1. Introduction

The green mirid, *Creontiades dilutus* (Stål), is one of the key early season pests on cotton in Australia. Adults and nymphs feed preferentially on the meristematic tissue (both apical and axillary buds) of the cotton plant (Bishop, 1980). Severe infestations cause cotton plants to lose squares and also cause damage to growing tips, resulting in significant delays in growth and maturity of the plant (Adams and Pyke, 1982; Chinajariyawong *et al.,* 1988). This delay can lead to loss in yield and/or quality.

Currently, populations of *C. dilutus* in commercial cotton are suppressed by insecticide sprays (mainly synthetic pyrethroids, organophosphates, cyclodienes and carbamates) applied for *Helicoverpa* spp. In high infestations, dimethoate is the only effective insecticide available for *C. dilutus* control. The use of these insecticides early in the season disrupts beneficial insect activity and deters any chance of a true integrated pest management (IPM) program being developed for cotton. However, with the proposed advent of transgenic cotton in Australia by 1997-98, it is expected that synthetic insecticide use on cotton against *Helicoverpa* spp. will be reduced at least initially when the insects have yet not develop resistance to the transgenic plants and *C. dilutus* may assume greater importance in the Australian cotton industry since they are unaffected by these plants (Fitt pers. comm.). The development of new management techniques for green mirids which do not rely on insecticides could be crucial.

The principle of insect control by trap cropping has been known and exploited for centuries, but to date, practical applications of this cultural method in modern agriculture has been few. In trap cropping, plant stands are grown to attract insects to protect target crops from pest attack. Protection may be achieved either by preventing the pests from reaching the crop or by concentrating them in a certain part of the field where they can be controlled.The importance of trap cropping in pest management has been extensively reviewed by Hokkanen (1991). Interplanting afalfa in cotton is reportedly very effective in keeping lygus bugs out of cotton in California (Stern *et al.,* 1969; Sevacherian and Stern, 1974). Trap crops have also being used to manage boll weevils in cotton farms in North and Central America (Hokkanen, 1991). In Australia, no definitive studies have been conducted to determine the role of trap crops in the management of green mirids in commercial cotton nor has any attempt been made to include trap crops into cotton IPM programmes.

In this study, we determined whether *C. dilutus* prefer lucerne (*Medicago sativa*) to cotton and the potential of lucerne strips within commercial cotton to act as a trap and so aid in the management of green mirids. In addition, we examined

and compared green mirid management in commercial cotton interplanted with lucerne under IPM and under conventional insecticide regimes.

2. Materials and methods

All laboratory experiments were conducted in a Sarlon mesh house (4m x 10m x 1.8m) during summer in 1992-93 at the Australian Cotton Research Institute (ACRI) (30° 13'S, 149° 47' E) at Narrabri, New South Wales, Australia. The cotton plants used in all mesh house studies were potted plants, 0.5m tall, all of the same age, and were grown from seed in the same mesh house where experiments were conducted. The lucerne plants were cv. Auroras and the cotton cv. Sicala VI. *C. dilutus* adults used in all the mesh house experiments were obtained from a laboratory colonies established from individuals originally collected from lucerne and cotton plants in January 1993. Colonies were maintained on *Phaseolus vulgaris* L. in a controlled room illuminated by a single 1 m 40 W fluorescent tube with a photoperiod of L12: D12, thermostatically controlled with a fan heater and an air conditioner (Moazzem Khan unpubl.). Temperatures ranged from 23-27°C and relative humidities between 45-55% as measured by a 7-d recording thermohygrograph.

2.1 Laboratory studies of *C. dilutus* on cotton and lucerne

2.1.1 Free choice test for orientation and ovipositional preference of C. dilutus. The experiment, conducted in the mesh house started on September 1993 when the cotton and lucerne plants were six weeks old, the age when both plants were more preferred for oviposition by *C. dilutus* (Moazzem Khan unpublish.).

