oil + NPV and Bt against Helicoverpa spp. in the laboratory*

Studies were conducted in January 2001. Pre-squaring potted cotton plants were sprayed with either 0.75% NPV or 2% Bt or combined mixtures with of 1%, 2% and 5% v/v UV-protected Canopy oil. Each treatment was applied to leaves in the morning using a calibrated spray can. Treated plants were left in the sun and the leaves were sampled from Day 0 (30 minutes after application) to Day 5. Leaf discs were taken from each treatment and exposed to Helicoverpa armigera 1st instar larvae to feed for 24 hours. Larvae were then transferred to artificial diet until pupation. Larval mortality and development were recorded.

5.7.2 *Field studies*

5.7.2.1 *Phytotoxicity of Caltex PSOs* on *commercial irrigated cotton crops*

The study was conducted on an irrigated cotton fields at Yarral near Narrabri in the 1999/2000 season. The treatment evaluated were (1) UV-protected Canopy® oil, (2) UV-protected Caltex PSO 5499, (3) Non-UV-protected DC-tron oil and (4) conventional insecticide (control). The PSO concentrations used were 1.0%,2.0%, 3.0%, 5.0% and 10.0% (v/v). Plots were arranged in a randomized complete block design with 4 replicates. Each treatment replicate measured 8 metres wide and 50 metres long. An 8 metre buffer separated the replicates.

Foliar application of the PSO treatments (first) spray) was done on 10 December 1999. Thereafter, the crops were sprayed on the 20 December 1999, 6 January 2000, 12 January 2000 and 21 January 2000. In all, 5 PSO sprays of each treatment and 4 insecticide sprays were applied. Plants in the PSO plot was sprayed to run-off. The conventional insecticide treated plots were sprayed by the grower based on economic thresholds. Assessments were made of the effect of PSO on chlorophyll content, leaf, root, stem, squares and boll dry weights.

5.7.2.2 *Efficacy of Caltex Canopy® oil on aphids and predatory insects on cotton*

This study was conducted in an irrigated cotton field at the Australian Cotton Research Institute in Narrabri during 1999/2000 cotton season.Trials were conducted using 5 different concentrations of Caltex Canopy® oil. The oil concentrations evaluated were 0.25%, 0.5%, 0.75%, 1.0% and 2% (v/v). Unsprayed and conventional insecticide treated plants were used as controls. Both aphids and predatory insects were sampled using a D-vac. Counts were made every 7 days until the end of the study. Aphids encountered in the treated plots were predominantly cotton aphids (*Aphis gossypii*). Data were expressed as numbers per metre per sample date.

5.7.2.3 *Efficacy of Caltex Canopy® oil on Helicoverpa spp. on cotton*

The study was conducted in an irrigated cotton field at Auscott in Narrabri during the 2000/2001 season. A Caltex PSO (Canopy®) was applied at 2% (v/v) as either a prophylactic spray (every 10-14 days) or threshold spray. Helicoverpa threshold used was either 2 larvae per metre or predator to pest ratio of 0.5. These were compared with synthetic insecticide managed (treated control) and proposed unsprayed plot which was later sprayed upon the advise of the grower. Each treatment was replicated 4 times in a randomised complete block design. Each replicate measured 16 rows wide and about 1000 metres long. Conventional sprays used were selected by the grower from the Cotton Industry Insecticide resistance Management strategy. The decision to apply a conventional spray was based on pest threshold. *Helicoverpa* spp. eggs and larvae were assessed visually every week in a randomly selected 1 metre row cotton in each treatment until the end of the study.

5.7.2.4 *Efficacy of Caltex Canopy® oil + NPV and Bt against Helicoverpa spp. first instar larvae in the field*

Treatment evaluated were 0.5% PSO + ).75% NPV; 1.0% PSO + 0.75% NPV; 1.5% PSO + 0.75% NPV; 2.0% PSO + 0.75% NPV, NPV alone; and unsprayed (control). Plots of 0.10 ha were arranged in a randomised complete block design with 4 replicates per treatment.

Each treatment was applied to leaves at 7 pm on 15 January 1999 from a ground rig. Three days after treatment application, 24 larvae were collected from each treatment and placed into 24 well plates containing artificial diets. Larvae were kept 1 to a well to avoid cross infection of the virus. The number of dead larvae were counted and recorded daily until all the surviving larvae had pupated. The percentage mortality for each treatment was calculated relative to the control plot.

## 6.0 ANALYSIS OF DATA

All experimental data were analysed using repeated measures ANOVA (Graphpad Instat Software Inc. Version 2.03, San Diego, California). Tukey-Kramer Multiple Comparisons tests were used to separate means.

## 7.0 RESULTS AND DISCUSSION

7.1 *To assess the value of integrating Envirofeast® sprays, lucerne refugia, virus spray and synthetic insecticides for an IPM program on transgenic and normal cotton.*

The results showed that when the lucerne refugia system, Envirofeast® (food) spray and predatory insects were integrated with Bt and NPV, cotton yields were 6.18 bales and 5.68 bales/ha on Bt and NPV plots. These yields were significantly higher ($P<0.01$) than those achieved when Envirofeast® was used alone on lucerne/cotton interplants (2.72 bales/ha) but lower than the conventional insecticide manged cotton (8.40 bales/ha).

When synthetic insecticides were strategically integrated with lucerne strip refugia, supplementary food spray and biopesticides to form an IPM program it produced cotton yields that was not significantly different ($P>0.05$) from synthetic insecticide managed cotton. The average yield harvested from the conventional insecticide managed Ingard® cotton crops at all study sites was 8.90 bales/ha compared with 9.22 and 9.12 bales/ha on the IPM and conventional normal cotton crops respectively. In economic terms, the average gross margin in terms of insecticide usage for IPM plot was A$3,255 compared to A$3,020 and A$3,218 for the plots that were treated with conventional insecticide on Ingard® cotton and normal cotton respectively.

The total number of synthetic insecticide applications to the IPM treated plot was reduced relative to the insecticide managed cotton at all the study sites. The study showed that 50% of synthetic insecticide applications at all the study sites were replaced by biological sprays in the IPM plots thus conserving the natural enemies and increasing the environmental advantage on the IPM plots. The use of transgenic cotton affected a 25% saving on synthetic insecticides.

The number of *Helicoverpa* spp. pupae, per metre per sample date was significantly lower ($P<0.01$) under transgenic cotton under Envirofeast® based IPM than normal cotton under Envirofeast® IPM regime and unsprayed cotton. The highest number of pupae per metre per sample date was recorded on the unsprayed cotton followed by Envirofeast® based IPM on normal cotton. There was no pupae recorded in the lucerne strips within the transgenic and normal cotton crops. In all, 90 per cent of the pupae recorded in all the treatments were *Helicoverpa armigera*, 5 per cent were *H. punctigera* and 5 per cent did not emerge. *H. punctigera* pupae occurred in December and early January whereas all pupae recorded from January until May were all *H. armigera*. All the pupae recorded under Ingard® was *H. armigera*.

The results clearly indicate that a refined IPM approach could have a distinctive advantages in terms of economic and environmental impacts on cotton production. The success of such an approach lies in a strict adherence to its methodology. A paper detailing the findings of this study is in press in the International Journal of Pest Management. A reprint will be sent to CRDC after publication in January 2002.

