Cotton Research & Development Corporation

"OPTIMAL EARLY SEASON INSECT CONTROL STRATEGIES FOR COTTON "

(DAN 68 C) (July 1992 to June 1995)

AND

"PEST MANAGEMENT IN ORGANIC COTTON "

(DAN 89 C) (July 1994 to June 1995)

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NSW AGRICULTURE

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

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NSW Agriculture

Australian Cotton Research Institute, Myall Vale, Narrabri, NSW 2390

APPROVAL FOR SUBMISSION OF FINAL REPORT

Approval has been granted to Dr Robert Mensah to submit to Cotton Research and Development Corporation' (CRDC) the attached final reports *"Optimal early season insect control strategies for cotton" (DAN 68C)* and "*Pest Management for organic cotton" (DAN 89C).* The report has been refereed by his peers and considered to be adequate.

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Dr Richard Spurway
Program Manager (FO&SP)
NSW Agriculture

Date:
1/10/95

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ABSTRACT

In Australia, management of cotton pests is insecticide based. Beneficial insects are neglected due to the disruptive impact of the insecticides, lack of techniques to maximise their abundance and effectiveness and also lack of ecological diversity in Australian cotton systems which are monoculture and militate against beneficial arthropods. Studies to develop a control strategy for early season pests on cotton which has minimal effect on natural enemies commenced in July 1992 until June 1995. These studies showed that provision of supplementary food through Envirofeast® spray can attract, conserve and augment naturally-ocurring predatory insects, including transverse, three-banded, two-spotted ladybird beetles, red and blue beetle, big-eyed bug, damsel bug and green lacewings. These insects are natural enemies of cotton pests especially *Helicoverpa* spp. However, thiodicarb and endosulfan which were previously known to the industry to be "soft" on beneficial insects were shown in this study to significantly reduce predatory insect numbers. Interplanting of lucerne, as strips within cotton farms, served as a trap crop or sink for early season cotton pests such as green mirids and as refugia for predatory insects. Green mirids and predatory insects on cotton can be effectively sampled using Dvac. The integration of Envirofeast® and the lucerne/cotton interplant (i.e. refugia technology) into a pest management system eliminated the need for early season synthetic insecticide sprays and reduced total synthetic insecticide sprays per season by 60 per cent. Envirofeast® product unfortunately is not rainfast and production technology needs to be developed to produce the product in large quantities for commercial use. With resistance of *Helicoverpa* spp. to insecticides increasing, and the possibility that insect resistance will be a major problem even with transgenic cotton, the control strategy developed in this study should be integrated with transgenic cotton to sustain future cotton production.

SUMMARISED REPORT

The cotton industry is one of the major agricultural export earners for New South Wales with a gross value of over $400 million in earnings for the state. In Australia, insecticides are used extensively early in the cotton season on cotton against thrips, mirids, mites and *Helicoverpa* spp. With the trend to early cotton, the early season use of insecticides has increased significantly and this has resulted in the development of resistance in most of the major pests, especially *Helicoverpa* spp., disruption of natural enemies of the pests and resurgence of other minor pests and environmental problems. A major concern of the cotton industry is to reduce the dependence on insecticides and maximise the long term sustainability of the industry. This can be achieved by developing a control strategy that places much more emphasis on natural enemies of the pest, especially early in the cotton season.

This report combines two projects (DAN 68 and 89C) which are aimed to develop a control strategy for cotton pests based on natural enemies. The project DAN 89C was, however, developed according to the results achieved in DAN 68C so that separating the two projects will result in repetitions in the reports, especially DAN 68C.

The objective of project DAN 68C was to (1) assess the value of provision of supplementary food in the conservation and augmentation of beneficial insects in cotton and their impact on cotton pests especially early in the season; (2) assess the ovipositional response of the major pests especially *Helicoverpa* spp. to various food supplements; (3) determine whether early season pests and beneficial insects are attracted to colour and identify the most effective coloured trap that can be used to effectively monitor their flight activity and populations; (4) develop an appropriate sampling procedure for green mirids (5) compare and identify the most effective seed treatment method to control early season pests with minimal effect on beneficial insects; (6) determine the impact of "soft" insecticides on natural enemies of cotton pests; (7) determine the role of trap crops in the management of green mirids and (8) establish preliminary trials to evaluate the commercial prospect of the control strategy developed in DAN 68C under the non-synthetic insecticide (DAN89C) regime.