A pot containing 5 plants each of lucerne and cotton were placed in the mesh house and 100 pairs of 3-day old *C. dilutus* adults were introduced in the mesh house. In all, ten pots of each plant were introduced in the mesh house. The number of *C. dilutus* adults on each host plant were counted by sex after 8 days when eggs commence to hatch (Hori and Miles, 1993; Moazzem Khan pers. comm.). The plants were removed from the mesh house, cleared of adult mirids using mouth aspirator and the number of eggs laid on each host plant were counted under a binocular microscope.

2.1.2 No-choice ovipositional preference of C. dilutus. The no choice preference test between cotton and lucerne was measured by egg production and nymphal survival. Egg production was studied on the basis of the number of eggs produced on these two host plants. The experiment commenced in the mesh house in January 1994 using 6-week old cotton and lucerne plants. A pot

of 5 plants each of cotton and lucerne were enclosed in separate mesh cages (70 x 70 x 120 cm) within the mesh house described previously and four pairs of 3- day old *C. dilutus* adults were released into each cage for life. The plants within each cage were replaced every 8 days and the number of eggs present recorded. In all, 10 cages each enclosing a pot of 5 plants each of cotton and lucerne were used and forty pairs of insects were thus studied on each host plant. The number of eggs laid per plant and per female were recorded.

In another experiment, 10-newly emerged *C. dilutus* second instar nymphs were caged on a pot of 5 plants each of cotton and lucerne in the mesh house as previously described. This procedure was repeated five times for each plant and nymphal survival to adult and developmental duration on each host plant was recorded.

2.2 Field studies of *C. dilutus* on cotton and lucerne

2.2.1 Preference of C. dilutus to lucerne and cotton. A trial was conducted on a 3 ha irrigated cotton farm at ACRI from October 1992 to March 1993 to determine the preference of green mirids to lucerne and cotton under field conditions. Lucerne strips, 8 metres (or rows) wide and 100 metres long, were planted within the cotton. For every 42 metres (or rows) of cotton, one strip of lucerne was planted, this was repeated three times across the field. The lucerne was planted on 15 September 1992 and cotton 5 October 1992. The lucerne strips were irrigated at the same time as the cotton irrigation depended on the soil moisture level. Alternate 4 metre bands of each lucerne strip were slashed every 4 weeks and the slashings baled as hay. The 4-week slashing sequence which was developed prior to the study was to stimulate new growth and prevented the lucerne from haying off before the end of the study (i.e. end of the cotton season).

Adults and nymphs were sampled once every week from 2 November 1992 to 23 March 1993 by using a small portable suction sampler, D-vac (Homelite Textron Inc., NC, USA) with 120 mm diameter cone and a nozzle speed of approximately 10 metre per second. A gauze bag (25 cm deep) was inserted into the suction tube to collect insects sucked from plants. In a single pass, the tube of the vacuum sampler was drawn along the tops of test plants and a 20 metre of row of vacuum sampling on either plant constituted a sample. After each sampling, the contents of the D-vac were transferred to a plastic bag, chilled and taken to the laboratory and frozen until later counting and identification. Data were expressed as numbers of *C. dilutus* per metre for each treatment.

2.2.2 Comparison of cotton crops with and without interplanted lucerne. The experiment was conducted in two irrigated cotton fields at Norwood

