Evaluation of Coloured Sticky Traps for Monitoring Populations of *Austroasca viridigrisea* (Paoli) (Hemiptera: Cicadellidae) on Cotton Farms

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ABSTRACT Field tests on the colour response of *Austroasca viridigrisea* adults were conducted using square (30 x 30 cm) coloured sticky traps placed in a cotton field. Among the colours tested, adults were attracted most to yellow traps emitting light in the 500-600 nm region (peak reflectance at 560 nm), followed by green and orange, then red, deep blue, black, magenta and true blue. Dilution of yellow with white to produce yellow-white hues resulted in a significant decline in *A. viridigrisea* captures. Reflectance spectra of painted surfaces of enamel colours and also traps with different hues of yellow indicated that *A. viridigrisea* capture rates were directly related to the amount of light reflected in the 500 - 600 nm zone, the wavelength at which peak reflectance of green plants occurs. This positive behavioural response of *A. viridigrisea* to yellow suggests that the leafhopper can discriminate foliage-like hues (500-580 nm) from non foliage-like hues (<500 nm and > 580 nm) and therefore could detect herhaceous foliage on the basis of colour. Significantly higher number of adults were caught at heights between 25-75cm than at 100, 125 and 150 cm above ground level. To monitor flight phenology and populations of *A. viridigrisea* yellow sticky traps should be placed at heights between 25 and 75 cm above ground level.

Introduction

The vegetable leafhopper, *Austroasca viridigrisea* (Paoli) is one of the important early season pests of cotton in Australia. Adults and nymphs feed preferentially on leaves and new regrowth but are more likely to attack mature leaves during the flowering stage of the crop. Severe infestations can produce a stippling effect on leaves and this can cause damage to seedlings and new regrowth, resulting in significant delays in the growth of the plant (Room and Wardhaugh 1977; Forrester and Wilson, 1988). Currently *A. viridigrisea* populations are readily controlled by synthetic sprays applied during the early part of the cotton season for control of *Helicoverpa* spp. and other pests. These insecticides disrupt natural enemies of the pests and eliminate any chance of development of an integrated pest management program for cotton.

With the proposed introduction of transgenic cotton in Australia by the 1996-97 season, it is expected that synthetic insecticide use on cotton against *Helicoverpa* spp. and other pests will be reduced, and *A. viridigrisea* may assume even greater importance since they are not affected by these plants (G. P. Fitt, pers comm.). Therefore, a better understanding of the stimuli to which *A. viridigrisea* adults respond is essential to the development of more effective trapping techniques to reliably estimate the adult numbers and flight phenology for use in control programmes. Coloured traps have been used to monitor populations of many phytophagous insects in field crops (Ridgway and Mahr, 1986; Mensah and Madden, 1992). The responses of hemipterans to colour have been extensively studied, with most species strongly attracted to green and yellow (Ridgway and Mahr, 1986; Adams and Los, 1989; Mensah and Madden, 1992). However, apart from studies by Alverson *et al.* (1977) and Meyerdirk and Oldfield (1985) who evaluated the effectiveness of colour traps in monitoring leafhopper populations, studies on colour responses of leafhoppers are rare, and the few studies that have been conducted have focussed on host finding behaviour of leafhoppers (Todd *et al.*, 1990). For the vegetable leafhopper, *A. viridigrisea*, no studies on the colour stimuli to which it responds have been conducted.

The purpose of this study was to determine the relative attractiveness of coloured sticky traps to *A. viridigrisea* adults in cotton, and to find a suitable coloured trap to reliably estimate *A. viridigrisea* populations in the field.

Materials and methods

The colour and height preference studies were conducted in a commercial cotton farm at Auscott Narrabri, using field trapping techniques similar to those of Prokopy (1972). The traps consisted of aluminium squares (30 x 30 cm) painted on both sides with the test colour, coated with a thin layer of Bird Tangletrap® (The Tanglefoot Company, Grand Rapids, Michigan, USA), attached vertically to a steel rod pushed into the ground. The reflectance characteristics of the colours were measured by a Field Spec™.UV/VNIR (350-1050 nm) visible recording spectroradiometer (Analytical Spectral Devices, Inc., Boulder, CO., USA).

Three experiments were conducted from 1992 to 1994. The first experiment assessed the response of *A. viridigrisea* to 30 x 30 cm square yellow, orange, green, red, deep blue, black, magenta and true blue (Duralex Aust., Pty Ltd, Rydalmere, NSW) painted traps from November, 1992 until May, 1993.

Based on the results of experiment 1, the second experiment assessed the response of *A. viridigrisea* to different hues of yellow painted traps from November, 1993 to April, 1994. The colours tested in that study were yellow and white enamels (Duralex Aust., Pty Ltd, Rydalmere, NSW) and three intermediate hues made by mixing the yellow (Y) and white (W) enamels in the following proportions: 3Y:1W; 1Y:1W; 1Y:3W.

The third experiment determined the optimum height for exposure of the most attractive colour traps identified in experiment 1 in order to maximize trap catch. This evaluation was conducted from November, 1993 until April, 1994. In this study each of the three painted coloured traps were placed at 25, 50, 75, 100, 125 and 150 cms from the ground to the base of the panel. The experiments were arranged in a randomized complete block design of eight (experiment 1), five (experiment 2) and three (experiment 3) colour treatments with three replications. The colour traps were placed 2 m apart in a random order.

A. viridigrisea adults trapped over each 7 day period were collected from each side of the sticky traps and transferred with a pin into a tube containing kerosene. The insects were later sexed and counted under a dissecting microscope. Following each collection, each trap was washed with kerosene, dried in the sun, recoated with Tangletrap adhesive and returned to the field.

Analysis of data: All trap catch data were transformed to ($\sqrt{X} + 0.5$) and submitted to repeated measures analysis of variance (Graphpad Version 2.03, Instat Software Inc., San Diego, California) with the least significant difference test (LSD) used to separate means. Arithmetic rather than transformed means are given in the results.

Results

The colour preference test (experiment 1) between November 1992 and May 1993 showed that yellow traps caught significantly ($P<0.05$) more *A. viridigrisea* adults (8.12 per trap per day) than any of the other colours tested (Table 1). Green and orange colour traps were second in preference. This was followed by red, deep blue, black and magenta, with true blue recording the lowest number of adults captured (Table 1). When comparing different hues of yellow (experiment 2), significantly ($P<0.05$) more *A. viridigrisea* adults were collected on full yellow (Y) than on any of the other hues or white (Fig. 1). This was followed by 3Y:1W and 1Y:1W, the latter not significantly different from 1Y:3W. The white traps caught the least number of adults. During the period of study, 49.2 per cent of the total adults caught on all the coloured traps were males and 50.8 per cent females (Fig. 1). The proportion of trapped males and females on each test colour did not differ significantly ($P>0.05$) within colours during any sample period indicating no preference for colour by sex (Fig. 1). The highest number of *A. viridigrisea* adults were caught in January and colour preference was not affected by season.

The reflectance spectra of the painted surfaces are given in Figure 2. Scanning from 350 to 750 nm indicates maximum reflectance between 500-600 nm region except for full white. The peak reflectance of yellow and the three intermediate hues occurred in the 550 and 560 nm region, and for white at 450 nm (Fig. 2). There was a positive correlation between numbers of *A. viridigrisea* adults caught by traps of each colour and the per cent total reflected light emitted by each of the test colours in the 500 and 600 nm region ($P<0.001$) (Fig. 3).

The optimum height to place either yellow, green or orange traps in the field was between 25-75 cm above ground level for yellow and orange and 25-50 cm for green (Table 2). The least number of adults were caught at 150 cm above ground level for all three colours tested (Table 2). The yellow colour trapped the maximum number of adults at each of the heights tested (Table 2).