The results of a study to determine the effect of provision of supplementary food in the conservation and augmentation of natural enemies of cotton pests showed that adult lady beetles, red and blue beetles, big-eyed bugs, damsel bugs and green lacewings responded more positively and numbers increased significantly throughout the study on plots sprayed with Envirofeast® than in all other treatments. The conventional insecticides virtually exterminated the predatory insects.

In the study to determine the ovipositional response of *Helicoverpa* spp. to Envirofeast®; Envirofeast 2; sugar; and a mixture of petroleum oil and kelgum, *Helicoverpa* spp. layed fewer eggs on plants treated with Envirofeast than in the other treatments and the control (water-sprayed) plants, both in the mesh house and in the field plots. The suppression of oviposition by Envirofeast spray in the mesh house was higher in *Helicoverpa punctigera* (Wallengren) than *H. armigera* (Hubner) and therefore could be partially offset by increased *H. armigera* infestations in the field. Nevertheless the study demonstrated oviposition suppression by Envirofeast® product towards *Helicoverpa* spp. on cotton. Envirofeast® could be used in an integrated approach especially early season to reduce pest numbers.

The study to develop the most appropriate sampling technique for early season pests especially green mirids and other beneficial insects also indicated that sampling with Dvac (a blower-suction type of machine) is more effective than a sweep net for green mirids and jassids but not thrips and *Helicoverpa* spp. Predatory insects are also effectively sampled with Dvac.

Field tests on colour attraction and flight activity of early season pests and coccinellid adults were studied using a 30 x 30 cm coloured sticky traps placed in commercial cotton field. The test colours were yellow, green, orange, red, deep blue, true blue, black, magenta and white. Among the colours tested, thrips were attracted most to white and true blue, mirids to green and a mixture of yellow and greeen (3G:1Y), and green vegetable jassids, transverse ladybird beetle and two-spotted ladybird beetle to yellow. Dilution of the green colour with orange or yellow to produce green-orange hues or green yellow hues resulted in a decline in green mirid catch, with the exception of the 3G:1Y hue

which caught similar numbers as the green. Also the green jassid and the coccinellids had a positive response to yellow. In all the insects, with the exception of thrips in which trap counts were not differentiated between sexes, the sex ratio of captured adults was 1:1 indicating no colour preference by sex. Therefore coloured sticky traps could be used to monitor their flight activity and populations.

Field tests to determine the most effective insecticide for seed treatment or in furrow application of seedling cotton to control early season pests, especially thrips, were conducted in commercial irrigated cotton. Treatments were Temik, Promet, Gaucho, Semevin, Envirofeast® and untreated control. Promet, Gaucho and Semevin were applied as seed treatment, Temik as in furrow application during planting and Envirofeast® applied to seedlings after emergence. The results showed that significantly fewer ($P<0.05$) number of thrips (adults and immature) were found on the insecticide treated plots compared with the Envirofeast® plots, the latter being not significantly differeut from the unsprayed plot. A negative and significant relationship ($P<0.001$) was found between dry weights of terminal shoots of cotton plants and the uumber of thrips (adults and immatures). In this study, the cotton plants in each treatment recovered quickly from thrip attack and therefore seed treatment before sowing and in furrow application of insecticides immediately after sowing did not significantly affect yield. Temik persisted longest and resulted in a higher terminal shoot dry weight than all other treatments and the control. Integrating Envirofeast® with the seed treatments and in furrow application of temik resulted in a rapid establishment of beneficial insects in these plots. Establishment of beneficial insects was, however, earlier in the temik treated plot than any other treatment and control .

Synthetic insecticides like Larvin, Endosulfan, Helix and *Bacillus thuringiensis* (Bt) are regarded by the cotton industry as "soft" (i.e. having a minimal effect) on natural enemies of cotton pests, especially *Helicoverpa* spp. when applied against them. A study to determine the effect of application of these insecticides on predators of cotton pests, viz: predatory beetles, bugs, lacewings and spiders, indicated that significantly lower numbers of predatory insect adults were recorded in the larvin and endosulfan treated plots, followed by Helix with *Bacillus thuringiensis* and the unsprayed (control) plots recorded the highest numbers. No larvae of the predatory insects sampled were recorded in the insecticide treated plot plots, with the exception of *B. thuringiensis* . The study therefore showed that Bt is soft, Helix is partially soft but larvin and endosulfan are hard on predatory insects.