(29° 28' 149° 50'), near Moree in New South Wales, Australia. The sizes of the two cotton fields were 20 (field 1) and 45 (field 2) hectares respectively and were adjacent to each other, separated by a 20 metre access road. In field 1 two lucerne strips each measuring 12 metres (or rows) wide and 592 metres long were planted as borders to sandwich 100 metres (rows) wide and 592 metres of cotton.This was repeated three times across the field. The lucerne strips were half slashed alternatively and baled as hay every 4 weeks to stimulate growth and prevent the lucerne from haying off. The second (field 2) had no lucerne strips planted within the cotton but the field was divided into three subplots and each subplot (9 hectares cotton) was treated as a replicate of cotton without lucerne strips. Field 1 was left unsprayed until 6 January and then sprayed with Envirofeast® (food) supplements (a product of NSW Agriculture, Narrabri, Australia) and *Bacillus thuringiensis* (Bt) sprays. These products are known to have no effect on *C. dilutus* on cotton (Mensah unpubl). However, fields 2, 3 and 4 were left unsprayed until 15 December and thereafter sprayed with conventional insecticides which had most effect on *Helicoverpa* spp. The spray regime and pest management on the sole crops were varied because *C. dilutus* and *Helicoverpa* spp. numbers on cotton crops in fields 2, 3 and 4 which had no lucerne strips planted within them were high and most of the fruits were being damaged by the pests. The grower therefore became concerned and decided to spray these plots with conventional insecticide instead of Envirofeast® and Bt sprays used in field 1 to protect the crop from further damage.

C. dilutus adults and nymphs were sampled weekly by taking a 20 metre row vacuum sample as previously described, separately from each of the three lucerne strips and of cotton in field 1 and also from each of the subplots in field 2. Sampling started on 30 November 1993 and finished on 17 March 1994. Data were expressed as numbers of *C. dilutus* per metre in lucerne strips and in cotton with and without lucerne strips.

2.2.3 Integration of lucerne with commercial cotton under an IPM regime. The experiment was conducted on a 46 hectare commercial irrigated cotton field at Auscott in Narrabri, NSW in 1993-94 season. The reason for this study was to determine whether incorporation of lucerne into cotton crops under an IPM regime could control mirids to the same extent as conventional insecticide use. The two lucerne strips each measuring 8 metres (or rows) wide and 620 metres long were planted as borders to sandwich 250 metres (rows) of cotton and this was repeated three times across the cotton field. The lucerne strips were managed by alternate slashing of 4 rows every 4 weeks and baled as hay. Another three cotton fields (each measuring 60 ha) without lucerne strips, but with mirids managed with conventional insecticides sprayed against *Helicoverpa* spp.,

was used as a control. Thus the control plots had three replicates. The control plots were located 100 metres away from the IPM plot. The cotton in the IPM field received nine Envirofeast® (food) supplements (a product of NSW Agriculture, Narrabri, Australia) and four *Bacillus thuringiensis* (Bt) sprays. These products are known to have no effect on *C. dilutus* on cotton (Mensah unpubl). The conventional insecticide-managed plot received 9 synthetic insecticide sprays against *Helicoverpa* spp.

A 20 metre row vacuum sample of *C. dilutus* adults and nymphs was taken weekly from each of the three lucerne strips and from cotton in the IPM plot and also from each of the three conventional insecticide managed plots. Sampling started on 28 October 1993 and finished on 21 March 1994. Data were expressed as numbers of *C. dilutus* per metre in lucerne and cotton under conventional insecticide and IPM regimes.

2.3 Analysis of data

All experimental data were analysed using repeated measures analysis of variance (Graphpad Instat Software Inc. Version 2.03, San Diego California) on transformed data (X^1 = Log (X+1) and Tukey-Kramer Multiple Comparisons test (in the case of field studies) and least significant differences were used to separate means.

3. Results

3.1 Laboratory studies of *C. dilutus* on cotton and lucerne

3.1.1 **Free choice test for orientation and ovipositional preference of *C. dilutus*.** Significantly higher numbers of males ($P<0.001$) and females ($P<0.005$) were found on lucerne than cotton indicating that *C. dilutus* adults preferred lucerne to cotton. Significant differences ($P<0.01$) in ovipositional preferences were found between lucerne and cotton (Table 1). Lucerne had significantly higher ($P<0.01$) egg counts than cotton. However the number of eggs per female per pot of 5 plants were not significantly different ($P>0.05$) between lucerne and cotton indicating that females do not restrain oviposition on cotton even though it is not a preferred host (Table 1).