Discussion

The results of the experiment show a stronger response of *A. viridigrisea* adults to yellow than any of the other colours tested. When the yellow colour was diluted with 25, 50 and 75 per cent (of total volume) white to produce (3Y:1W), (1Y:1W) and (1Y:3W) yellow-white hues respectively, it reduced the per cent total reflected light emitted in the 500-600 nm region and this resulted in a significant decrease in *A. viridigrisea* capture, indicating the degree to which yellow was attractive to the insects. This positive behavioural response of the insects to yellow suggests that *A. viridigrisea* adults can discriminate foliage-like hues (500-580 nm) from non foliage-like hues (<500 nm and > 580 nm) (Prokopy and Owens, 1983) and therefore could detect herbaceous foliage at least in part on the basis of colour. Yellow appears to represent very bright leaves, and like leaves, it reflects little energy below 500 nm and much between 500-600 nm. Yellow therefore acts as a supernormal stimulus for foliage to many phytophagous insects because it elicits a greater alighting response than colours more closely resembling preferred hosts (Prokopy and Owens, 1983). In studies on colour response of aphids, Mooney and Gulmon (1982) noted that increased responsiveness to yellow aids some aphids in finding young, expanding leaves that are high in nitrogen, and often characterized by a yellow colour. Since *A. viridigrisea* adults prefer to feed on young growing herbaceous leaves, their increased responsiveness to yellow suggests an adaptation to locate their hosts and the sites for feeding. This is important because plants are primarily composed of carbohydrates and the amount of nitrogen is usually limited and unequally distributed (McNeill and Southwood, 1973) so that an adaptation to locate preferred food plants and feeding sites will enhance the success of the species.

Several studies have indicated that many insects are attracted to yellow (Coombe, 1981; Meyerdirk and Oldfield, 1985; Zehnder and Speese, 1987; Adams and Los, 1989) and yellow sticky traps have been used to monitor flight activity and populations of hemipterans (Todd *et al.*, 1990; Meyerdirk and Moreno, 1984; Summy *et al.*, 1986; Adams *et al.*, 1983; Meyerdirk and Oldfield, 1985; Ridgway and Mahr, 1986; Adams and Los, 1989; Mensah and Madden, 1992).

The present study has shown that there was no difference in *A. viridigrisea* preference for colour by sex and that a yellow sticky trap supported by a metal pole 25-75 cm above ground level will serve as an effective trapping system for monitoring the flight phenology and populations of all adults. As well, coccinellids (mostly *Adalia bipunctata* (Linnaeus) and *Coccinella transversalis* (Fabricius) which are major predators of *Helicoverpa* spp., were also captured on full yellow (Mensah unpublished). This means that the large scale employment of these traps must be carefully considered.

Acknowledgements

I thank Wendy Harris for technical support, Messrs. Dave Anthony and Stefan Henggeler (Auscott, Narrabri) for cooperating in this study, Mr Graeme Bell and Dr Alison Specht (Centre for Coastal and Resource Management, University of Southern Cross, Lismore, Australia) for providing the spectroradiometer used in the reflectance measurements, and Dr John Madden (Department of Agricultural Science, University of Tasmania, Hobart, Tasmania, Australia) for reviewing the manuscript. The work was supported by the Australian Cotton Research and Development Corporation (grant DAN 68C).

Table 1. Captures of adult *Austroasca viridigrisea* on different coloured traps in commercial cotton at Auscott in Narrabri 1992-1993.

Colour enamels	Mean catch per trap per day [1] X ± SE	Per cent total reflected light emitted in the 500-600 nm region
Yellow	8.12 ± 0.94 a	26.8
Orange	5.92 ± 0.89 b	13.9
Green	5.87 ± 0.82 b	17.1
Red	5.20 ± 0.82 c	11.8
Deep blue	4.78 ± 0.71 c	7.0
Black	4.60 ± 0.64 cd	5.2
Magenta	4.11 ± 0.62 d	8.7
True blue	3.15 ± 0.52 e	7.7

[1] Means based on counts on 19 dates between 20 November 1992 and 3 May 1993; Three replications of each colour per date.

Means with the same letter are not significantly different (P< 0.05), Least significant difference test (LSD).

Table 2. Response of adult *Austroasca viridigrisea* on coloured traps placed at different heights in commercial cotton at Auscott in Narrabri 1993 - 1994.

Trap height (cm)	Mean catch per trap per day [1]		
	Yellow	Orange	Green
	X ± SE	X ± SE	X ± SE
25	6.88 ± 1.09 ab	3.08 ± 0.54 a	3.96 ± 0.71 a
50	6.84 ± 1.19 ab	3.21 ± 0.45 a	3.46 ± 0.45 ab
75	8.53 ± 1.29 a	3.10 ± 0.47 a	3.17 ± 0.42 b
100	5.75 ± 0.94 b	2.29 ± 0.22 b	2.59 ± 0.32 bc
125	4.47 ± 0.81 bc	1.90 ± 0.23 bc	2.03 ± 0.27 cd
150	3.37 ± 0.60 cd	1.47 ± 0.20 c	1.68 ± 0.25 d

[1] Means based on counts on 19 dates between 8 November 1993 and 6 April 1994; Three replications of each colour per date.

Means (within columns) followed by the same letter are not significantly different (P>0.05), Least significant difference test (LSD).

Fig. 1. Captures of *A. viridigrisea* on sticky traps painted with yellow, white, and intermediate hues, from November 1993 to April 1994. ▩ total, ■ males, □ females. Means with the same letter are not significantly different ($P > 0.05$, LSD test). Error bars represent standard errors.

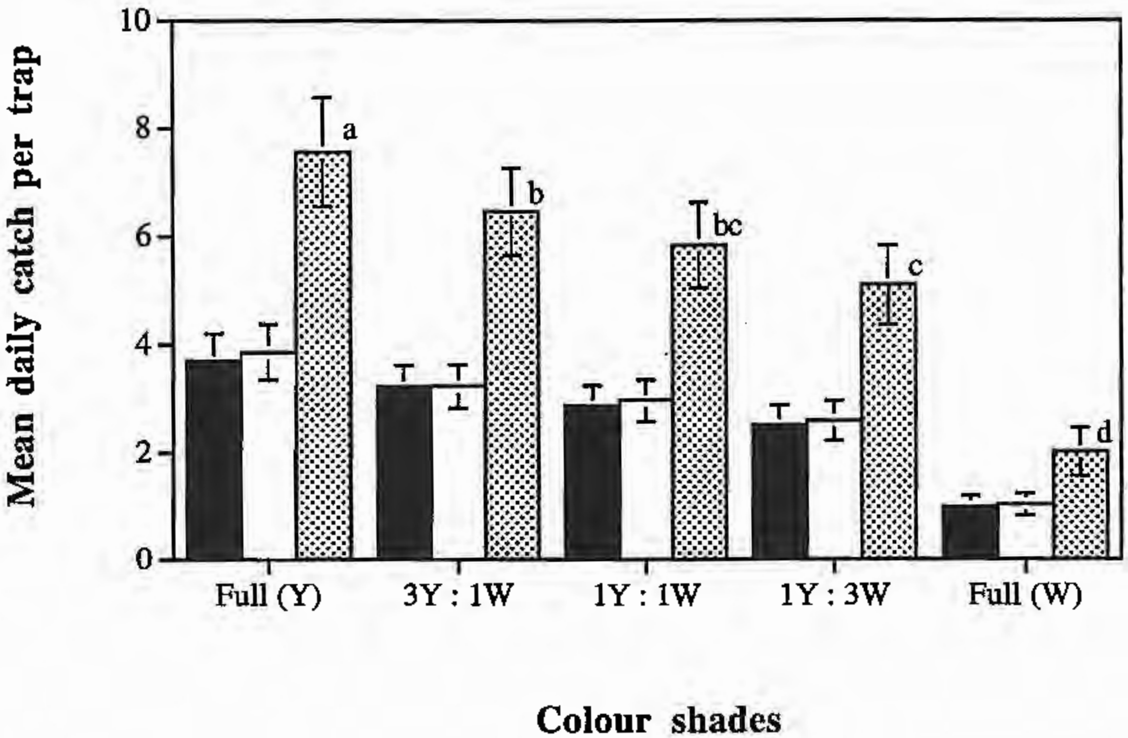

Mean daily catch per trap
10
8
6
4
2
0
a
b
bc
c
d
Full (Y)
3Y : 1W
1Y : 1W
1Y : 3W
Full (W)
Colour shades

Fig. 2. Reflectance spectra of yellow and white enamels and shades. Y = yellow; W = white and Y:W = various mixtures of yellow and white colour enamels.