7.2 *To determine levels of Helicoverpa spp. control on transgenic cotton with and without lucerne strip refugia.*

The study showed that interplanting lucerne in Ingard® cotton crops did not reduce the number of *Helicoverpa* spp. eggs laid on the Ingard® crop. Thus the presence of lucerne strips did not affect egg lay. Similarly, the number of *Helicoverpa* spp. larvae recorded on Ingard® crops interplanted with lucerne crops was not significantly different from Ingard® crops interplanted with normal cotton crops.

Green mirid numbers were significantly lower (P<0.05) on Ingard® cotton crops interplanted with lucerne than with normal cotton (Figure 1). Furthermore, populations of predatory beetles, bugs, lacewings and spiders were significantly higher (P<0.01) on Ingard® cotton crops interplanted with lucerne than Ingard crops interplanted with normal cotton crops (Figure 1). Both the Ingard® with lucerne and normal cotton strips received four synthetic insecticide sprays against *Helicoverpa* spp. during the season. However, the Ingard® crop with lucerne interplant yielded 3.1 bales per acre compared with 2.9 bales per acre in the Ingard® with normal cotton interplant.

The study clearly indicate that the use of lucerne strips not only produce beneficial insects for the Ingard® cotton crop, it also assist in the management of green mirids. For effective use of lucerne strips in cotton systems, it should be managed so that the lucerne do not hay or dry off. This can be done by slashing alternate half of the strips every 4 weeks. The first cut should be done when the lucerne starts to flower. Alternate slashing will ensure that fresh lucerne regrowth (which green mirids prefer) is available in the strips throughout the cotton growing season.

7.3.1 *Effect of Envirofeast®/Gemstar mixture on the survival of Helicoverpa spp. larvae*

At Yarral study site, 1.5 kg Envirofeast®/ NPV (Gemstar®) mixture caused significantly higher (P<0.05) mortalities (54.2%) to *Helicoverpa* spp. neonates compared to mortalities (41.7%) caused by NPV alone, and when NPV was mixed with 1.0 kg of Envirofeast® (Table 1). No significant difference (P>0.05) was obtained when NPV was mixed with either 1.5kg or 2.0 kg of Envirofeast®.

Similar trend was observed at the Norwood study site. 1.5kg of Envirofeast® mixed with NPV caused 45% mortality of *Helicoverpa* spp. neonates compared to 33.8% mortality when NPV was sprayed alone. The study clearly showed that Envirofeast® rate of 1.5kg/ha is the optimum rate required in combined mixture with NPV.

Envirofeast® may be acting as a feeding stimulant to increase the feeding of the larvae and the uptake of a lethal dose of the NPV toxin. The optimum time to apply Envirofeast®/NPV mixture is early in the morning or late in the afternoon when the sun goes down. Growers should avoid daytime sprays as NPV are destroyed by UV light and Envirofeast® has no UV filters to protect the virus.

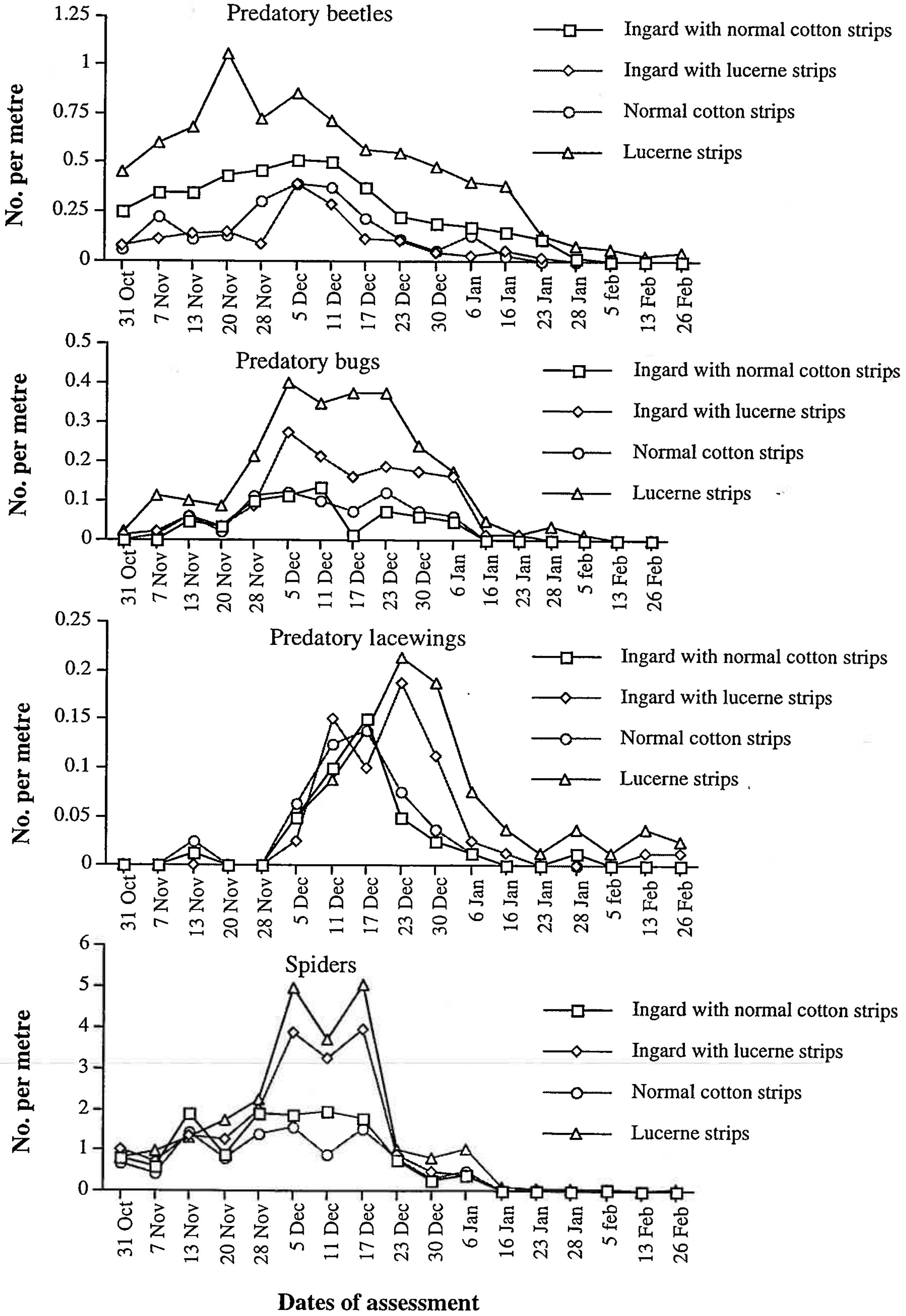



**Figure 1.** Numbers of predatory beetles, bugs, lacewings and spiders in Ingard® cotton crops interplanted with lucerne and normal cotton crops at Norwood, 1998-99.

7.3.2 *Responses of predatory insects to Envirofeast® spray applied to cotton crops with varying numbers of true leaves*

The study showed that plots treated with Envirofeast® at 4-true leaf stage recorded the highest number of predatory beetles, bugs and lacewings per metre compared with plots treated at 8-true leaf stage and unsprayed (control) plots. The cumulative total number of predatory beetles, bugs and lacewings recorded throughout the season in both treated and control plots was 12.43 per metre. Out of this total, plots treated at 4 true leaf stage recorded the highest (6.1 per metre) (i.e 48.8%), followed by 8 true-leaf stage (4.4 per metre) (i.e. 35.1%) and the unsprayed (control) plot recorded the lowest (2.0 per metre (16.0%). Spider numbers were similar among treatments.