3.1.2 **No-choice ovipositional preference of *C. dilutus*.** The number of eggs laid per female per pot of 5 plants on cotton and lucerne were 8.40 ± 0.90 and 9.10 ± 0.82 respectively and these were not significantly different ($P>0.05$) (Table 3). Fewer *C. dilutus* second instar nymphs survived to adulthood when caged on

both cotton and lucerne (Table 3). Both the per cent nymphal survival and developmental duration to adulthood were not significantly different (P>0.05) on both cotton and lucerne (Table 3).

3.2 Field studies of *C. dilutus* on cotton and lucerne

3.2.1 **Preference of *C. dilutus* to lucerne and cotton.** Significantly higher (P<0.001) numbers of *C. dilutus* adults and nymphs were found on lucerne strips (Fig. 1). Numbers of adult mirids peaked at 1.5 per metre on lucerne and 0.5 on cotton on 1 December, after which numbers on both lucerne and cotton declined. From 30th December until the end of the study few *C. dilutus* adults were recorded on lucerne, but none on cotton. Numbers of nymphs also peaked on lucerne on 9 and 15 December, and subsequently declined. In contrast, numbers of nymphs on cotton were relatively low and remained fairly constant from 1 December until 14 January when numbers fell. At the end of study 5.5 and 4.7 times fewer mirid adults and nymphs respectively had been recorded on cotton compared to lucerne (Fig. 1).

3.2.2 **Comparison of cotton crops with and without interplanted lucerne.** Significant differences (P<0.001) were found between the numbers of *C. dilutus* adults and nymphs on cotton with and without lucerne strips (Fig. 2). The least number of *C. dilutus* adults were recorded from cotton with lucerne strips and the highest on cotton without lucerne strips, the latter was not significantly different (P>0.05) from the lucerne strips in the cotton/lucerne interplant (Fig. 2). Nymphal counts followed trends similar to adult counts, differing significantly (P<0.001) among treatments (Fig. 2).

Numbers of *C. dilutus* adults peaked at approximately 5.0 per metre on cotton without lucerne strips on 17 December and thereafter declined with the population collapsing by 6 January. The adult population on lucerne strips within cotton/lucerne interplant peaked on 22 December and then declined and stabilized at 1.5 per metre until 1 February when numbers declined further (Fig. 2). Numbers on cotton within the lucerne/cotton interplant remained low through the season. Numbers of mirid nymphs peaked first on lucerne strips (31 December) and then cotton without lucerne strips (6 January).

At the end of the study 15 and 35 times more mirid adults and nymphs respectively were recorded on cotton without lucerne strips in comparison to cotton with lucerne strips. Also within the lucerne/cotton interplant 18 and 42 times mirid adults and nymphs respectively were recorded on the lucerne strips compared with the cotton.

3.2.3 **Integration of lucerne with commercial cotton under an IPM regime.** Significantly higher (P<0.01) numbers of *C. dilutus* adults and nymphs were found on lucerne than on the IPM and conventional cotton plants (Fig. 3). Numbers *C. dilutus* adults recorded on the IPM and conventional cotton were significantly different (P<0.05) on the 22 November to 6 December thereafter green mirid numbers on both treatments were not significantly different (Fig. 3A). In contrast, the number of nymphs recorded on the IPM and conventional cotton were not significantly different (P>0.05) (Fig. 3B). Number of *C. dilutus* adults peaked at 7.93 per metre on 22nd November on the lucerne strips and declined to one per metre within 7 days after half-slashing the lucerne strip. The decline in *C. dilutus* numbers on the lucerne strips following peak densities did not result in a corresponding increase in numbers on the IPM cotton plants indicating minimal movement from lucerne to cotton. However we observed an increase in numbers of *C. dilutus* adults on a wide range of weeds including grasses,wild turnip (*Brassica campestris* L.), Noogoora burr (*Xanthium pungens* Wallr.), variegated thistle (*Silybum marianum* L.) etc growing adjacent to the study site indicating that there might have been some movement of *C. dilutus* adults, not nymphs, from lucerne onto these weeds rather than onto cotton. On the IPM cotton plants *C. dilutus* numbers reached 2.13 per metre on 6 December and this coincided with the peak squaring period of the cotton. However no significant damage was caused to the squares. *C. dilutus* numbers on the conventional insecticide managed plot remained low throughout the season due to the insecticide sprays targeted against *Helicoverpa* spp. and which might have killed the mirids.