The role of lucerne in the management of green mirids on cotton especially early season was evaluated in the mesh house and in the field.The results showed that under both field and mesh house conditions, lucerne was preferred over cotton by green mirid adults for oviposition. However, under no-choice tests, oviposition on lucerne and cotton and also the survival of mirid nymphs on these plants were not different. This indicates that green mirid adults have a distinct preference for lucerne over cotton but in the absence of lucerne, however, the female mirid will not restrain oviposition, but will deposit the same number of eggs on cotton. When lucerne was planted as strips within commercial cotton crops, 15 and 35 times fewer mirid adults and nymphs respectively were recorded on cotton compared to cotton without lucerne strips. Apart from serving as a trap crop for green mirids, lucerne strips also served as a refugia for beneficial insects.

The IPM program developed for conventional cotton, under project DAN 68C, utilises beneficial insects as basic components through the use of Envirofeast® (food) attractant spray. These measures are integrated with lucerne (trap crop) planted as strips within commercial cotton and Bt to manage cotton pests. The commercial prospect of this IPM strategy was tested under a conventional cotton situation at Auscott in Warren and in a non-synthetic insecticide (organic) cotton situation at Alcheringa in Boggabilla and Bellevue in Warren (project DAN 89C). The size of farm used for the trial at Auscott in Warren was 92.2 ha and that at Alcheringa and Bellevue were 170 and 136 hectares respectively. The trial at each site was compared with similar size farms managed with conventional insecticides.The study showed that the IPM plots which had 9 Envirofeast® (food) sprays, one Curacron spray and 2 comite sprays controlled cotton pests similarly to conventional cotton which had 7 synthetic insecticide sprays. The IPM plot yielded yielded 3.2 bales per acre compared with 3.53 bales per acre from the synthetic insecticide managed cotton.

The result of the control strategy tested under non-synthetic insecticide regime showed that significantly ($P<0.01$) fewer number of eggs were laid on the food sprayed plots compared with the conventional insecticide and the unsprayed plots. At the end of study as many as 2.03 and 2.76 times *Helicoverpa* spp. eggs had been recorded in the unsprayed and insecticide treated plots respectively compared with the IPM plot. However cotton yield from the insecticide treated plot was 2.38 bales per acre compared with 1.13 bales and 0.68 bales from the Envirofeast® and the unsprayed plots. The reason for the lower yield on the organic cotton plot was that it received only one irrigation so that plants were stressed compared to about 4-5 irrigations for the conventional cotton. Also the organic cotton plot was attacked by Fusarium wilt which caused fruit loss as well as plant death. Yield was also low on the organic cotton at the Bellevue site compared with conventional insecticide treated plots.

1. INTRODUCTION

The cotton industry is one of the major agricultural export earners for New South Wales with a gross value of over $400 million in earnings for the state. Cotton crops are attacked by a wide range of insect pests, especially early in the cotton season, the key ones being *Helicoverpa* spp. larvae, green mirids, two-spotted mites and thrips. To sustain production the cotton industry currently relies heavily on synthetic insecticides to control these pests. Over-reliance on insecticides and associated problems of insecticide resistance in the major pests, disruption of natural enemies of the pests and environmental consequences have cast doubt on the long term viability of the classical insecticide approach. There is a need to develop alternative strategies, especially for early in the cotton season, which do not rely solely on synthetic insecticides but integrate other forms of control with beneficial insects as basic components. Much research has been devoted to the development of techniques for augmentation of *Trichogramma* spp. for management of *Helicoverpa* spp. but the technique does not appear feasible for intensive cotton systems at this stage. Experience overseas indicates that provision of supplementary food can increase beneficial insect numbers and enhance their activity, however no attempt has been made to develop a technique which can either increase densities of beneficial insects or suppress numbers of the key pest in order to shift the predator to prey ratio in favour of the natural enemies especially early season to control the pest. Any such technique or strategy if developed should be tested under non-synthetic insecticide regime because it is only in a non-chemical environment that the true impact of non-chemical pest management tactics can be studied, clearly understood and refined into a better integrated pest management program.

2. OBJECTIVES

Two projects (DAN 68 and 89C) are combined in this report because the objective of DAN 89C was based on results achieved from DAN 68C during the period 1992-1994. The control strategy developed in DAN 68C based on the objective outlined below was further evaluated under non-synthetic insecticide regime (i.e DAN 89C) in 1994/95 season to determine their commercial prospects. The objective of DAN 68C study was to (1) assess the value of provision of supplementary food in the conservation and augmentation of beneficial insects and their impact on cotton pests especially in early season; (2) assess the ovipositional response of the major pest, spp. to various food supplements; (3) determine whether early season pests especially green mirids are attracted to colour and identify the most effective coloured trap that can be used to monitor their flight activity and populations; (4) develop appropriate sampling procedure for green mirids (5) compare and identify the most effective seed treatment method against early season pests that have minimal effect on beneficial insects; (6) determine the impact of "soft" insecticides on natural enemies of cotton pests, and (7) determine role of trap crops in the management of green mirids (8) establish preliminary trials to develop integrated pest management program (IPM) for early cotton.