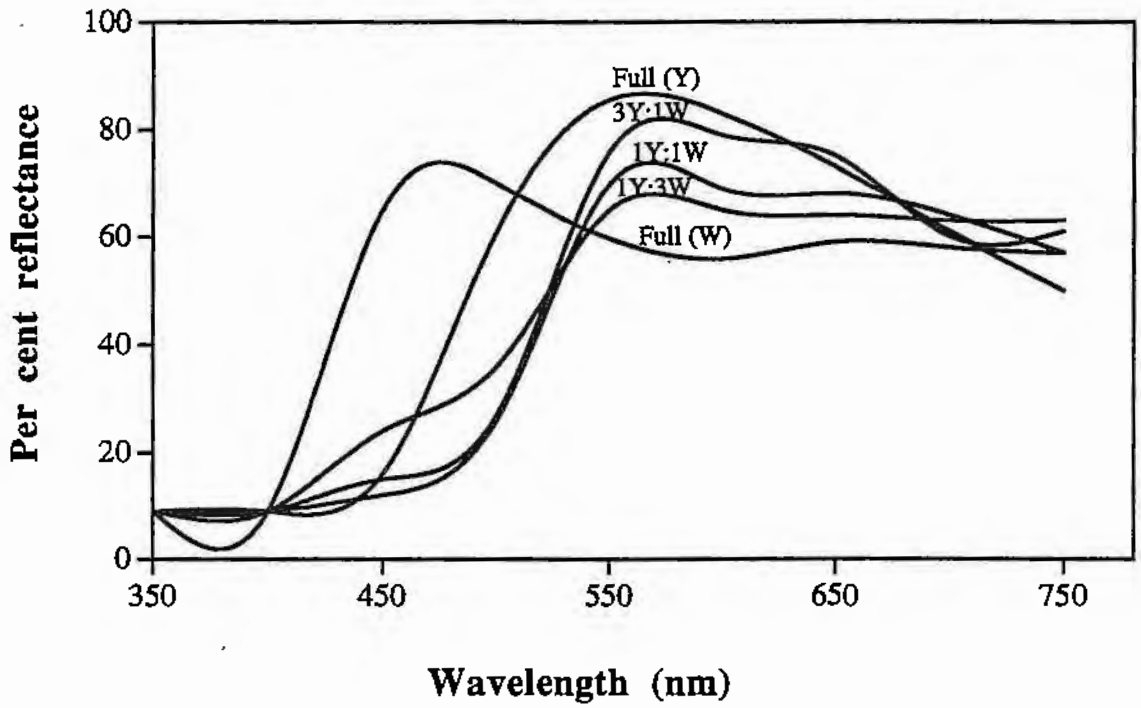
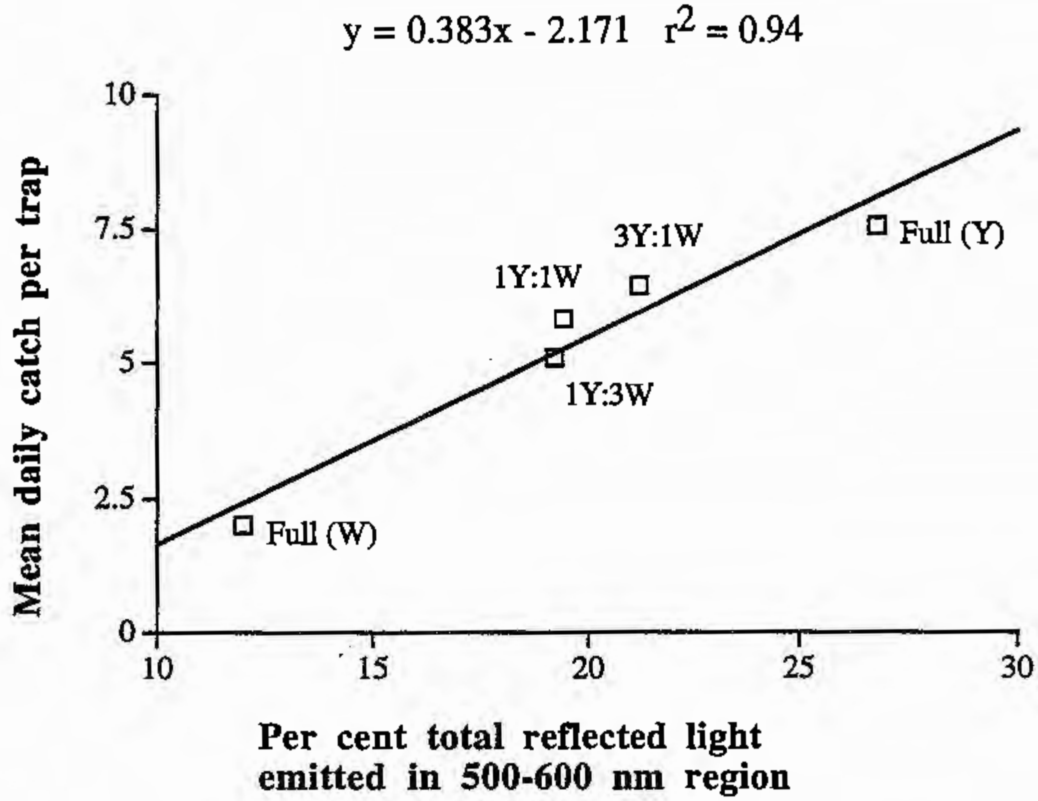

Full (Y)
3Y:1W
1Y:1W
1Y:3W
Full (W)
Per cent reflectance
0
20
40
60
80
100
350
450
550
650
750
Wavelength (nm)

Fig. 3. Relationship between the per cent total reflected light emitted in the 500-600 nm region by white, yellow and intermediate hues and the mean daily catch of *Austroasca viridigrisea* adults in commercial cotton at Auscott in Narrabri from November 1993 until April 1994.


y = 0.383x - 2.171   r2 = 0.94
Mean daily catch per trap
10
7.5
5
2.5
0
10
15
20
25
30
3Y:1W
1Y:1W
Full (Y)
1Y:3W
Full (W)
Per cent total reflected light
emitted in 500-600 nm region

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RESPONSE OF *HELICOVERPA* SPP. (LEP. : NOCTUIDAE) AND THEIR NATURAL ENEMIES TO PETROLEUM SPRAY OIL IN COTTON IN AUSTRALIA

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Refined petroleum products have been used since last century for the control of phytophagous arthropod pests. The response of *Helicoverpa* spp. and its natural enemies to petroleum oil sprays on cotton was investigated under laboratory choice/no-choice and small plot field conditions at the Australian Cotton Research Institute at Narrabri in New South Wales. In oviposition choice and no-choice tests, petroleum oil sprays suppressed oviposition in *Helicoverpa punctigera* (Wallengren) but not *H. armigera* (Hubner)(Lepidoptera : Noctuidae). *H. punctigera* females laid about seven times as many eggs on the control (water sprayed) cotton plants as on either petroleum oil spray alone or oil mixed with Kelgum. However *H. armigera* females laid the same number of eggs on both treated and control plants. In field trials, the number of eggs per metre per sample date found on the plots treated with petroleum oil spray was 3.83 compared with 6.29 and 7.82 eggs respectively on plots treated with conventional insecticide sprays and the unsprayed plots. The number of larvae found on plots treated with petroleum oil sprays was 2.9 times higher than the conventional insecticide sprayed plot, however, this was 1.6 times fewer than the unsprayed plot. The cotton yields from plots treated with petroleum oil sprays was 3.70 bales/ha compared with 7.32 and 2.69 bales respectively from the conventional insecticide treated and the unsprayed plots. Petroleum oil sprays had little or no effect on predatory beetles, bugs, lacewings and spiders.