4 Discussion

Our study indicated that *C. dilutus* distinctly prefers lucerne to cotton and that lucerne could be used as a trap crop to manage mirids in commercial cotton. Under free choice tests and field conditions cotton was less preferred for oviposition by *C. dilutus.* However, under no choice tests in the mesh house, *C. dilutus* adults laid the same number of eggs on both lucerne and cotton indicating that in the absence of lucerne, the female green mirid will not restrain oviposition and will deposit the same number of eggs on cotton. When *C. dilutus* second instar nymphs were caged on cotton and lucerne in the mesh house to determine survival to maturity, nymphal survival between the two host plants was not significantly different (P>0.05), indicating that the low populations recorded in field studies on cotton with lucerne strips was not due to reduced survival on cotton, but to a strong preference for lucerne.

In commercial cotton interplanted with lucerne as strips *C. dilutus* was controlled on cotton compared with commercial cotton without lucerne strips. The

high numbers of *C. dilutus* adults on the lucerne strip came about at the expense of the cotton, again indicating a strong preference for lucerne. The lucerne/cotton interplant under an IPM regime, which had no insecticide spray through the season to control *Helicoverpa* spp., reduced mirid numbers to levels similar to those achieved by commercial cotton without lucerne strips but receiving 9 synthetic insecticide sprays. These insecticide sprays, though targeted against *Helicoverpa* spp., controlled *C. dilutus*. The high numbers of *C. dilutus* on the lucerne at the expense of cotton under the IPM regime indicates that the former is a useful trap crop, and acts as a sink for the pest.

The idea of using trap crops as a control measure is not new, but its practical and effective implementation is recent. For example Haseman (1918) and Taylor (1945) suggested the use of alternative crops to keep *Lygus hesperus* Knight out of cotton and Stern *et al.* (1969) successfully interplanted alfalfa with cotton to deter lygus bugs from cotton. Sevacherian and Stern (1974) also determined the host preference of lygus bugs in alfalfa-interplanted cotton and reported that the bugs preferred lucerne to cotton. All these workers stressed the need to stimulate regrowth and retain the freshness of the trap crop in order to maintain its attractiveness to the pest.

In this study, we stimulated and maintained new growth of lucerne throughout the cotton season by slashing half of each lucerne strip every 4 weeks at each study site. Apart from other environmental factors like rainfall, temperature, relative humidity, competition etc, the half-slashing and baling of the lucerne might have accounted for the decline of *C. dilutus* numbers especially the nymphs following peak densities. This decline did not result in increased *C. dilutus* numbers on cotton during that period, indicating no movement from lucerne onto cotton. However, there might have been some movements of *C. dilutus* adults onto weeds adjacent to the study site since our observation indicated an increased numbers of *C. dilutus* adults on these weeds especially grasses, wild turnip (*B. campestris*), Noogoora burr (*X. pungens*), variegated thistle (*S. marianum*) etc after half-slashing of the lucerne strips. In contrast, the decline in number of *C. dilutus* nymphs could be due mainly to the slashing and baling of the lucerne strips since *C. dilutus* nymphs are not as mobile as the adults. The movement of *C. dilutus* adults onto weeds around the study site instead of cotton could indicate that cotton may not be a preferred host. Khan (pers. comm.) said that the hardness and hairiness of the cotton plant are some of the factors which affect *C. dilutus* oviposition and establishment on cotton crop. Hence the lucerne in this study was acting as a a sink not a source of *C. dilutus* to cotton. The collapse of *C. dilutus* populations in January at all study sites could be due to aerial application of synthetic pyrethroids in the vicinity of the study area.