3. RESULTS and DISCUSSIONS

3.1. *Effect of provision of supplementary food in the conservation and augmentation of beneficial insects and their impact on cotton pests especially in early season.*

This study was conducted in an irrigated commercial cotton farms at Auscott in Narrabri and Norwood near Moree in New South Wales. The food products evaluated were Envirofeast® and Envirofeast 2 developed by the author in this study. The other food products evaluated were sugar; and a mixture of petroleum oil (Caltex Lovis, a C_{21} narrow range oil with a 50% distillation temperature of 361^{o}C at 101.33 kpa) and Kelgum (Kelco & Co., San Diego, CA). These treatments were compared in commercial cotton to an unsprayed (untreated control) and conventional insecticide (treated control) plots. The most important predatory insect groups collected using sweep net and Dvac were the predatory beetles, bugs, lacewings and spiders. They included *Coccinella repanda* (Thunberg)(Transverse lady beetle), *Harmonia arcuata* (Fabricius)(Three-banded ladybeetle), *Diomus notescens* (Blackburn)(Two-spotted ladybeetle), *Dicranolauis bellulus* (Guerin)(Red and blue beetle), *Geocoris lubra* (Kirkaldy)(Big-eyed bug), *Nabis capsiformis* (Germar)(Damsel bug), *Chrysopa* spp. (Green lacewings), *Lycosa* and *Oxyopes* spp. (Spiders). The study indicated that adult lady beetles, red and blue beetles, big-eyed bugs, damsel bugs and green lacewings responded more positively

and numbers increased significantly throughout the study on plots treated with Envirofeast® spray than all other treatments. In presence of Envirofeast® the predatory insects failed to respond consistently or cleartly to either sugar or a protein supplement spray used in Envirofeast 2. The conventional insecticides virtually exterminated the predatory insects. This study supports the findings of previous researchers that application of supplementary food can attract and concentrate varieties of entomophagous arthropods to enhance biological control of crop pests.

3.2. *Assessment of ovipositional response of Helicoverpa spp. to various food supplements*

The ovipositional response of Envirofeast®, Envirofeast 2 and the other food products indicated in experiment 3.1. were investigated under mesh house with choice and no-choice and large scale field conditions at the Australian Cotton Research Institute (ACRI) at Narrabri, Norwood near Moree and Alcheringa near Boggabilla in New South Wales. The results showed that fewer numbers of Heliothis eggs were laid on Envirofeast® and 2 treated plants than in any other treatment and control (water-sprayed) plants, both in the mesh house choice and no-choice tests and the in the field plots sprayed at fortnightly intervals and exposed to natural population of *Helicoverpa* (heliothis) spp. Suppression of oviposition by Envirofeast sprays in the mesh house was higher in *Helicoverpa punctigera* (Wallengren) than *H. armigera* (Hubner) and therefore could be partially offset by increased *H. armigera* infestations in the field. This was evident in the field trial at Norwood where the number of eggs laid on Envirofeast® treated plots though was significantly lower than in any other treatments tested, but peaked in February to coincide with the period when the moth populations were dominantly *H. armigera*. Nevertheless the study demonstrated oviposition suppression by Envirofeast® product towards *Helicoverpa* spp. on cotton. Therefore Envirofeast® could be used in an integrated approach, especially early in the season, to reduce heliothis numbers.

3.3. *Development of an appropriate sampling or trapping technique for early season pests especially green mirids and beneficial insects in cotton.*

3.3.1. Comparison of the effectiveness of net sweeping and Dvac in sampling early season pests and beneficials.

This study was conducted in commercial cotton at Norwood near Moree. The study showed that Dvac sampling is more effective than a sweep net for green mirids, jassids but not for thrips, mites and *Helicoverpa* spp. Predatory insects were also effectively sampled with the Dvac (Homelite Textron Inc., NC, USA). To use the Dvac on commercial farms, samples should be taken over 20 metre sections of cotton rows. Tapered collection bags should be used and a single pass should be made over the crop area to be sampled. The nozzle of the sampler should be inside but not on the top of the plant canopy. Avoid sampling wet plants. After every 20 metre sampling, the insects in the Dvac bag should be transferred into plastic bag and placed in an esky. The insects can be counted either directly in the plastic bags (in the case of growers or consultants) or washed on filter paper and counted under a microscope (in the case of researchers). The disadvantage of using a sweep net in sampling is that only insects on the top of the cotton foliage are sampled leaving those insects in the middle and bottom of the plant. Also during mid and late season when cotton plants have developed fruits and squares, sweep netting usually remove the squares on the top of the plant.