KEY-WORDS: *Helicoverpa armigera, Helicoverpa punctigera*, integrated pest management (IPM), petroleum spray oil, kelgum, surfactant.

Cotton crops in Australia are attacked by a wide range of insect pests, the key ones being the larvae of *Helicoverpa punctigera* (Wallengren) and *H. armigera* (Hubner) (Lepidoptera : Noctuidae). Although no regular studies have assessed the yield losses caused by insects in commercial cotton crops, early studies with unsprayed cotton indicated insects caused about 50 - 90% yield reductions (Hearn *et al.*1981). Recently Fitt *et al.* (1992) have given values in the

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range of 10 - 30% although in some years this loss may be higher. McGahan *et al.* (1991) estimated the average annual loss due to *Helicoverpa* spp. alone in Queensland cotton at 7.7%, despite expenditure of A$7.5 million for control. Extrapolating such estimates over the entire Australian crop suggests losses of A$60-70 million in 1990-1991, despite the expenditure of almost A$90 million on control (Fitt 1994).

To sustain production, the cotton industry currently relies heavily on pesticides for the control of these major pests. Over-reliance on insecticides, associated problems of insecticide resistance especially in *H. armigera,* disruption of natural enemies and environmental consequences have cast doubt on the long term viability of the cotton industry using a traditional insecticide approach. A control programme that has minimal effect on natural enemies and the environment with negligible chances of inducing resistance would be a desirable alternative. Petroleum oil sprays have been used extensively on a wide variety of crop pests (Lee *et al.* 1991; Beattie 1991; Johnson 1985; Riehl 1981; Simanton and Trammel 1966) and are now an essential component of many integrated pest management (IPM) programmes for scale insects and mites (Beattie 1991). They are also used as surfactants with the bacterial insecticide, *Bacillus thuringiensis* for the control of *Helicoverpa* spp. on cotton. However, no research has been conducted on cotton to determine the effect of petroleum oil sprays *per se* on *Helicoverpa* spp. and their natural enemies.

In this study, we examined the effects of petroleum oil spray and a mixture of petroleum oil and Kelgum sprays on *Helicoverpa* spp. oviposition in choice and no-choice tests in a mesh house and in small plot field trials. In addition the effect of petroleum oil spray on *Helicoverpa* spp. and predatory insect populations and cotton yield was studied in a commercial cotton crop.

MATERIALS AND METHODS

CHEMICALS

The treatments evaluated were petroleum spray oil (Caltex Lovis, a C_{21} narrow-range oil with a 50% distillation temperature of 361°C at 101.33 kpa), Kelgum (Kelco & Co., San Diego, CA) and a mixture of Lovis petroleum oil and Kelgum

SOURCES OF PLANT AND INSECT MATERIALS

Unless otherwise stated, all experiments were conducted in a Sarlon mesh house (4 m x 10 m) during summer 1992/93 and 1993/94 at the Australian Cotton Research Institute at Narrabri in New South Wales, Australia.

The experimental plants used in all studies were potted cotton plants (Sicala VI), 0.5m high. The plants were grown from seeds in pots in the same mesh house where experiments were carried out. *Helicoverpa* spp. moths used in all the mesh house experiments were from colonies established by the Institute's Insecticide Resistance Management Group. All experimental data were subjected to analysis of variance (Graphpad Version 2.03 Instat Software Inc. San Diego, California) and least significant difference (lsd) used to separate the means (Zar 1984).

OVIPOSITIONAL PREFERENCE OF *HELICOVERPA* SPP. TO PETROLEUM OIL SPRAY

Experiments were conducted in January 1993 when cotton plants were 4 weeks old. A randomised complete block design was used for each experiment with three treatments and a control. There were 5 replicates of each treatment, with each replicate consisting of 8 plants.

The treatments were 0.5% (vol/vol) Lovis petroleum spray oil, 0.01% (wt/vol) Kelgum, a mixture of 0.5% Lovis petroleum oil and 0.01% Kelgum and water (control). Separate experiments were conducted for *H. armigera* and *H. punctigera.*

Under free-choice conditions, the plants were treated run off (approximately 100 ml of test solution) using a knapsack sprayer. Following treatment 110 pairs of *H. armigera* or 100 pairs of *H. punctigera* were introduced into the mesh house. The numbers of eggs laid on the plants were counted daily until all adults died thus giving the total number of eggs laid per plant per treatment.

Under no-choice conditions plants from each treatment were enclosed in separate cages within the mesh house and eight pairs (*H. armigera*) or five pairs (*H. punctigera*) adults were released into each cage. Numbers of eggs per plant per treatment were recorded daily.

FIELD STUDIES ON *HELICOVERPA* SPP. AND THEIR NATURAL ENEMIES

Experiments were conducted in a commercial irrigated cotton field at Norwood (29° 28'S, 149° 50'E) near Moree, NSW. The treatments were (1) 0.5% petroleum oil (Lovis) spray, (2) control (untreated) and (3) plot treated with conventional insecticide sprays (treated control) viz Endosulfan (organochlorine), *Bacillus thuringiensis*, Thiodicarb (carbamate), Profenofos (organophosphate), Esfenvalerate (pyrethroid) and Chlorfluazuron (chitin inhibitor) (treated control). One ha plots were arranged in a randomized complete block design with 4 replicates per treatment.

Foliar applications of each treatment were applied on October 27, 1992 and thereafter at 14 d intervals using a ground rig until the end of February, 1993 when spraying ceased. On each occasion 142 litre/ha of petroleum oil spray was applied. Eight applications of this treatment were made during the season. The control (untreated) was left unsprayed and the treated control received 10 applications of synthetic insecticides during the season.

Pre-treatment counts of insects were made 24 h before treatment application and then every 7 days until the end of the experiment (13 weeks).Visual counts of *Helicoverpa* spp eggs and larvae on plants were made on one metre row of cotton plants in each replicate i.e. 4 metres per treatment. Cumulative total number of eggs and larvae from each treatment and control were computed and expressed as cumulative numbers per metre.

Cotton in each treated plot and unsprayed contol plots was harvested at the end of the season and the average yield (bales per acre) were compared.

Predators of *Helicoverpa* spp., were sampled weekly with sweep nets and identified and counted in the laboratory. On each sampling occasion, one sweep per plant for 50 plants in each treated plot was made on the outer top foliage of each plant following completion of visual assessments of prey numbers. Predators were separated into predatory beetles, bugs, lacewings and spiders and data expressed as cumulative predator numbers per sweep.

RESULTS

OVIPOSITIONAL PREFERENCE OF *HELICOVERPA* SPP. TO PETROLEUM OIL

In choice tests, the treatments did not suppress oviposition by *H. armigera* (Tahle 1). *H. punctigera* females laid significantly fewer ($P<0.05$) eggs on plants treated with petroleum oil and petroleum oil-Kelgum mixture than on the unsprayed (control) and Kelgum sprayed plants (Table 1). Under no-choice tests, *H. punctigera* again laid significantly ($P<0.05$) more eggs on the control and Kelgum sprayed plants compared with the petroleum oil and petroleum oil-Kelgum mixture sprayed plants (Table 2). *H. armigera* however, laid the same numher of eggs on both treated and control plants.

FIELD STUDIES ON *HELICOVERPA* SPP. AND THEIR NATURAL ENEMIES

Approximately equal numbers of eggs were found on all treatments until the seventh sampling date (28 January). Thereafter, significantly fewer ($P< 0.05$) eggs were found on plants sprayed with petroleum oil than on unsprayed and insecticide treated plants (Fig. 1a). The number of eggs per metre per sample date found on plots treated with petroleum oil was 3.83 compared with 7.82 and 6.29 eggs respectively found on the conventional insecticide sprayed and the unsprayed plots respectively. The lower number of eggs may result from either adult repellency or fewer adults present in the treated plots.

Significant differences ($P<0.05$) in numbers of larvae were also found between treatments with the conventioual insecticide sprayed plots recording the least numbers of larvae, followed by the plot sprayed with petroleum oil (Fig 1b). The highest numbers of larvae were found on the unsprayed control plot. At the end of study 4.4 and 1.6 times fewer larvae had been recorded on the conventional insecticide and petroleum oil sprayed plots respectively compared with the unsprayed control plot (Fig. 1b).