The size of the lucerne strip may also determine the efficiency of

interplanting lucerne as a trap crop to manage green mirids in commercial cotton. This study did not determine the optimum size of lucerne strips required to hold *C. dilutus* throughout the cotton season, and further work is needed in this topic.

In this study, we have artificially diversified the cotton system and introduced a host choice situation by interplanting lucerne with cotton. This resulted in attraction of the pest onto the preferred host plant (i.e. lucerne) leaving the cotton crop relatively free from damage. Interplanting lucerne in cotton especially transgenic cotton where *C. dilutus* may assume even greater importance will enable the management of these insects in these crops without the use of synthetic insecticides. The lucerne strips will also serve as a refugia for natural enemies of *Helicoverpa* spp. and other pests after cotton is harvested (Mensah and Harris, 1996) and this could be a source of natural enemies especially early in the cotton season before *Helicoverpa* spp. infest the crops thus influencing the survival of these pests. We conclude that lucerne could be used as strips within commercial cotton in Australia to manage green mirids which could otherwise be controlled only by synthetic insecticides.

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Table 1. Free choice test for orientation and ovipositional preference of C. dilutus *adults (n = 100 pairs) to cotton and lucerne plants (n = 10 pots each of 5 plants per species per treatment) in a mesh house at the Australian Cotton Research Institute Narrabri, 1993.*

Host plants	Total no. adults per pot of 5 plants X ± SE	No. adult females per pot of 5 plants X ± SE	Total no. eggs per pot of 5 plants X ± SE	No. of eggs per female/pot of 5 plants X ± SE
Cotton	4.90 ± 0.75 a	3.20 ± 0.49 a	19.60 ± 2.16 a	7.10 ± 0.99 a
Lucerne	11.90 ± 1.09 b	6.20 ± 0.83 b	35.10 ± 3.74 b	6.66 ± 1.17 a

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

Table 2. No choice test for oviposition of C. dilutus *(n = 4 pairs) on cotton and lucerne plants (n = 10 pots each of 5 plants per species per treatment) in a mesh house in the Australian Cotton Research Institute at Narrabri, 1994*

Host plants	No. of eggs/plant X ± SE	No. of eggs/female/plant X ± SE
Cotton	8.40 ± 0.90 a	4.20 ± 0.45 a
Lucerne	9.10 ± 0.82 a	4.55 ± 0.41 a

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

Table 3. Survival to adulthood of C. dilutus *second intar nymphs (n = 10) when caged on cotton and lucerne (n = 5 pots each of 5 plants per species per treatment) in a mesh house in the Australian Cotton Research Institute at Narrabri, 1994.*

Host plants	Total no. nymphs per treatment	No. surviving to adulthood X ± S.E.	Nymphal survival X ± S.E.	Nymphal duration X ± S.E.
Cotton	50	3.40 ± 0.25 a	34.00 ± 2.45 a	12.4 ± 0.14 a
Lucerne	50	3.60 ± 0.60 a	36.00 ± 6.00 a	12.8 ± 0.18 a

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

Figure 1. Number of Creontiades dilutus *adults (A) and nymphs (B) in lucerne strips (■) and in cotton (▩) at the Australian Cotton Research Institute farm at Narrabri, 1992-93. Error bars represent standard errors.*