3.3.2. Field studies on the colour response of jassids, thrips, mirids and coccinellids in commercial cotton farms

Field tests on colour attraction and flight activity of early season pests and coccinellid adults were studied using 30 x 30 cm coloured sticky traps placed in commercial cotton field. The test colours were yellow, green, orange, red, deep blue, true blue, black, magenta and white. Among the colours tested, thrips were attracted most to white and true blue, mirids to green and a mixture of yellow and greeen (3G:1Y), green vegetable jassids, transverse lady beetle and two-spotted lady beetle to yellow. Dilution of the green colour with orange or yellow to produce green-orange hues or green yellow hues resulted in a decline in green mirid catch with the exception of the 3G:1Y hue which caught similar numbers as the green. The green- yellow hue emitted the highest amount of light in the 500-560 nm zone so that any trap to be used for trapping green mirids should reflect maximum light in this zone. Also the green jassid and the coccinellids had a positive response to yellow. The

reflectance spectra of painted surfaces of enamel colours and also traps of different hues of yellow indicated that jassid capture rate was directly related to the proportion of light reflected in the 550 nm zone, the wavelength in which peak reflectance of green plants occur. In all the insects with the exception of thrips in which trap counts were not differentiated between sexes, the sex ratio of captured adults was 1:1 indicating no colour preference by sex. Therefore coloured sticky traps can be used to monitor populations of green mirids, jassids and predatory insects especially ladybirds and lacewings.

3.4. *Determination of the most effective seed treatment method against early season pests , especially thrips , and their impact on beneficial insects*

Field tests to determine the most effective seed treatment control of early season pests, especially thrips, were conducted in commercial irrigated cotton at Auscott in Narrabri in New South Wales. The treatments evaluated were Temik, Promet, Gaucho, Semevin, Envirofeast® and untreated control. Promet, Gaucho and Semevin were used as seed treatments, Temik as an in furrow application during planting and Envirofeast® was applied to seedlings after emergence. The results showed that significantly fewer ($P<0.05$) number of thrips (adults and immature) were found on the Temik, Gaucho and Semevin treated plots compared with the Envirofeast® and the unsprayed plots. A negative and significant relationship ($P<0.001$) was found between dry weights of terminal shoots of cotton plants and the number of thrips (adults and immatures). This means, the higher the number of thrips on cotton seedling the lower the dry weight of the plant (i.e. the higher the damage). However the thrip damage did not significantly affect the final yield of the crop because the plants recovered quickly from the thrip damage. The effects of temik persisted longer, with a higher terminal shoot dry weight, than all other treatments and the control. Integrating Envirofeast® spray with the seed treatments or with in furrow application of temik resulted in a rapid establishment of beneficial insects in these plots. This indicated that seed treatment or in furrow application of temik after sowing can boost plant growth and provide shelter for beneficial insects to become established. The establishment of beneficial insects, however, was earlier in the temik treated plot than any other treatment and the control. None of the insecticide tested had a negative effect on the beneficial insects.

3.5. *Determination of the impact of "soft" insecticides on natural enemies mainly predatory insects of cotton pests.*

Synthetic insecticides like Larvin, Endosulfan, Helix and *Bacillus thuringiensis* (Bt) are regarded by the cotton industry as "soft" (i.e. having a minimal effect) on natural enemies of cotton pests, especially *Helicoverpa* spp., when applied against them. A study was therefore conducted in commercial irrigated cotton farm at Boggabri in New South Wales to assess the numbers of predatory insects in plots treated with each of the insecticides compared with the unsprayed plot (control). The predatory insects recorded in this study were similar to those in Experiment 3.2. The study indicated that significantly ($P<0.01$) lower numbers of predatory insect adults were recorded in the larvin and endosulfan treated plots, followed by Helix with *Bacillus thuringiensis* and the unsprayed (control) plots recorded the highest numbers. No larvae of the predatory insects sampled were recorded in the insecticide treated plots, indicating no establishment in these plots due to the sprays. But ladybird beetle and lacewing larvae were found in the plots treated with *B. thuringiensis* and the unsprayed control plot. However, few adults of predatory beetles and bugs were found in the insecticide treated plots one week after spraying. There could be an influx from the unsprayed and Bt plots to the insecticide treated plots since the decline in numbers on the unsprayed plot coincided with increased numbers in the insecticide plot. It could also mean that the residual effect of larvin and endosulfan has minimal effect on the predatory insects. The study therefore showed that Bt is soft, Helix is partially soft but larvin and endosulfan are hard on the predatory insects when sprayed directly on them.