The study clearly showed that knowledge of when to apply a food spray particularly Envirofeast® to achieve greater conservation of beneficial insects is crucial and in this study the optimum period to commence application of food sprays is when the crop is at a 4 true leaf stage.
A detail paper has been submitted to International Journal of Pest Management for review and publication. A reprint will be sent to CRDC after publication.

7.3.3 *Responses of predatory insects to Envirofeast® product applied as a "band" or "skip row" spray*

The study showed that the number of predators recorded in cotton crops treated with Envirofeast® as a band spray (33-50% band) or skip-row spray (i.e. every second row) was not significantly different ($P>0.05$) from plots where the product was applied as a solid spray (no banding, no skip-row) to the entire crop. Thus tailoring Envirofeast® treatment in this way will ultimately reduce the quantity of product used, cost of product and allow cotton growers to adopt a multiple use pattern for the product to support IPM programs in cotton.

7.4.1 *Effect of Envirofeast® on the consumption rate of C. transversalis adults.*

In this study, *C. transversalis* consumed significantly higher ($P<0.05$) *Helicoverpa* spp. eggs placed on leaves treated with Envirofeast® compared with eggs placed on leaves treated with sugar solution and untreated leaf (Figure 2). The effect of Envirofeast® on *C. transversalis* feeding declined from day 1 until day 6 when the number of eggs consumed was not different from the sugar treated and untreated leaves (Figure 2).

The study showed that apart from Envirofeast® having ovipositional deterrent activity against *Helicoverpa* spp. on cotton and also can attract and conserve natural enemies of this pest, it can increase the searching activity induced by contact with and feeding upon Envirofeast® with subsequent increase in predation of *Helicoverpa* spp. eggs and larvae.

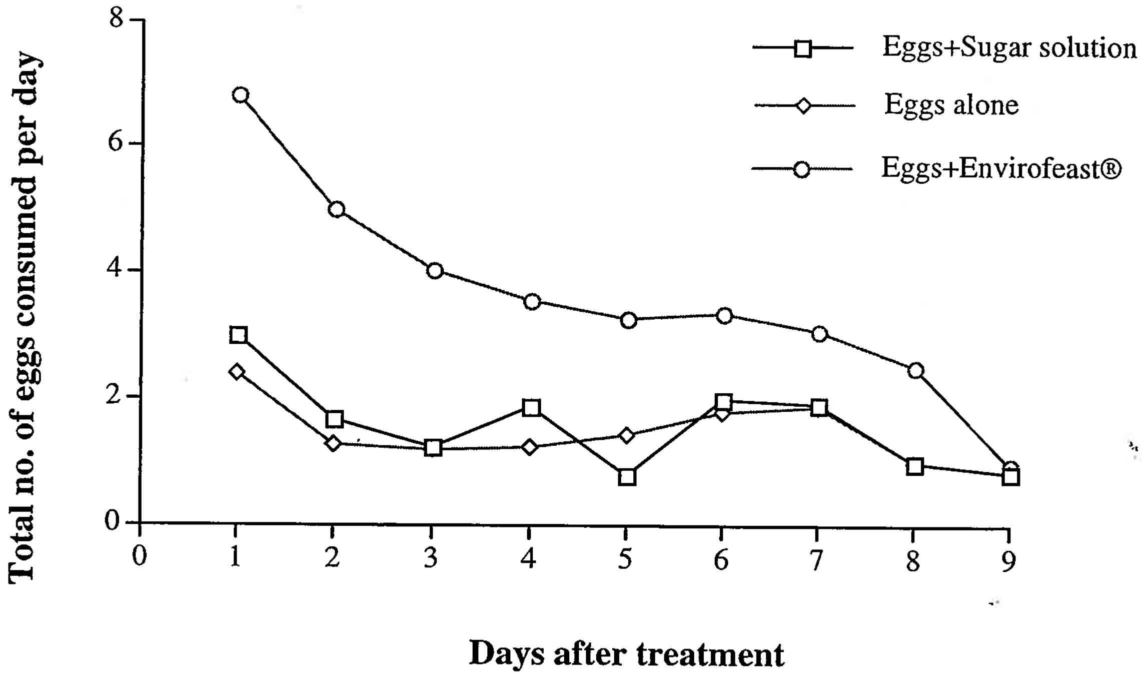



**Figure 2.** Daily consumption of *Helicoverpa* spp. eggs by *C. transversalis* over 9 days

7.4.2 *Functional response of Coccinella transversalis to Helicoverpa* spp. *eggs and larvae.*

*Coccinella transversalis, Adalia bipunctata and Dicranolauis bellulus* eat eggs and larvae of *Helicoverpa* spp. in both laboratory and field. Increasing the number of prey particularly *Helicoverpa* spp. eggs and larvae increases their consumption rate until it reaches a period when any increase in egg or larval density did not increase consumption rate (Figure 3). The amount of prey they consume also affect their weight and in turn affect the number of eggs laid and survival rate.

7.4.3 *Determination of predator to pest (Helicoverpa spp.) ratio required to manage Helicoverpa spp. in cotton crops*

The study identified beneficial insects as a major part of integrated pest management (IPM) system. An IPM system which incorporates food sprays and refugia system focuses on manipulating beneficial insects particularly predators to manage the pests. The study determined a predator to pest ratio as a threshold to incorporate the activity of the predators into pest management decisions. A predator to pest ratio of 0.5 or higher means the IPM system is functioning well.

Therefore the accepted predator to pest threshold is 0.5 or higher.

- When the predator to pest ratio fall below 0.5 but is higher than 0.4 and *Helicoverpa* population is mostly eggs, a food supplement such as Envirofeast® can be applied to attract more predators to feed on the eggs and improve the ratio.

- However, when the *Helicoverpa* population falls below 0.5 but is higher than 0.4 and Helicoverpa population in your bug check is predominantly neonates (rather than eggs) then a food spray and a biological pesticide should be applied to restore the ratio to 0.5 or higher (see IPM guidelines in Entopak, 1999 for details).
- If the predator to pest ratio is 0.4 or lower following application of biological insecticide and Helicoverpa population is more of larvae, use a selective insecticide to control the larvae before they develop to mediums. Three days after applying a selective insecticide, re-apply Envirofeast® to restore the system.

The application of predator to pest ratio to manage *Helicoverpa* spp. on Ingard® and normal cotton crops are explained in detail in the IPM guidelines. The ratio has been incorporated into CottonLogic. A paper on this study is in press in the International Journal of Pest Management.

A reprint will be sent to CRDC as soon as it is published in January 2002.

7.5 *To investigate the utility of lucerne crop planted in a block adjacent to cotton fields in the management of green mirids and conservation of beneficial insects.*

The study showed that a lucerne crop planted in a block can manage green mirids on adjacent cotton fields located 50 metres away. The lucerne serve as a trap crop for green mirids. To serve this purpose, the lucerne crop should be kept attractive through the cotton growing season. The attractiveness of the lucerne can be maintained by slashing a quater of the block at a time starting when the lucerne commence flowering. This will ensure that the lucerne block is always composed of older and younger lucerne growth. Slashing one-quarter at a time means that the older three-quarters is still attractive. A second cut should commence as soon as the slashed shoots develope new nodes. The lucerne should not be allowed to dry off. If it dries off, the lucerne all the mirids will move into the adjacent cotton fields.