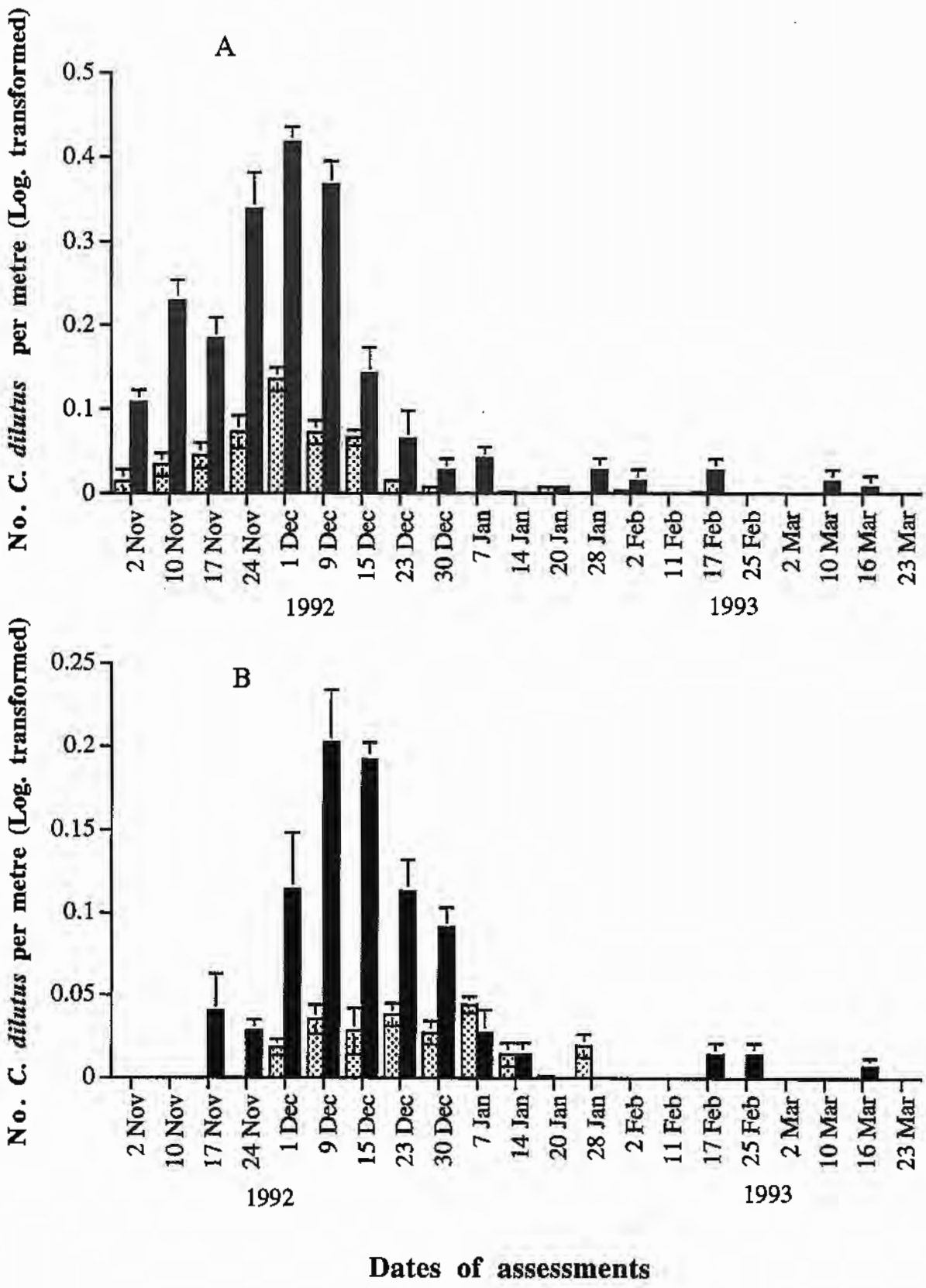

A
B
No. C. dilutus per metre (Log. transformed)
0.5
0.4
0.3
0.2
0.1
0
0.25
0.15
0.05
2 Nov
10 Nov
17 Nov
24 Nov
1 Dec
9 Dec
15 Dec
23 Dec
30 Dec
7 Jan
14 Jan
20 Jan
28 Jan
2 Feb
11 Feb
17 Feb
25 Feb
2 Mar
10 Mar
16 Mar
23 Mar
1992
1993
Dates of assessments

Figure 2. Comparison of number of Creontiades dilutus *adults (A) and nymphs (B) in lucerne strips (--o--), cotton with (—o—) and without (—□—) lucerne strips at Norwood near Moree, 1993-94. Error bars represent standard errors.*