3.6. *Determination of the role of lucerne (trap crop) in the management of green mirids in cotton*

The green mirid, *Creontiades dilutus* (Stal) is one of the most serious early-season pests of cotton. The industry currently relies on broad spectrum insecticides targeted against *Helicoverpa* spp. to control this pest, which in turn disrupts biological control of other major cotton pests. Field experiments to evaluate the role of lucerne, in the management of green mirids on cotton were conducted under mesh house free/no choice and commercial farm conditions at Norwood near

Moree, and at Auscott and the Australian Cotton Research Institute at Narrabri in New South Wales. In the mesh house choice tests and under field conditions, lucerne was preferred over cotton by green mirid adults for oviposition. However, under no-choice tests, oviposition on lucerne and cotton and also the survival of mirid nymphs on these plants were not significantly different. This indicates that green mirid adults have a distinct preference for lucerne over cotton. In the absence of lucerne, however, the female will not restrain oviposition, but will deposit the same number of eggs on cotton. In an experiment where lucerne was planted as strips within commercial cotton crops, 15 and 35 times fewer mirid adults and nymphs respectively were recorded on cotton compared with cotton without lucerne strips. When lucerne was interplanted with commercial cotton under integrated pest management (IPM) regime which had no insecticide sprays against *Helicoverpa* spp., mirid numbers were reduced to levels similar to that achieved by nine insecticide sprays. Apart from serving as a trap crop for green mirids, the strips served as refugia for beneficial insects in cotton.

3.7 *Preliminary evaluation of integrated pest management (IPM) program in commercial cotton under conventional insecticide and non-synthetic insecticide (organic) regimes.*

The IPM program developed for conventional cotton under (project DAN 68C) utilises beneficial insects as basic components through the use of Envirofeast® (food) attractant spray. These are integrated with lucerne (trap crop) planted as strips within commercial cotton and Bt to manage cotton pests. Envirofeast® sprays attract and conserve beneficial insects that are mainly predatory insects on cotton. The commercial prospect of this IPM program was tested in conventional cotton situation at Auscott in Warren in New South Wales, and in non-synthetic insecticide (organic) cotton situations at Alcheringa in Boggabilla and Bellevue in Warren (project DAN 89C). The size of farm used for the trial at Auscott in Warren was 92.2 ha and that at Alcheringa and Bellevue were 170 and 136 hectares respectively. The trial at each site was compared with similar sized farms managed with conventional insecticides.The study at Auscott in Warren showed that the IPM with 9 Envirofeast® (food) sprays, one Curacron spray and 2 comite sprays, yielded 3.2 bales per acre compared with 3.53 bales per acre in the conventional cotton which had 7 synthetic insecticide sprays. This means that with the use of Envirofeast® and lucerne strips, the use of synthetic insecticides could be reduced significantly without any apparent loss in yield. Since the cost of Envirofeast product is cheaper than conventional insecticides the grower did not suffer any loss in economic terms in this study.

At the Alcheringa study site significantly ($P<0.01$) fewer numbers of eggs were laid on Envirofeast® plots compared with the conventional insecticide and the unsprayed plots. At the end of study as many as 2.03 and 2.76 times more *Helicoverpa* spp. eggs had been recorded in the unsprayed and insecticide treated plots respectively compared with the Envirofeast® plot. This indicates that effect of the food spray combined with natural enemies were suppressing egg numbers in the food spray plot. The number of larvae recorded in the Envirofeast and the conventional insecticide plots were not significantly different ($P>0.05$). However cotton yield from the insecticide treated plot was 2.38 bales per acre compared with 1.13 bales and 0.68 bales from the Envirofeast® and the unsprayed plots. The reason for a lower yield on the organic cotton plot was due to crop rather than pest management. The Envirofeast® which represented the organic cotton received only one irrigation with no fertilizer application, compared to five iirigations for the conventional cotton. Also the organic cotton plot was affected by Fusarium wilt and this might have caused further yield reduction in this crop. The Bellevue study site yielded 1.5 bales per acre compared with 3.24 bales in the conventional. The lower yield in this plot was also due to the agronomic management of the farm. The Bellevue plot received two irrigations without fertilization compared with the conventional insecticide plot. Also there was shortage of Envirofeast® product in January and February 1995, which were periods of high *H. armigera* infestation that resulted in loss of fruits.