Significantly higher ($P<0.01$) cotton yields (7.32 bales/ha) were harvested from plots which received conventional insecticide sprays than from petroleum oil sprayed plots (3.70 bales/ha). The latter yield was significantly higher ($P<0.01$) than that from the unsprayed control plot (2.69 bales/ha). No phytotoxicity was detected on any of the plots.

Natural enemies of Helicoverpa spp.

Predators of *Helicoverpa* spp., identified from the plots, are given in Table 3. The highest numbers of predatory beetles and bugs per plot were recorded on the unsprayed, followed by petroleum oil and the synthetic insecticide treated plots (Figs 2). Predatory lacewings per plot were significantly higher ($P<0.05$) on the petroleum oil treatment followed by the unsprayed control with the insecticide treatment recording the least numbers (Fig. 3a). Similar numbers of spiders were recorded in the petroleum oil and the unsprayed control plots and these were significantly higher ($P<0.001$) than in the insecticide treated plot (Fig. 3b).

DISCUSSION

The reduced oviposition recorded in these experiments suggests that oil acted as a repellent discouraging egg deposition (Davidson *et al.* 1991; Larew and Locke 1990; Larew 1989). Laboratory tests conducted by Ochou (1985) and Hesler (1986) showed that mineral oils produced significant mortality of eggs and larvae of tobacco budworm, *Heliothis virescens* (F). In orchards, oils have been used as dormant sprays to control scale insects, mites, insect eggs and hibernating caterpillars, and as summer sprays to control aphids, mealybugs, mites, thrips, psyllids and whiteflies (Metcalf *et al.* 1962; Chapman 1967). In Australia, petroleum oils have been used in citrus to control a range of scales and mites and form a major component of an integrated pest management programmes (Beattie 1990; Beattie 1991).

While the field results indicated that petroleum oil apparently affected oviposition, the suppression effects were not as pronounced as in the mesh house experiments. This may be due to the fact that the oil has an effect only on *H. punctigera* and not *H. armigera* and under field conditions treated plants were exposed to both species for oviposition. Also it may be due to the failure of timing oil sprays to the development of new leaves which were of good quality, attractive and highly acceptable as suitable oviposition sites by *Helicoverpa* spp. The ovipositional suppressant effect therefore could have been partially offset by increased *H.*

armigera oviposition, the eggs of which could not be separated during the period of study from those of *H. punctigera* and also plant suitability. The high numbers of eggs recorded on all treated plots in February - March was the result of heavy *H. armigera* infestations. The answer to why the oil was effective on *H. punctigera* but not *H. armigera* might possibly be found if petroleum oil sprays with different mean molecular weights were tested. It may be possible that *H. armigera* oviposition can be suppressed by using oils with lower or higher mean molecular weights than Lovis petroleum oil used in these assays.

In spite of the non-appreciable effect on *H. armigera,* the yield from the oil sprayed plot was 1.4 times higher than the unsprayed control plot. Petroleum oils could be used most effectively before January when populations are predominantly *H. punctigera.*

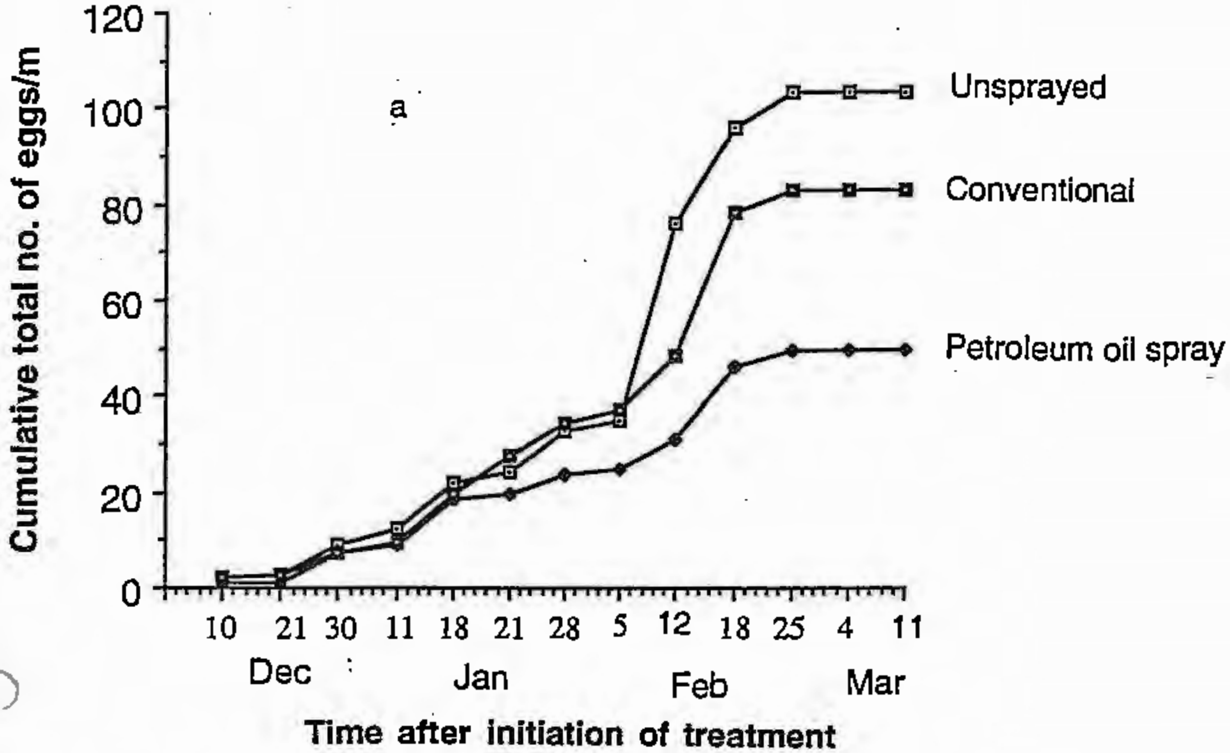
Predatory beetles and bugs were suppressed by the petroleum oil spray but lacewings and spiders were not. Although predatory beetles and bugs may have come into direct contact with the oil spray, there was no evidence of dead beetles and bugs in oil sprayed plots as was found in the insecticide treated plots. The short-term residual activity of petroleum oil sprays does not severely affect populations of beneficial insects which reinvade plots after spray, although most predators and parasites are killed ou contact when sprayed directly (Davidson *et al.* 1991). Therefore the impact of oil sprays on beneficial insect species may vary depending on the mobility of a species and its ability to reinvade sprayed areas from other locations. Spiders, which are less mobile compared with the predatory insects, were not affected by the spray probably because spiders on field cotton plants usually prefer the undersurface of leaves and also could descend the cotton plants into crevices in the soil. This behaviour usually helped them to avoid direct spray contact.

It should be noted that the differences observed in our mesh house oviposition choice and no-choice tests and small field plots may not be evident in a large scale commercial cotton situation under high *H. armigera* infestations. A large scale commercial cotton field presents even very mobile pests like *Helicoverpa* spp. with essentially no choice of oviposition site. Thus, the potential effectiveness of petroleum oil sprays in laboratory and field trials for *H. armigera* remains to be demonstrated. The successive applications (8 times) required for partial reduction of *Helicoverpa* population and its associated lower cotton yields makes the product too expensive for the farmer to use. However, petroleum oil may enhance potency of insect control agents improving thereby the control of *Helicoverpa* species.