The lucerne crop planted in block is also a source of predators particularly predatory beetles, bugs and lacewings to adjacent cotton fields. However, given the abundance of food resources, shelter, mating, oviposition sites etc within the lucerne crop, higher numbers of the predators may not have been inclined to move from the lucerne block to forage the adjacent cotton crop. The movement can be improved by either applying food sprays to the adjacent cotton crop to attract predatory beetles, bugs and lacewings onto the cotton or slash half of the lucerne block if mirid population in the lucerne is low to move some of the predators into cotton.

7.6 *To evaluate the newly developed petroleum spray oils (PSOs) on the survival of Helicoverpa spp. and their natural enemies in cotton*

Experiments were conducted in the laboratory and field on irrigated cotton between 1999 and 2001.

7.6.1 *Laboratory experiments:*

Two experiments were conducted. In all experiments, *H. armigera* eggs and first instar larvae were used.

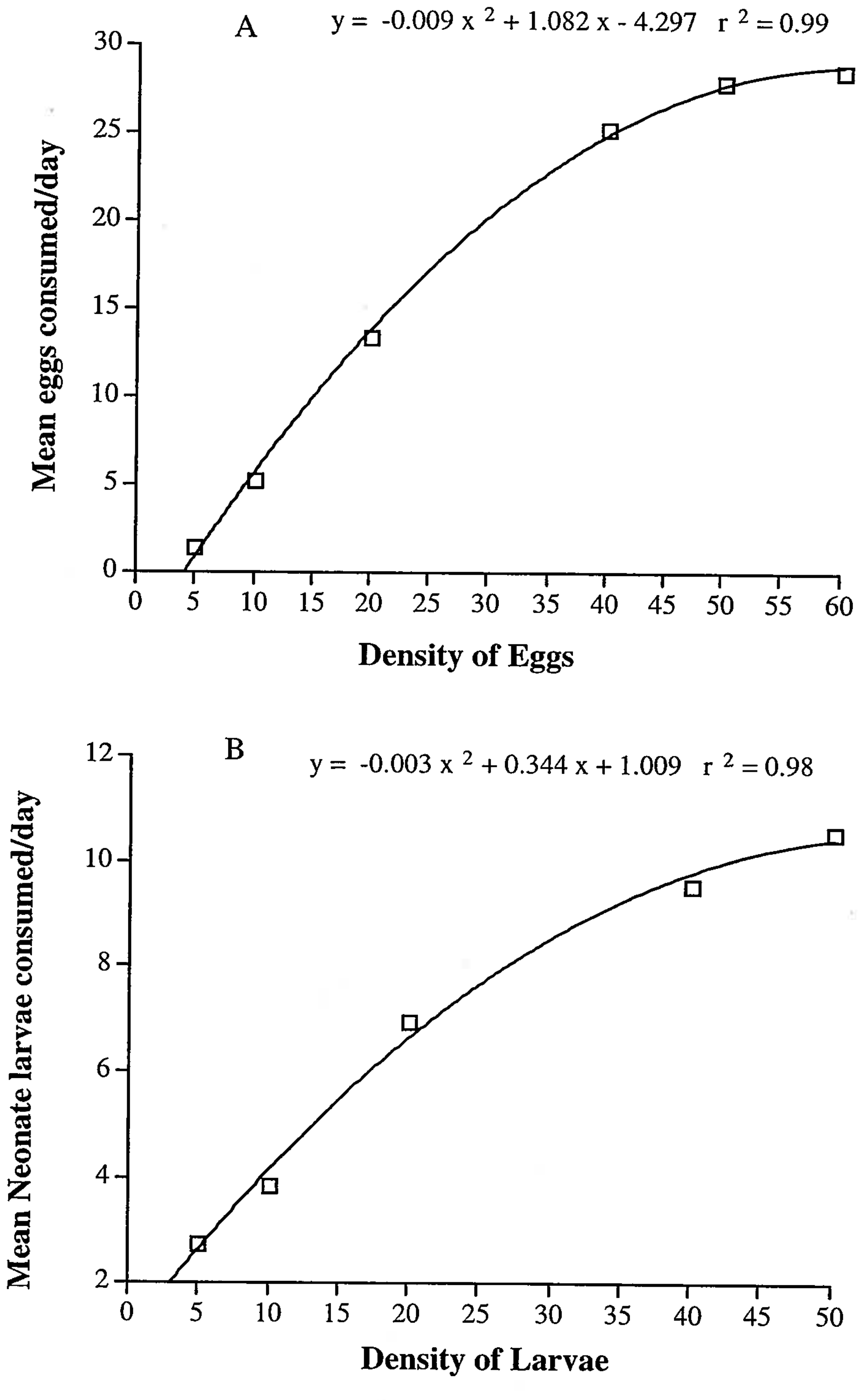



**Figure 3.** Functional response of *C. transversalis* adult females to *Helicoverpa* spp.eggs (A) and larvae (B) in the laboratory at ACRI, Narrabri, 1998-99.

*7.6.1.1 Efficacy of Caltex Petroleum spray oil against H. armigera eggs*

At 2% PSO, 60% of white eggs did not hatch compared with a 100% in the 0-1.2% treatments. Most brown eggs (90%) hatched, but only 40% survived to the end of the first instar stage.

*7.6.1.2 Efficacy of Caltex Petroleum spray oil against H. armigera first instar larvae*

The mortality of *H. armigera* larvae increased with oil concentration. At 0.75% PSO, 25% of the larvae were killed. At 1, 1.2, 1.5 and 2.0% PSO 41.6, 33.3, 66.7 and 75% of the larvae were dead. There were no mortalities in the control.

7.7.2 Field studies

*7.7.2.1 Phytotoxicity of Caltex PSOs on commercial irrigated and dryland cotton crops*

No phytotoxicity was found when Caltex PSO Canopy and RD 54 were applied at concentrations of 2 to 10 per cent on irrigated crops. Similar results were achieved when the product was applied on dryland cotton crops at concentrations of 2-5 per cent. RD 54 did not cause phytotoxicity when sprayed at 2-5 per cent concentration. However, when the product was applied at 10 per cent concentration, it significantly ($P<0.05$) reduced the dry weight of the cotton stems. DC tron cotton spray oil is a commercial product used as adjuvants in insecticides, herbicides and defoliants in the cotton industry. Application of 5-10 per cent DC-tron significantly reduced the leaf area and dry weights of leaves and stems. The phytotoxicity detected on the RD 54 and DC-tron plots were not visible as damage the field and growers could not have detected it in the field.

Overall, none of the PSO concentrations evaluated affected lint yield or fibre quality on both irrigated and dryland cotton crops.

*7.7.2.2 Efficacy of Caltex Canopy® oil on Helicoverpa spp. on cotton*

Canopy oil applied at 2% v/v as either a prophylactic spray (10-14 days) or threshold spray compared with conventional insecticide treated and reduced insecticide spray (control) are given in Figure 4. The result showed that Canopy oil applied as either prophylactic or threshold spray controlled *Helicoverpa* spp. similar to conventional insecticides.