4. GENERAL DISCUSSION

The trend to produce early cotton in Australia has resulted in an increase in early season use of insecticides against early season pests, thus disrupting biological control. This study indicated that an early season insect control strategy based on beneficial insects, trap crops and *Bacillus thuringiensis* sprays can eliminate the need for early season synthetic insecticide sprays. The Envirofeast® food product developed in this study was shown to attract, conserve and enhance the activities of naturally occuring natural enemies, viz. predatory beetles, bugs and lacewings, which are important predators

of cotton pests especially *Helicoverpa* spp. Apart from conserving beneficial insects, Envirofeast® spray can deter *Helicoverpa* spp. oviposition. The ovipositional deterrent effect of this food product is stronger on *H. punctigera* than *H. armigera*, indicating that increased infestations of the latter could partially offset the ovipositional deterrent effect. Nevertheless the fact that the product can concentrate predatory insects of the moths can help to shift the predator to prey ratio in favour of natural enemies to enhance biological control. Envirofeast® is being commercialised by Rhone-Poulenc Rural (Australia) Ltd and an international patent is being sought to protect the product. The study has also shown that green mirids which are important early season pests in cotton can be effectively managed by planting lucerne as strips within commercial cotton farms. These insects normally would have been controlled by dimethoate at high infestations. To manage green mirids effectively the lucerne should not be allowed to hay off but rather new growth should be maintained and stimulated throughout the cotton season. This was achieved by mowing alternate halves of each lucerne strip every 4 weeks. Pest control decisions are usually based on pest populations in the crop. The IPM program developed in this study for conventional cotton used the Envirofeast® food product to utilise beneficial insects in the farm. These were integrated with trap crops (lucerne), *Bacillus thuringiensis* and synthetic insecticides. The IPM program in this study eliminated any need to spray early season and reduced insecticide sprays by 60 per cent without sacrificing yield. The IPM program when tested under a non-synthetic insecticide regime could again manage pests. Evaluation of the effectiveness of control programmes and the time to implement any control strategy, depends on an ability to effectively sample pest and beneficial insect populations. This study assessed two sampling methods (Sweep net and Dvac) and identified Dvac as the most effective one that can be used to sample mirids, jassids and predatory insects on cotton. The advantage Dvac method has over sweep netting is the fact that it does not destroy cotton squares as in sweep netting and also more insects are caught with this method. The other insects like *Helicoverpa* spp. can be assessed through the normal visual counts. Mites and thrips can be assessed by taking plant leaves and terminals. The flight activity and populations of thrips, jassids, mirids and predatory beetles, bugs and lacewings can also be assessed by trapping them in coloured sticky traps. In this study thrips were attracted to true blue or white sticky traps reflecting light in the 400-500nm zone, green mirids to either green or a mixture of 75% yellow and 25% green trap and jassids and ladybird beetles to full yellow. The yellow and green colours emitted light in the 500-600nm zone. To maximise catch of these insects the traps should be placed at heights between 25-75 cm above ground level. For the insects responding positively to coloured traps emitting light in the 500-600 nm zone with peak reflectance at 550 nm (the wavelength at which green plants reflect most light), it could be possible that these insects detect cotton foliage, in part, on the basis of colour. Several studies have indicated that insects are attracted to different colours and that coloured sticky traps can be used to monitor their populations.

Overall this study has developed an optimal control strategy for cotton pests especially early season pests which has minimal impact on natural enemies of the the pests. This control strategy could be integrated with transgenic cotton

5. CONCLUSIONS, RECOMMENDATIONS AND APPLICATION TO INDUSTRY

For years now, beneficial insects have been neglected in cotton pest management systems due to the disruptive impact of pesticides, the lack of techniques to maximise their abundance and effectiveness and also the lack of ecological diversity in Australian cotton systems which are monocultures that militate against beneficial arthropods. This study has developed Envirofeast® (food) product which attracts, conserves and augments predatory insects of the major pests in cotton. Envirofeast® also deters oviposition of *Helicoverpa* spp. on cotton. A refugia technology, which involves growing lucerne as strips within cotton farms to serve as trap crops for early season cotton pests such as green mirids and as refugia for beneficial insects, has also been developed in this study. Integration of Envirofeast® and the refugia technologies into a pest management system effectively eliminated early season synthetic insecticide sprays and reduced the total insecticide sprays by about 60 per cent. Envirofeast® product unfortunately is not rainfast and production technology needs to be developed to produce the product in large quantities for commercial use. After going through a tendering

process, Rhone -Poulenc Rural (Aust.) Pty Ltd was selected to be the commercial partner. The product is currently being evaluated prior to commercialization.