ACKNOWLEDGEMENT

We thank Stephen Ryman and Debbie Colless for providing technical assistance throughout this study. We also thank Dr John Madden (Department of Agriculture, University

Fig. 1. Response of *Helicoverpa* spp. (a) eggs and (b) larvae to petroleum oil and conventional sprays in commercial cotton at Norwood near Moree, 1992-93.


a
Cumulative total no. of eggs/m
120
100
80
60
40
20
0
10
21
30
11
18
21
28
5
12
18
25
4
11
Dec
Jan
Feb
Mar
Time after initiation of treatment
Unsprayed
Conventional
Petroleum oil spray

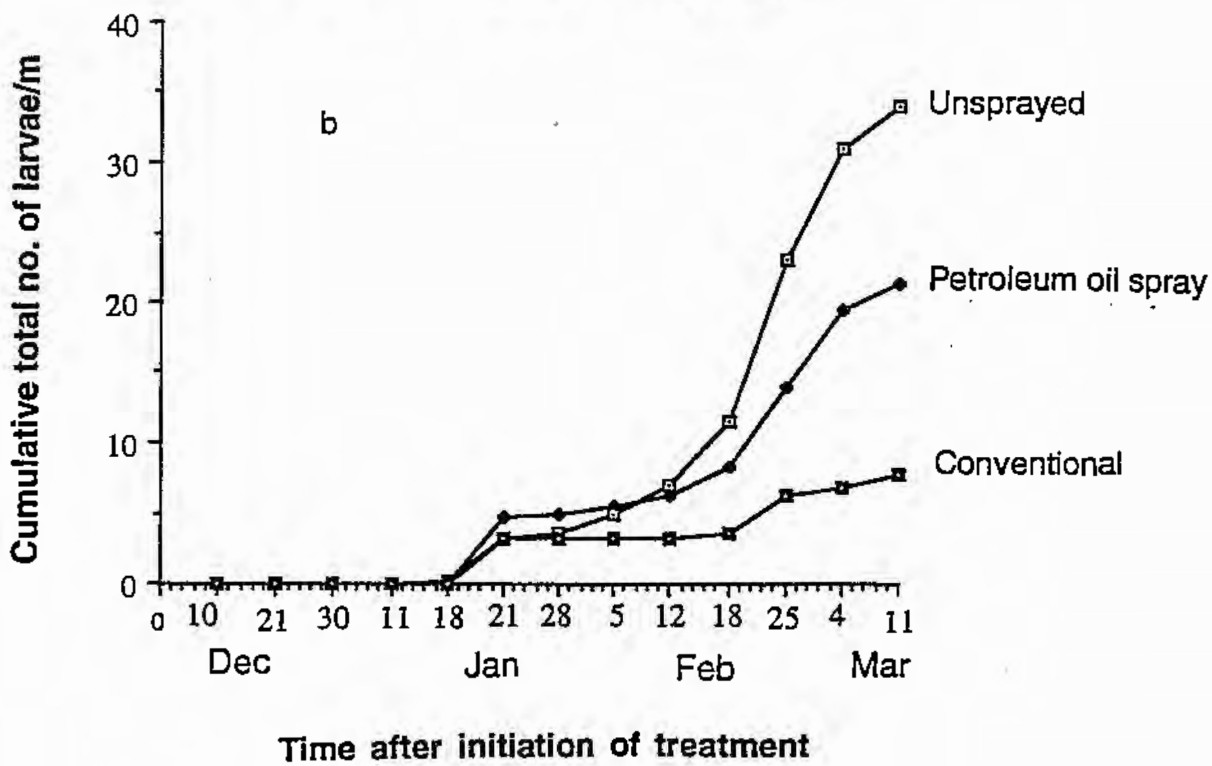

b
Cumulative total no. of larvae/m
40
30
20
10
0
0
10
21
30
11
18
21
28
5
12
18
25
4
11
Dec
Jan
Feb
Mar
Time after initiation of treatment
Unsprayed
Petroleum oil spray
Conventional

Fig. 2. Effect of petroleum oil sprays on the abundance of (a) predatory beetles and (b) bugs in commercial cotton at Norwood, 1992 - 93.

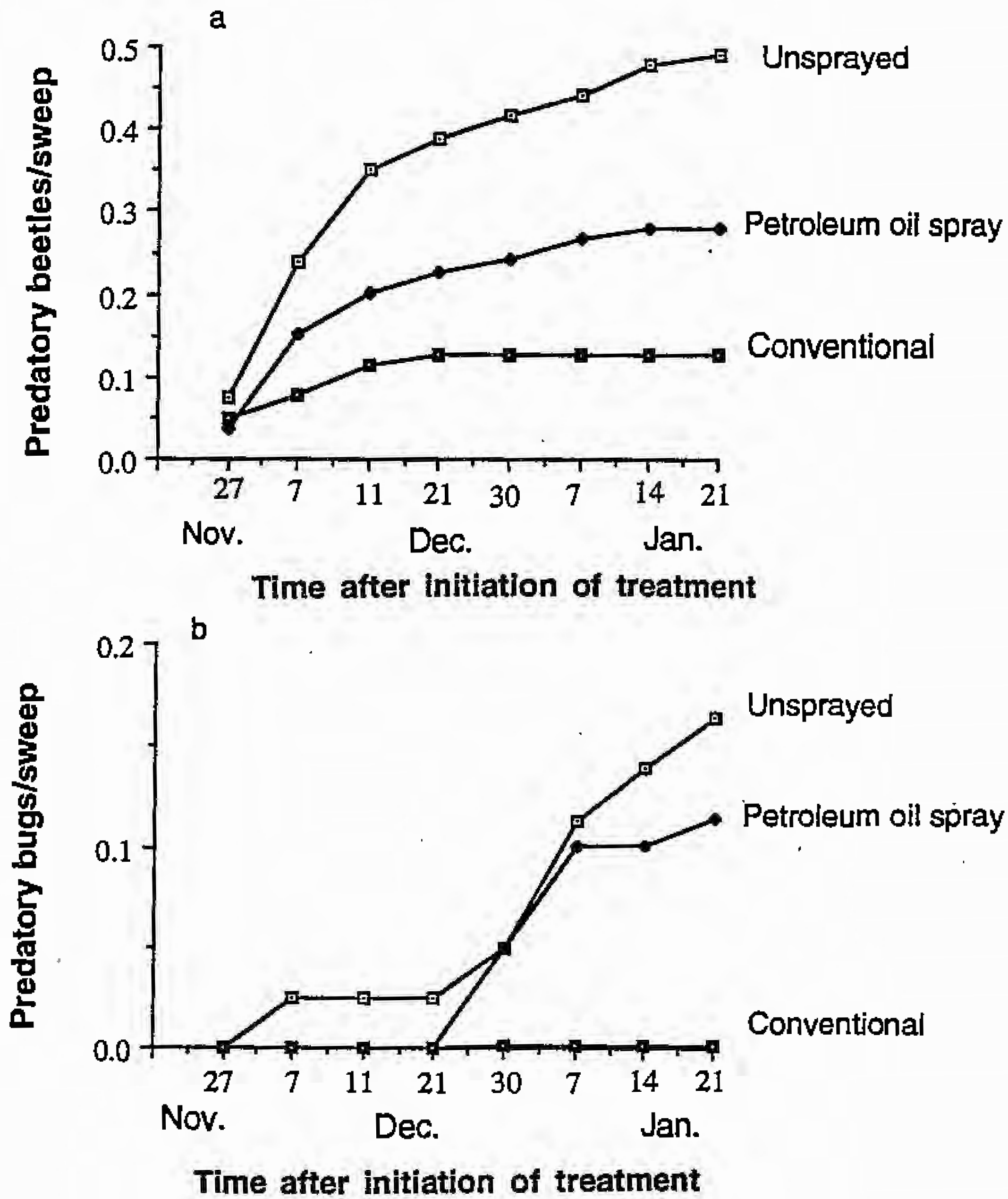
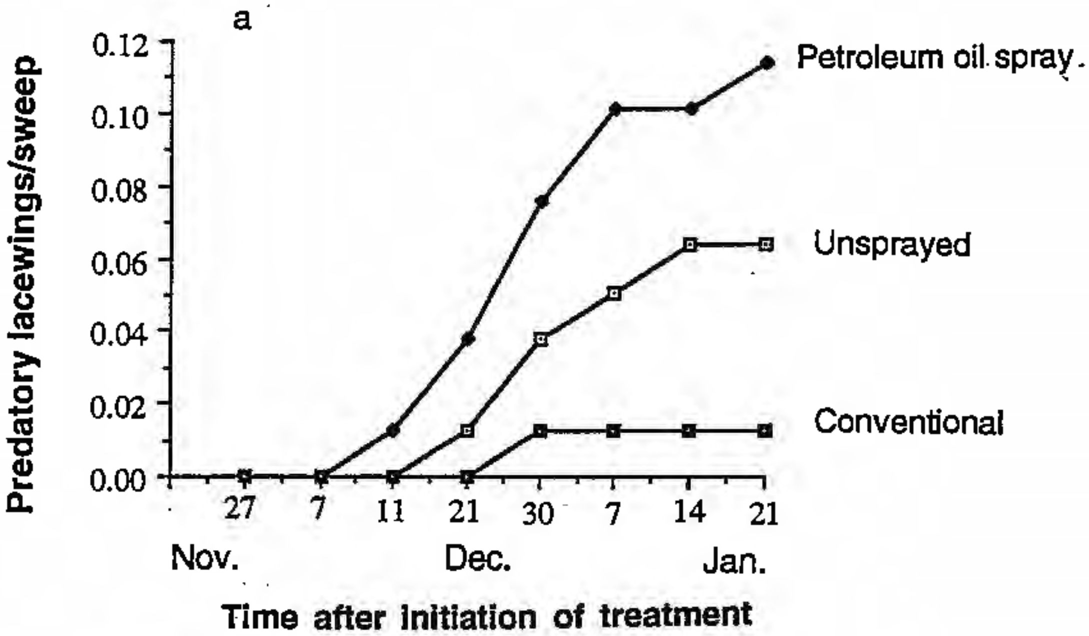
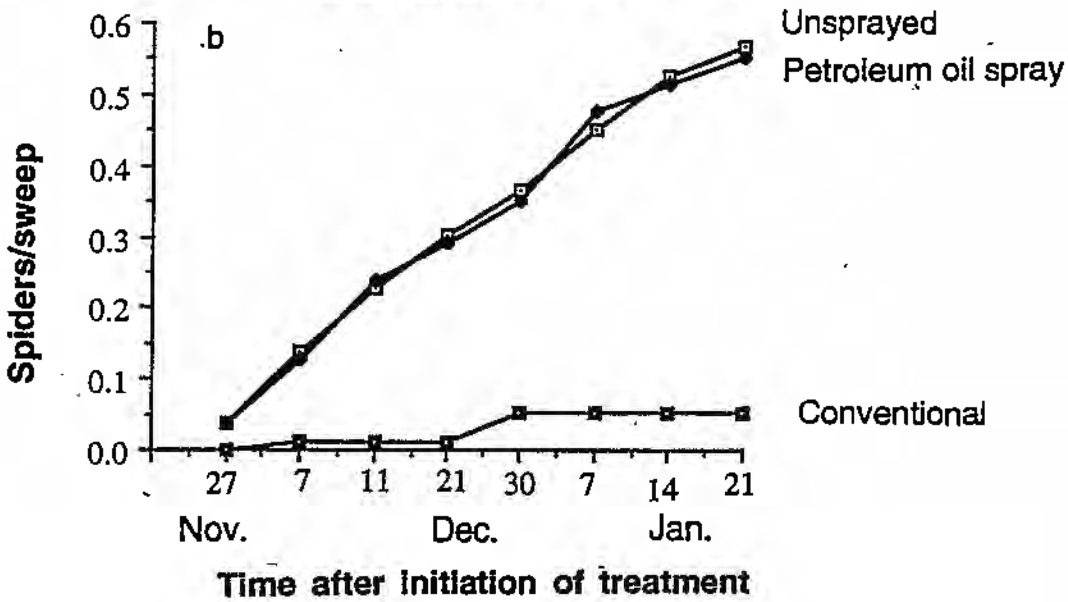