*7.7.2.3 Efficacy of Caltex Canopy® oil + NPV and Bt against Helicoverpa spp. first instar larvae in the field*

The mortality of *Helicoverpa* spp. larvae collected from field plots treated with Canopy oil + NPV was highest in plots treated with 2% oil + 0.75% NPV (66.7%). The mortality when the virus was sprayed alone with 0.75% NPV was 37.5%. There were no mortalities in the unsprayed plot.

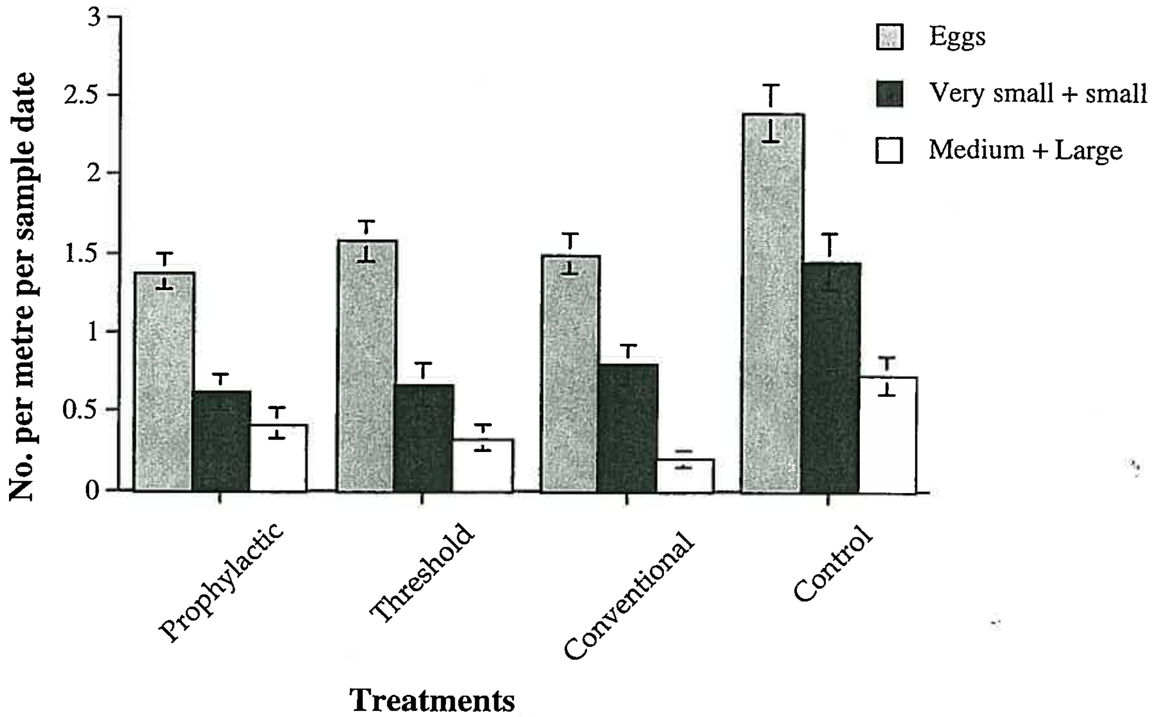



**Figure 4.** Comparison of different Canopy oil spray regimes for control of *Helicoverpa* spp. in commercial cotton field, Auscott, 2001.

7.7.2.4 *Efficacy of Caltex Canopy® oil + NPV and Bt against Helicoverpa spp.*

In another study where plants were treated with Canopy + NPV and Canopy + Bt mixtures and left in the sun over 5 days and leaves harvested and fed to *Helicoverpa* spp. neonate larvae mortality was significantly improved over when the biopesticides were sprayed alone (Figure 5). The efficacy of biopesticides used alone in cotton is sometimes inconsistent, particularly at high *Helicoverpa* spp. pressure. This may due to poor stability under UV light. Addition of UV protected oil such as Canopy oil may improve efficacy and persistence (Figure 5).

7.7.2.5 *Efficacy of Caltex Canopy® oil on aphids and predatory insects on cotton*

Effect of Canopy oil on aphids is given in Figure 6. The result showed that Canopy oil applied at different rates can be used to manage aphids effectively during early cotton season (Figure 6). However, during mid and late season the oil could not effectively control aphid numbers (Figure 6). The optimum rate for the control of aphids was determined at 2% v/v. To achieve control, Canopy oil should be sprayed to run-off. In mid to late season, the volume of water required to achieve run-off is very high, thus effective control was not achieved as in early season. Canopy oil has a minimal impact on natural enemies and the impact is more on newly hatched predatory insect larvae than mature larvae and adults. The oil residues have little or no effect on predatory insects. The effect Canopy oil has on predatory insects was minimal compared with the softest synthetic insecticides.