Larvin and endosulfan were previously known in the industry as "soft" to beneficial insects but this study has indicated that they are not. These insecticides can exterminate natural enemies of the pest, thus affecting its biological control. With resistance of *Helicoverpa* spp. to insecticides increasing, and the possibility that insect resistance will be a major problem even with transgenic cotton, the control strategy developed in this study should be integrated with transgenic cotton to sustain future cotton production.

6. COMMUNICATION OF RESULTS

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Mensah, R. K. (1993). Population dynamics of *Helicoverpa* spp. and food sprays. 3rd Early season Pest Management Workshop, Toowoomba, Queensland.

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Mensah, R. K. (1994). Habitat manipulation and conservation of predatory insects of *Helicoverpa* spp. on cotton. IPM Group Workshop, Narrabri, NSW, Australia. 12-13 May 1994

Mensah, R. K. (1994). Can beneficial insects be conserved in cotton fields? Proceeding 7th Australian Cotton conference, Gold Coast, Queensland, pp. 87-93.

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Mensah, R. K. (1994). Effect of lucerne in the control of green mirids, *Creontiades dilutus* (Stal) in cotton in Australia. Proceedings 25th Annual General Meeting and Scientific conference of Australian Entomological society, Adelaide, South Australia. pp. 52.

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Mensah, R. K. (1995). Numerical response of predatory insects of *Helicoverpa* spp. to a newly developed supplementary food spray (Envirofeast®) in commercial cotton.

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Mensah, R. K. (1995). Assessment of colour response and flight activity of *Austroasca viridigrisea* in commercial cotton farms in Australia. (Entomologia experimentalis et applicata, Kluwer Academic Publishers, Netherlands).

Mensah, R. K. (1995). Ovipositional deterrent activity of Envirofeast® a new food spray product on *Helicoverpa* spp. on cotton in Australia (Entomophaga, Journal of Biological and Integrated control published by Lavoisier, France)(in press).

Mensah, R. K. (1995). Effect of Envirofeast (food attractant) on *Helicoverpa* spp. and their natural enemies in cotton. Report for Product Commercialization to Rhone-Poulenc Rural (Aust.) Pty Ltd. 29 pp.

6.1 CONFIDENTIAL PATENT ARTICLE

Mensah, R. K. (1993). A method of controlling moth and other insect pests. Griffith Hack and Co., Patent Attorneys, Sydney, Austyralia. 24pp.

6.2 FIELD DAYS ADDRESSES TO GROWERS AND CONSULTANTS

1993: Food spray Technology does it worth a try?

Macintyre Field Day, Gwydir Field day, Namoi Field day

1994: IPM program using food spray and trap crops.

Macintyre Field Day, Gwydir Field day, Namoi Field day, Macquarie Field day

1995: Biorational cotton

Macintyre Field Day, Gwydir Field day, Namoi Field day, Macquarie Field day

Bourke Cotton Growers and Consultants, Macquarie IPM Group

7. APPENDIX

7.1.1 Budget (DAN 68C)

Item	1992/93		1993/94		1994/95	
	Amount requested $	Amount returned $	Amount requested $	Amount returned $	Amount requested $	Amount returned $
A. Salaries (including on costs)	22,933.69		47,527.64		56,085.29	
B. TRAVEL	2,000		2,003.07		10,076.16	
C. OPERATING	17,164.12		5,402.60		7,346.50	
D. CAPITAL	11,018.70		20,257.50		NIL	
TOTAL REQUESTED	54,162	1,045.49	75,190.81	NIL	75,084	1,576.05

7.1.1 Budget (DAN 89C)

Item	1994/95	
	Amount requested $	Amount returned $
A. Salaries (including on costs)	18,840	
B. TRAVEL	4,251	
C OPERATING	11,856	
D. CAPITAL	NIL	
TOTAL REQUESTED	34,947	NIL

7.2. Royalty and Intellectual property arrangements (patents etc).

Negotiations are in progress with Rhone-Poulenc Rural (Australia) Pty Ltd to carry out further Research and Development on the Envirofeast® product developed in this project and to commercialize it after 1997. Full details have been advised to CRDC under separate cover.