a
Predatory beetles/sweep
0.5
0.4
0.3
0.2
0.1
0.0
Unsprayed
Petroleum oil spray
Conventional
27 7 11 21 30 7 14 21
Nov.
Dec.
Jan.
Time after initiation of treatment
b
Predatory bugs/sweep
0.2
0.1
0.0
Unsprayed
Petroleum oil spray
Conventional
27 7 11 21 30 7 14 21
Nov.
Dec.
Jan.
Time after initiation of treatment

Fig. 3. Effect of petroleum oil sprays on numbers of (a) predatory lacewings and (b) spiders in commercial cotton at Norwood, 1992 - 93.


a
Predatory lacewings/sweep
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Petroleum oil spray
Unsprayed
Conventional
27
7
11
21
30
7
14
21
Nov.
Dec.
Jan.
Time after initiation of treatment


.b
Spiders/sweep
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Unsprayed
Petroleum oil spray
Conventional
27
7
11
21
30
7
14
21
Nov.
Dec.
Jan.
Time after initiation of treatment

of Tasmania, Hobart, Australia), Dr Allan Clift (Biological and Chemical Research Institute, Rydalmere, Australia) for their useful and timely suggestions and criticisms in the preparation of the manuscript, Dr Neil Forrester, Miss Lisa Bird, Mrs Anne Wall for providing insects used in the mesh house trials and Mr Peter Glennie and Kylie May for co-operating with the field trials.The Australian Cotton Research and Development Corporation provided funding for this project (grant DAN 68C).

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Table 1

Free choice tests for ovipositional preferences of Helicoverpa amigera *(n = 110 pairs) and* Helicoverpa punctigera *(n = 100 pairs) to cotton plants (n = 40 plants per treatment) sprayed with petroleum oil and Kelgum in a mesh house at Narrabri, 1992 - 93.*

Treatments	*Helicoverpa armigera* Eggs/plant	*Helicoverpa punctigera* Eggs/plant
Petroleum oil	21.93 ± 2.15 a	3.13 ± 0.77 a
Kelgum	27.03 ± 2.03 a	18.36 ± 1.71 b
0.01% Kelgum + 0.5% petroleum oil	25.20 ± 2.11 a	3.06 ± 1.04 a
Control (water)	28.50 ± 2.78 a	23.17 ± 2.76 b

Means within a column followed by the same letter not significantly different ($P > 0.05$) (Least significant difference).

Table 2

No choice test for oviposition of Helicoverpa armigera *(n = 8 pairs) and* Helicoverpa punctigera *(n = 5 pairs) on cotton plants (n = 40 plants/treatment) sprayed with petroleum oil and Kelgum in a mesh house at Narrabri, 1992 - 93.*

Treatments	*Helicoverpa armigera* Eggs/plant	*Helicoverpa punctigera* Eggs/plant
Petroleum oil	6.82 ± 1.59 a	2.54 ± 0.47 a
Kelgum	7.58 ± 1.04 a	5.36 ± 1.52 b
0.01% Kelgum +0.5% petroleum oil	5.33 ± 1.15 a	1.99 ± 0.10 a
Control (water)	7.61 ± 1.23 a	5.45 ± 1.21 b

Means within column followed by the same letter not significantly different ($P > 0.05$) (Least significant difference).

Table 3

Major predators identified from study plots within commercial cotton at Norwood near Moree, 1992 - 93.

Order	Family	Species
Coleoptera	Coccinellidae	*Harmonia arcuata* (Fabricius)
		Diomus notescens (Blackburn)
		Coccinella repanda (Thunberg)
	Melyridae	*Dicranolauis bellulus* (Guerin)
Hemiptera	Nabidae	*Nabis capsiformis* (Germar)
	Lygaeidae	*Geocoris lubra* (Kirkaldy)
	Pentatomidae	*Cermatulus nasalis* (Westwood)
Neuroptera	Chrysopidae	*Chrysopa* spp.
	Hemerobiidae	*Micromus tasmaniae* (Walker)
Araneidae	Lycosidae	*Lycosa* spp.
	Oxyopidae	*Oxyopes* spp
	Salticidae	*Salticidae* spp.
	Araneidae	*Araneus* spp.