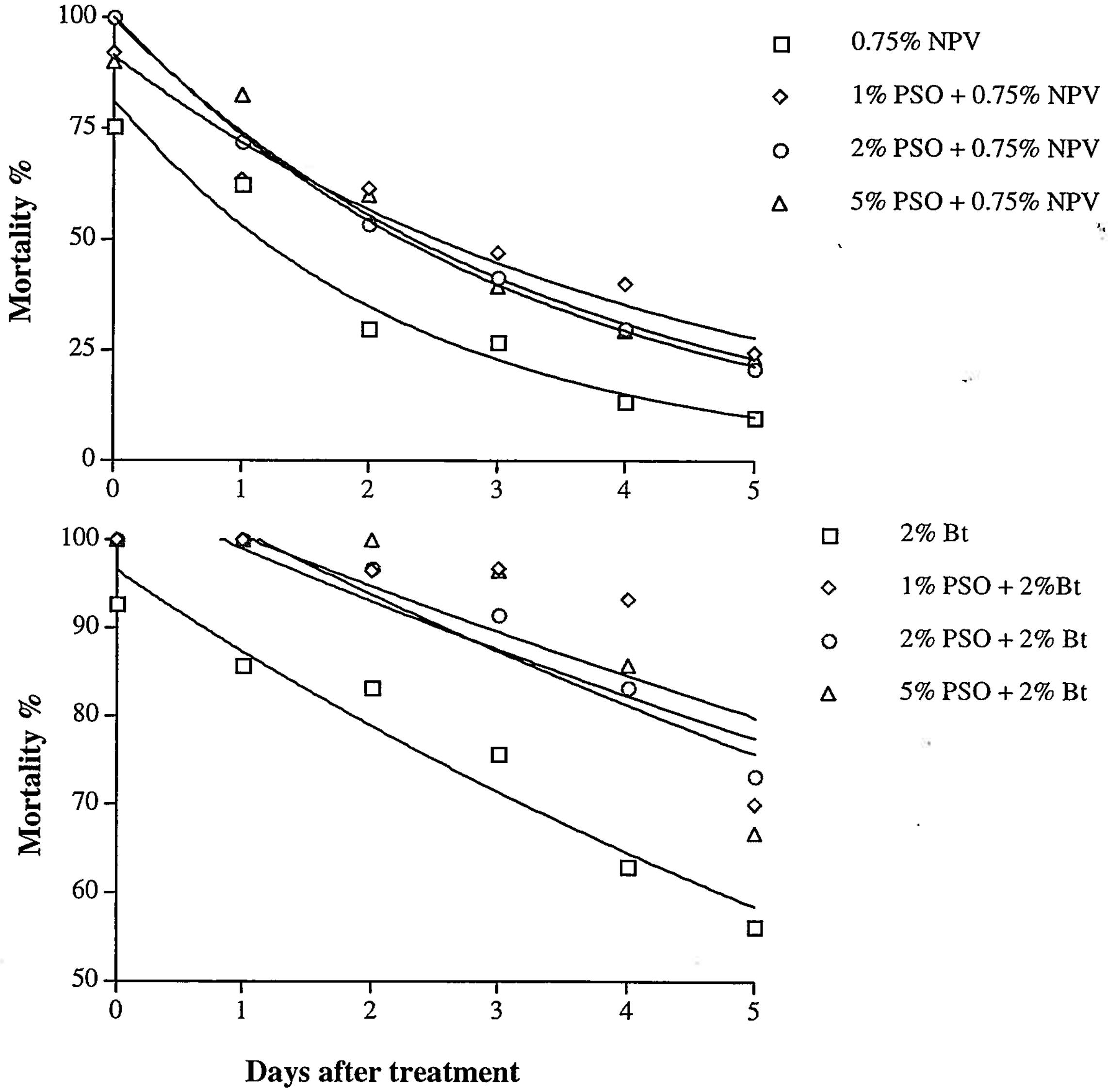
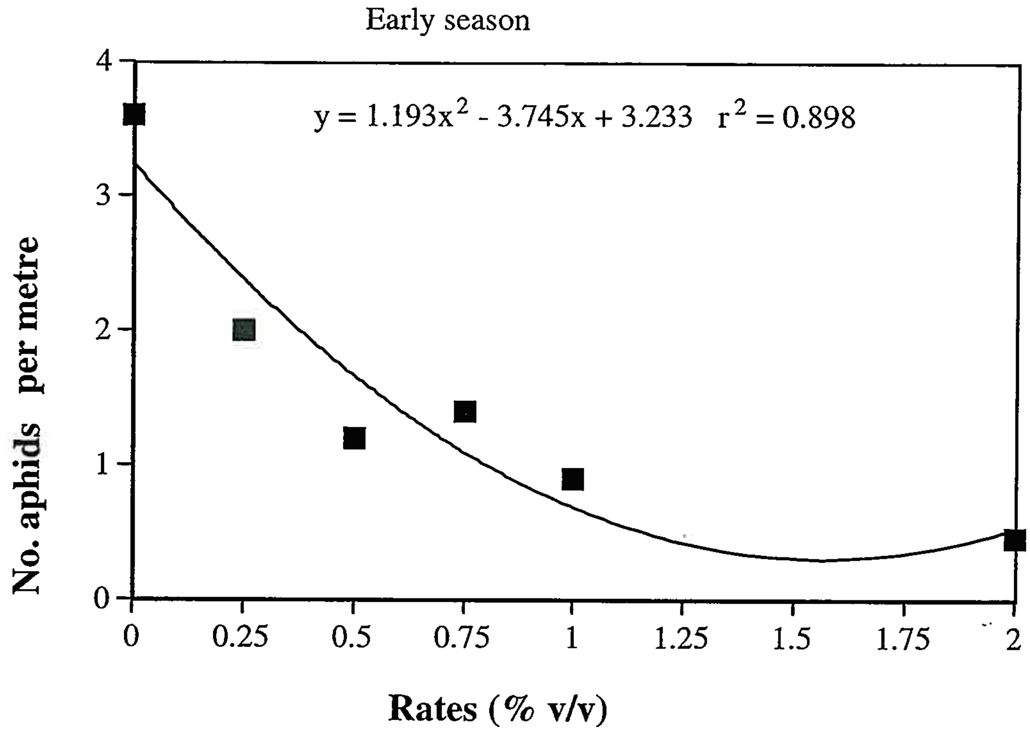



**Figure 5.** Canopy oil and biopesticides (NPV, Bt) mixtures against *Helicoverpa* spp. larvae, ACRI, January 2001.



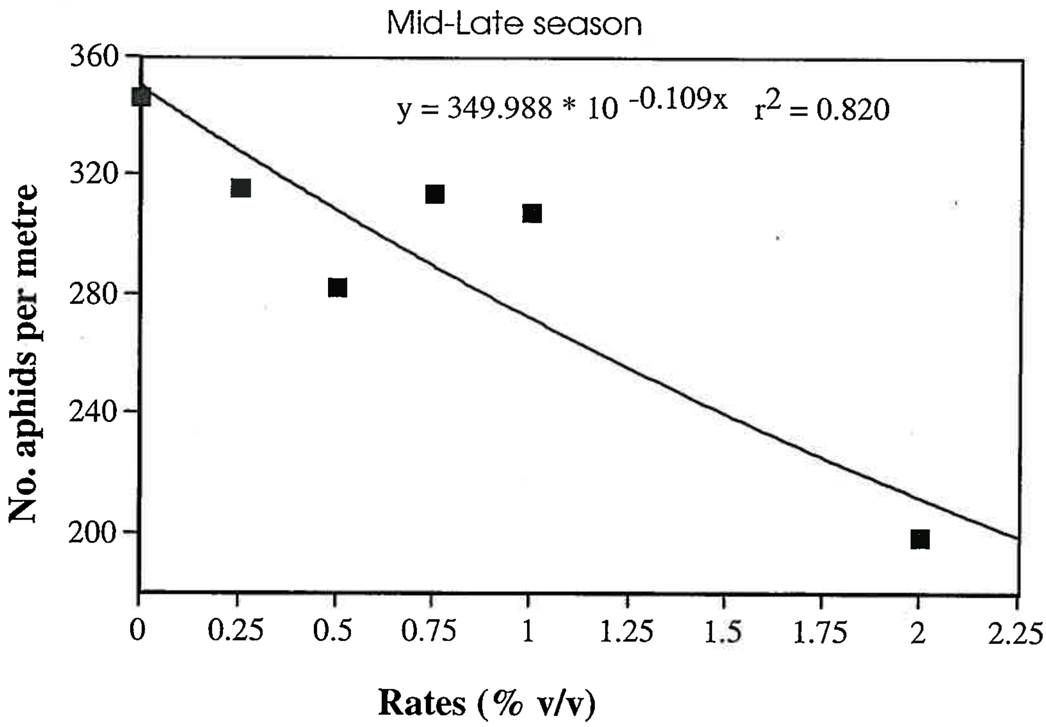




**Figure 6.** Field efficacy of Canopy oil against aphids on cotton, ACRI,

## 8.0 GENERAL DISCUSSION

The study has shown that utilisation of natural enemies as a base of IPM program is a viable alternative to chemical pest control because it can be a self-perpetuating solution to pest problems. However, the success and effectiveness of biological control agents will vary with the characteristics of each natural enemy group (predators, parasitoids, entomopathogens), inter and intra specific competition, environmental factors and the techniques used to utilise them in relation to the crop system. In this study, predatory insects were utilised as basic components of the IPM program and supported by using techniques such as a lucerne/cotton interplant system and a supplementary food spray called Envirofeast®. The intergration of these two techniques with biological and synthetic insecticides helped to achieve economic cotton yields relative to those under conventional insecticide managed crops.

The results clearly showed that the IPM program reduced the use of synthetic insecticides by 50 per cent without sacrificing cotton yield and profitability. In economic terms based on insect management, the average gross margin for the IPM plot was A$3,255 compared to A$3,020 and A$3,218 for the plots that were treated with (i) conventional insecticides on transgenic (Ingard®) cotton and (ii) conventional insecticide on non-transgenic cotton. The use of transgenic cotton affected a 25 per cent saving on synthetic insecticide usage.

In any IPM system, there is the need to have a decision support system which incorporates the activity of beneficial insects in the pest management system and which guides the grower or consultant to take pest management decisions non-deterimental to beneficial insect activity. In this study, the decision to use either biological or chemical insecticide to manage *Helicoverpa* spp. in cotton was based on predators to *Helicoverpa* spp. (pest) ratio. The study determined a predator to pest ratio of 0.5 as the minimum ratio. The guidelines for the use of predator to pest ratio has been detailed in the IPM guidelines.

Some growers and consultants are reluctant to interplant their cotton crops with lucerne strips because they view it as occupying space which might have been planted with cotton. Though this may be right, the advantages of using lucerne strip has been proven in this study. However, for those growers reluctant to use lucerne strips, they can plant lucerne crop in a centrally located block adjacent to cotton fields located 50 metres away from the lucerne block. The study showed that the lucerne crop planted in a block adjacent to cotton fields continued to serve as a trap crop for the green mirids for adjacent cotton fields provided it is located 1-50 metres away. The lucerne crop planted in block also served as a source of predators particularly predatory beetles, bugs and lacewings to adjacent cotton fields. However, given the abundance of food resources, shelter, mating, oviposition sites etc within the lucerne crop, higher numbers of the predators were not inclined to move from the lucerne block to forage the adjacent cotton crop. The movement can be improved by either applying food sprays to the adjacent cotton crop to attract predatory beetles, bugs and lacewings onto the cotton or slash half of the lucerne block if mirid population in the lucerne is low to move some of the predators into cotton.

The study also showed that interplanting lucerne in Ingard® cotton crops did not reduce the number of *Helicoverpa* spp. eggs and neonate larvae on the Ingard® crop but increased the populations of predators on the Ingard® cotton crops. Yield was also marginally higher on the Ingard® crop with lucerne interplant (7.67 bales per ha) compared with Ingard® with normal cotton interplant (7.17 bales per ha).

In IPM programs using predatory insects as a base, the establishment of beneficial insects in cotton crops is very crucial early in the cotton season prior to pest infestation. Thus the optimum timing of food sprays is important to achieve effective biological control. The study showed that the optimum time to apply Envirofeast® is at 4-true leaf stage. In addition, Envirofeast® as a band spray (33-50 per cent band) or skip row spray (i.e. to every second row) was not significantly different (P>0.05) from plots where the product was applied as a solid spray (no banding) to the entire crop (no skip row). Thus tailoring Envirofeast® treatment in this way will ultimately reduce the quantity of product used, cost of the product and allow cotton growers to adopt a multiple use pattern for the product to support integrated pest management programs in cotton.

The study also showed that mixing Envirofeast® with NPV can enhance the efficacy of NPV. A mixture of Envirofeast/NPV caused 54.2 per cent mortality to *Helicoverpa* spp. neonates compared to 41.7 per cent mortality caused by NPV alone. The reason for increased efficacy of NPV may due to increased feeding of the larvae due to Envirofeast thus allowing the larvae to ingest a lethal dose of the virus to cause higher mortalities. The optimum rate of Envirofeast in Envirofeast®/NPV mixture was determined at 1.5 kg/ha. Despite increased mortalities when NPV was mixed with Envirofeast, growers should avoid daytime sprays as NPV are destroyed by UV light and Envirofeast® has no UV filters to protect the virus.

As in many IPM programs developed worldwide, the IPM program developed in this project will require additional research for more selective and environmentally benign pest management tools to be incorporated into the program. The study showed that application of Canopy oil with ultra-violet filters at 2% v/v has significant effects against a range of cotton pests including *Helicoverpa* spp. eggs and neonate larvae and aphids in commercial cotton field. The oil, however, has minimal effect on beneficial insect populations. The study also showed that the efficacy of biopesticides (viruses, Bt) used alone in cotton is sometimes inconsistent, particularly at high *Helicoverpa* spp. pressure. This may due to poor stability of the products under UV light. Addition of UV protected PSOs may improve their efficacy and persistence. The use of PSOs against crop pests is advantageous over conventional insecticides because they are less disruptive to natural enemies of pests, insects do not develop resistance to them, they are less toxic to vertebrates, and they breakdown easily in the environment.

Integration of PSOs with the IPM program developed in this study will further reduce the use of synthetic insecticides and the industry's over-reliance on synthetic insecticides. This will assist the industry to achieve sustainability in cotton production.

## 9.0 CONCLUSIONS, RECOMMENDATIONS AND APPLICATION TO INDUSTRY

IPM program which involves the use of lucerne strips, supplementary food sprays, predatory insects integrated with biological and synthetic insecticides has been used to manage cotton pests, reduced synthetic insecticide use and significantly increase crop yields and profitability by conserving the natural enemies of the pests. The use of predator to pest ratio allowed biological control sufficient time to work in the IPM system in order to reduce chemical insecticide use without sacrificing yield. To conclude, this study has shown that

- Utilisation of natural enemies as a base of IPM program is a viable alternative to chemical pest control because it can be a self-perpetuating solution to pest problems.
- The integration of lucerne/cotton interplant system with supplementary food sprays retained and increased populations of predatory insects in the cotton crop.
- The strategic use of biopesticides (Bt and NPV) in IPM program can reduce the use of synthetic insecticides by 50 per cent without sacrificing cotton yield and profitability.
- The use of transgenic cotton affected a 25 per cent saving on synthetic insecticide usage.
- In terms of Ingard® refuge requirements, IPM managed cotton should be treated the same way as conventional insecticide managed cotton as they can produce similar numbers of pupae.
- Interplanting lucerne in Ingard® cotton crops did not affect *Helicoverpa* spp. eggs and larvae but increased populations of predators and also cotton yield in the Ingard® crop.
- A lucerne crop planted in a centrally located block adjacent to cotton fields can manage green mirids and increase predator populations on cotton fields located between 1 - 50 metres away from the lucerne block.
- For the lucerne to trap green mirids it should remain fresh or maintain new regrowths.
- Alternate slashing of lucerne crops in the block will ensure that the lucerne block is always composed of older and younger lucerne growth to trap green mirids. population in the lucerne is low to move some of the predators into cotton.
- Mixing Envirofeast® with NPV can increased the efficacy of NPV against Helicoverpa spp. neonate larvae.
- The optimum rate of Envirofeast/NPV mixture is 1.5kg Envirofeast per hectare.
- The optimum time to apply Envirofeast®/NPV mixture is early in the morning or late in the afternoon when the sun goes down.
- Growers should avoid daytime sprays as NPV are destroyed by UV light and Envirofeast® has no UV filters to protect the virus.
- The optimum time to commence Envirofeast application within an IPM program is when the cotton crop is at a 4 true-leaf stage.
- Envirofeast® spray applied as a band spray (33-50 per cent band) or skip row spray (i.e. to every second row) can attract similar numbers of predators as when the product is applied as a solid spray (no banding) or to the entire crop (no skip

row).