GENERAL DISCUSSION

The trend to achieve higher cotton yields and produce early cotton in Australia has resulted in an over-reliance on synthetic insecticides in the management of cotton pests. The cotton industry is currently at risk of losing most of the currently registered products due to increasing resistance and environmental problems. The development and introduction of transgenic cotton into the cotton industry was originally viewed as an answer to the industry's problems, but now there is the believe that *Helicoverpa* spp. will develop resistance to the transgenic crops. The crops will need to be managed in the context of IPM program if insect resistance to the crops is to be delayed. Also, despite the introduction of transgenic cotton in the cotton industry, there will still be 50-60 per cent normal cotton crops grown in the industry to avert risk and guarantee the future sustainability of the cotton industry. These normal cotton crops will require management against pests. However, with increasing resistance and societal pressure to progress from application of synthetic insecticides to innovative methods for insect control that are non-harzadous to human health and to environmental quality, pest management strategies involving the use of beneficial insects as basic components are essential to reach this goal. This is because *Helicoverpa* spp. which are major pests of cotton crops in Australia, are highly migratory and therefore can rapidly infest cotton crops and lay their eggs; natural enemies should therefore be present and well established in high numbers before the pest arrive to respond rapidly and control them. The development of a strategy that may conserve and maximise the abundance and effectiveness of the natural enemies of *Helicoverpa* spp. in cotton fields is important to enhance the control of these pests.

This study has shown that interplanting lucerne in cotton fields by strip-cropping can serve as a refugia to conserve beneficial insects in cotton fields. The refugia function of the lucerne strips may be attributed to the abundance of floral nectar and alternate prey, shelter, mating and oviposition sites etc harboured in the lucerne crop compared to monocultural conventional cotton. These resources enhanced the establishment of the predators in the lucerne. However, given the abundance of food resources, shelter, mating, oviposition sites etc within the lucerne strips, beneficial insects may not be inclined to move from the strips to forage the adjacent cotton crop. The movement of these beneficial insects from the lucerne to the adjacent cotton crop can be improved by applying Envirofeast® product to the cotton crop to attract the predators. Local density responses of predatory insects to Envirofeast® spray is not drastic but is a slow process resulting from attraction and arrestment of predators enabling them to build up over time and space. The build up of predators in cotton can also be affected by other factors such as use of synthetic insecticides especially pyrethroids, quantity and quality of food resource available, density of predators themselves, rainfall, relative humidity, temperature, irrigation, soil cultivation etc.,

Currently, there are many pest control tools ranging from biological pesticides such as NPV virus, conventional Bt, transgenic crops with Bt toxin, pheromones, *Trichogramma* spp., *Helicoverpa* spp. moth attractants, synthetic insecticides etc. which are available to cotton growers for managing cotton pests. Unfortunately, these tools have not being integrated into IPM programmes for use by growers. The current pest management strategy despite widespread use of thresholds and objective sampling belies any application of the term IPM because of their over-reliance on synthetic insecticides and there are no strategies to maximise the abundance of beneficial insects and utilise them in the strategy. A true IPM program can only be developed if pest control tools are integrated with strategies or techniques to use beneficial insects as basic components or base of the program.

This study has developed an IPM strategy based on Envirofeast® spray, lucerne refugia strategy, biological insecticides particularly Gemstar® (NPV) virus and selective insecticides and achieved cotton yields similar to or sometimes higher than conventional insecticides. This is the first attempt to courageously develop a true IPM program for the cotton industry. The study also has developed a threshold based not only on the pest (*Helicoverpa* spp.) as has being done and used originally (Entomologic) but based on the predator to pest ratio for any decision to intervene with any of the tools within the IPM program. The Envirofeast® IPM program has been developed on both normal and transgenic cotton.

The IPM program apart from achieving cotton yields similar to conventional insecticide managed cotton has also reduced the total insecticide use and replacement of synthetic insecticides particularly endosulfan with Envirofeast® and other biological insecticides. For the IPM strategy developed in this study to work effectively, it should be used in areas free from disruptive insecticides such as pyrethroids and this can be best achieved if neighbours co-operate to form a regional or area-wide group and use the strategy. Thus an area-wide or regional based Envirofeast® IPM program can be more successful than an individual grower adjacent to neighbours managing their cotton with synthetic insecticides.

After 6 years of developing this strategy, it has been shown that good results could be achieved with growers who do not panic spray, spend time to check their crops thoroughly, have a good power of observation and can predict an onset of pest problems and apply sprays at the correct time.

The study has also strengthened and confirmed the benefits of using Envirofeast® product within the IPM program. The results of the study showed that cotton crops managed with IPM tools without Envirofeast® had a yield loss of between 1.24 to 3.46 bales per hectare. This clearly shows that each of the components within the program contributes to the success of the whole IPM strategy.
For the future sustainability of the Australian cotton industry, there should be a reduction in the use of chemical pesticides. Envirofeast® IPM which has been developed in this study is an option to assist in this process.

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. This study has developed an IPM strategy based on Envirofeast® spray, lucerne refugia , biological insecticides particularly Gemstar® (NPV) virus and selective insecticides and achieved cotton yields similar to or sometimes higher than conventional insecticides. The IPM program apart from achieving cotton yields similar to conventional insecticide managed cotton, has also reduced the total insecticide use and replaced synthetic insecticides particularly endosulfan with Envirofeast® and other biological insecticides. The reduction in the total chemical use particularly endosulfan is important for the industry in line with NRA's recent restriction on the continuous use of endosulfan in the cotton industry. The refugia strategy which involves growing lucerne as strips within cotton farms served as trap crops for early season cotton pests particularly green mirids and as refugia to generate beneficial insects for cotton. The management of green mirids through the use of lucerne strips will help limit the use of dimethoate to control these pests during infestations. To conclude, this study has shown that

- Envirofeast IPM program can effectively manage cotton pests to achieve cotton yields similar to or sometimes higher than conventional insecticides.

- Envirofeast® when applied to cotton can attract and sustain beneficial insects enabling them to be utilised in IPM programmes.
- Performance of Envirofeast is enhanced by the presence of lucerne strips which serve as a refuge for beneficial insects and sinks to manage green mirids on cotton.
- Cotton crops managed with IPM tools without Envirofeast® had a yield loss of between 1.24 to 3.46 bales per hectare.
- Envirofeast® IPM on conventional cotton can belp manage resistance through the reduction in total insecticide use and replacement of synthetic insecticides, particularly endosulfan.
- Envirofeast® IPM on transgenic cotton enhances the efficacy and durability of the transgenic crops by increasing the activity of the beneficial insects and exposing *Helicoverpa* spp. neonates to a second mortality factor instead of a single killing mechanism i.e. the transgenic crop.
- Envirofeast IPM should be used in areas free from disruptive insecticides such as pyrethroids and this can be best acheived if neighbours co-operate to form a regional or area wide group and use the strategy. Thus area-wide or regional based Envirofeast® IPM program can be more successful than an individual adjacent to neighbours managing their cotton with synthetic insecticides.
- Envirofeast IPM will work for users who do not panic spray, spend time to check their crops thoroughly and apply the sprays at the correct time.
- Any decision to intervene with insecticides within the Envirofeast® IPM program should be based on the predator to *Helicoverpa* spp.(Heliothis) ratio which is calculated from regular sampling (bug checking). Guidelines for use of Envirofeast IPM are available to growers from the Technology Resource Centre at ACRI and Rhone-Poulenc representatives.
- For the future sustainability of the cotton industry there should be a reduction in the use of chemical pesticides and Envirofeast® IPM is an option to assist in this process.

For the Envirofeast and refugia technologies developed in this study to be fully adopted growers, the industry should place much more emphasis on educating farmers on the concept of a true IPM. Growers should improve their understanding of a true IPM, how it is developed and works and also the differences between Insecticide Resistance Management Strategy and IPM. The Best Managent Program should incorporate the IPM program developed in this study and assist growers to adopt it. Extension staff should also be involved in educating growers about the Envirofeast technology through workshops, field days, seminars and conferences.

COMMUNICATION OF RESULTS

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