- Tailoring Envirofeast® treatment in this way will ultimately reduce the quantity of product used, cost of the product and allow a multiple use pattern for the product.

- Predatory beetles, bugs and lacewings can consume eggs and larvae of *Helicoverpa* spp.
- Densities of prey and other predators can affect the consumption rate of predatory beetles.
- Factors such as temperature, rainfall, relative humidity, irrigation, food, competition, cultivation and synthetic insecticides can cause changes in the abundance of predatory insects in cotton farms.
- Predator to *Helicoverpa* spp. (pest) ratio of 0.5 can be used as a threshold to incorporate the activity of the predators into pest management decisions.
- Caltex (Canopy) oil applied at a concentration of 2-10 % on irrigated cotton crop and 2-5% on dryland cotton crops is not phytotoxic to cotton plants.
- Canopy oil with ultra-violet filters applied at 2% v/v has significant effects against *Helicoverpa* spp. eggs and neonate larvae and also aphids in commercial cotton field.
- The use of PSOs against crop pests is advantageous over conventional insecticides because they are less disruptive to natural enemies of pests.
- Addition of UV protected PSOs to biopesticides may improve the efficacy and persistence of biopesticides against *Helicoverpa* spp. neonate larvae.
- PSOs can be a key component of sustainable IPM in cotton.

For the IPM program and other technologies developed in this study to be fully adopted by growers;

- the industry should place much more emphasis on educating growers and consultants on the concept of beneficial insect conservation and adoption of a true IPM.
- Farmer participatory IPM should be encouraged and growers be educated on IPM guidelines through the establishment of Farmer Field Schools (FFS).
- The industry should put significant effort in IPM training rather than Insecticide Resistance Management Strategy because when farmers fully adopt IPM program insecticide resistance will automatically be managed.
- Extension staff should be involved in training growers through FFS and the set up of IPM demonstration farms.
- Growers should be encourage to attend IPM and Technology transfer workshops, field days, seminars and conferences.

**10.0 Describe the project technology (eg. commercially significant developments, patents applied for or granted licenses etc).**

- A worldwide patent has been taken for the Envirofeast technology and also on a method of controlling moths and other insect pests using food sprays.

- A USA patent was granted on August 14, 2001. The Patent number is US6,274,137 B1. I have been officially registered as the inventor and the assignee is NSW Agriculture. Rhone-Poulenc now Aventis holds the right to develop the product. The patent is for 20 years (i.e. until 2021).

## 11.0 Detail a plan for the activities or other steps that may be taken;

### (a) to further develop or to exploit the project technology.

Regarding Envirofeast® technology, the Cotton Industry in collaboration with NSW Agriculture should seek a new commercial partner to commercialise Envirofeast®. Non-chemical companies interested in biological control should be sought as commercial partners for the Envirofeast® technology. A biological product being commercialised by a purely chemical company always suffer at the expense of chemicals. CRDC should set funds aside for further studies to refine the product. For example to add new products to Envirofeast® top make it artificial honeydew. This will improve predatory insect attraction of the product.

### (b) for the future presentation and dissemination of the project outcomes.

Farmer Field Schools (FFS) is one of the ways this project outcomes can be passed on to growers. A training of the Trainer (TOT) which can be an extension officer or IPM teacher can be appointed to co-ordinate the FFS training for cotton growers. Extension staff should be encouraged to set up true IPM demonstration farms, organise workshops, field days in addition to FFS to train growers.

## 12.0 List the publications arising from the research project.

12.0 *REFEREED RESEARCH JOURNAL/BOOK PUBLICATIONS*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2. MENSAH, R. K. (2001). Development of an integrated pest management program for cotton: Part 2:Integration of lucerne/cotton interplant system, food supplement sprays with biological and synthetic insecticides. International Journal of Pest Management (in press).
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12. MENSAH, R. K. and SINGLETON, A. (1999). Conservation and Utilisation of beneficial insects in IPM in cotton: Role of strip cropping, food sprays and use of Predator to pest thresholds. "In Cotton CRC Research" Edited by Garry Fitt and Greg Constable, Pages 128-140.
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## 12.2 *FINAL REPORTS/INDUSTRY COMMISSIONED REVIEW PAPERS*

1 MENSAH, R. K. (2001). Phytotoxicity of Caltex Australia Petroleum spray oils and adjuvants on commercial irrigated and dryland cotton crops in Australia. Final Report prepared for Caltex Australia Pty Ltd 25 pp.
2. MENSAH, R.K. and MOORE, C (1999). A Review of behaviour modifying chemicals in relation to Pest host selection and management on Australian cotton 41 pp.
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## 12.3 *CONFIDENTIAL INTERNATIONAL PATENT ARTICLE*

MENSAH, R. K. (2001). Methods of Controlling moths and other insect pests on agricultural crops" Patent no. US6,274,137 BI Date: August 14, 2001. Griffiths Hack and Co, Patent Attorneys, Sydney, Australia 24pp.

## 12.4 *TECHNICAL CONFERENCES AND BULLETINS*

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12.5 *ADVISORY ARTICLES*

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2. MENSAH, R. K., SINGLETON, A and LIANG, WEIGUANG (2001). Spray oils: Oils Ain't Oils. In: Lower Namoi Cotton Field Day book pages 15-18.
3. BEATTIE, GAC, MENSAH, R. K. (2001). Relevance of recent research on horticultural and agricultural mineral oils to integrated crop management in cotton. In Cotton Consultants Annual General Meeting Advisory Article, pp 12-16.
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## 13.0 FIELD DAYS ADDRESSES TO GROWERS AND CONSULTANTS

**1998-99 season**

Attended and addressed growers and consultants at Macintyre, Lower Namoi, Gwydir and Macquarie valleys Field days.
Addressed Ingard Cotton Field days at Macintyre , Lower Namoi, Macquarie and Gwydir Valleys.
Organised and addressed Lucerne workshop for growers at Norwood

**1999-2000 season**

Attended and addressed growers and consultants at Macintyre, Lower Namoi, Upper Namoi,
Gwydir, Macquarie, Darling Downs, St George, Theodore and Biloela meetings.

Addressed IPM Support Group Meetings on Ingard and Envirofeast at Macintyre, Lower Namoi, Upper Namoi, Gwydir, Macquarie.

Addressed IPM meetings organised by CRDC at Macintyre, Lower Namoi, Upper Namoi, Gwydir, Macquarie valleys.

Addressed grower cotton conference in the Gold Coast.

Addressed growers and consultants at Ingard Field day at Macintyre valley.
Organised and addressed Lucerne strips workshop at Moree.

Addressed growers and consultants at the Envirofeast IPM Support Group meetings at Gwydir, Macintyre, Lower and Upper Namoi, Macquarie, St George, Darling Downs,

Addressed Extension Officers on Envirofeast IPM Extension Planning Meeting at Dalby,

**2000-2001 season**

Addressed grower field days at lower Namoi, Upper Namoi, Walgett, Darling Downs.

Addressed growers and consultants at IPM meetings at Walgett, Lower Namoi, Upper Namoi, Gwydir, Macquarie, Darling Downs

Addressed IPM meetings of visiting, Chinese, Russian and Vietnamese agricultural scientists.

## 14.0 ACKNOWLEDGEMENTS

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