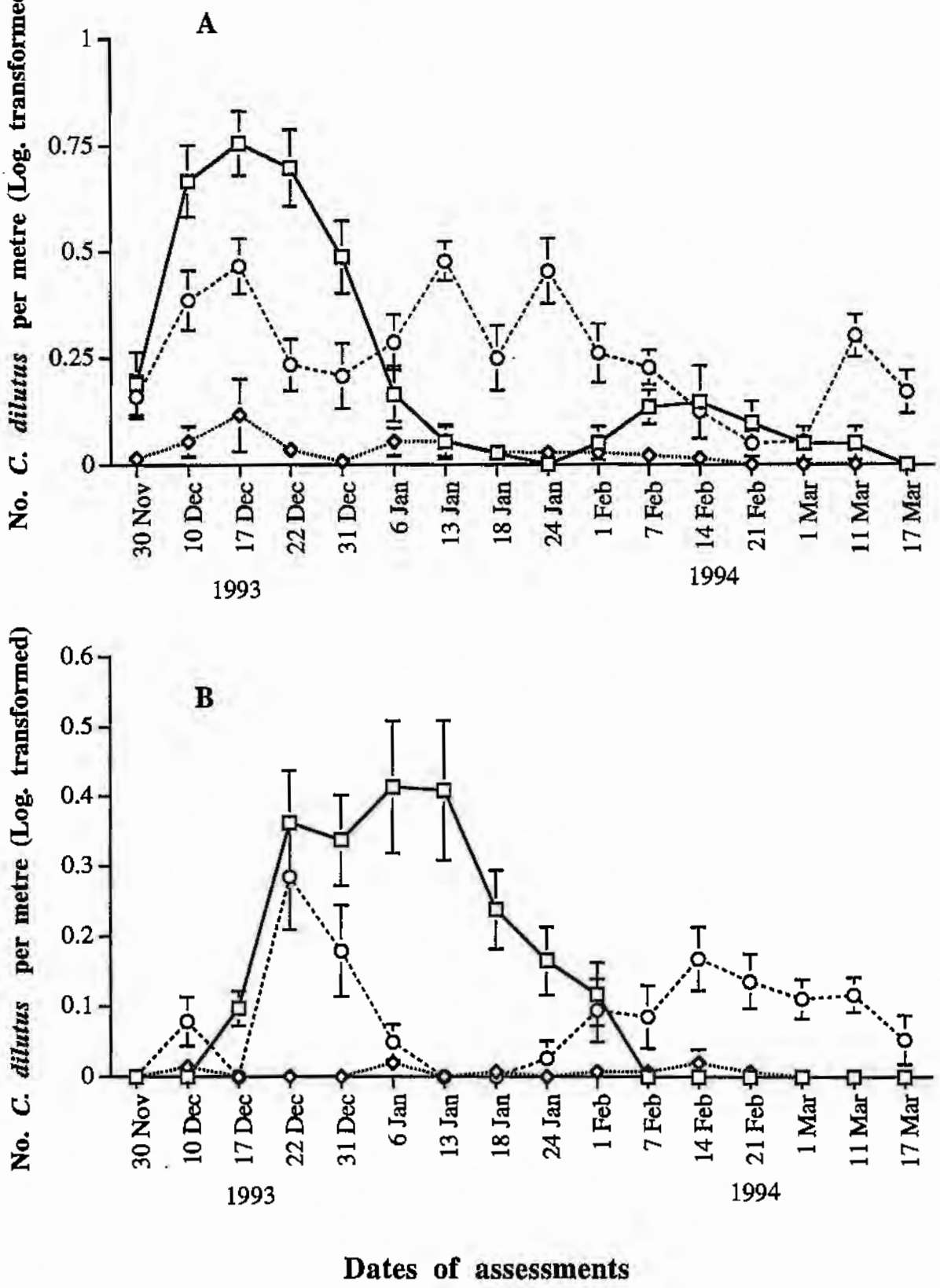
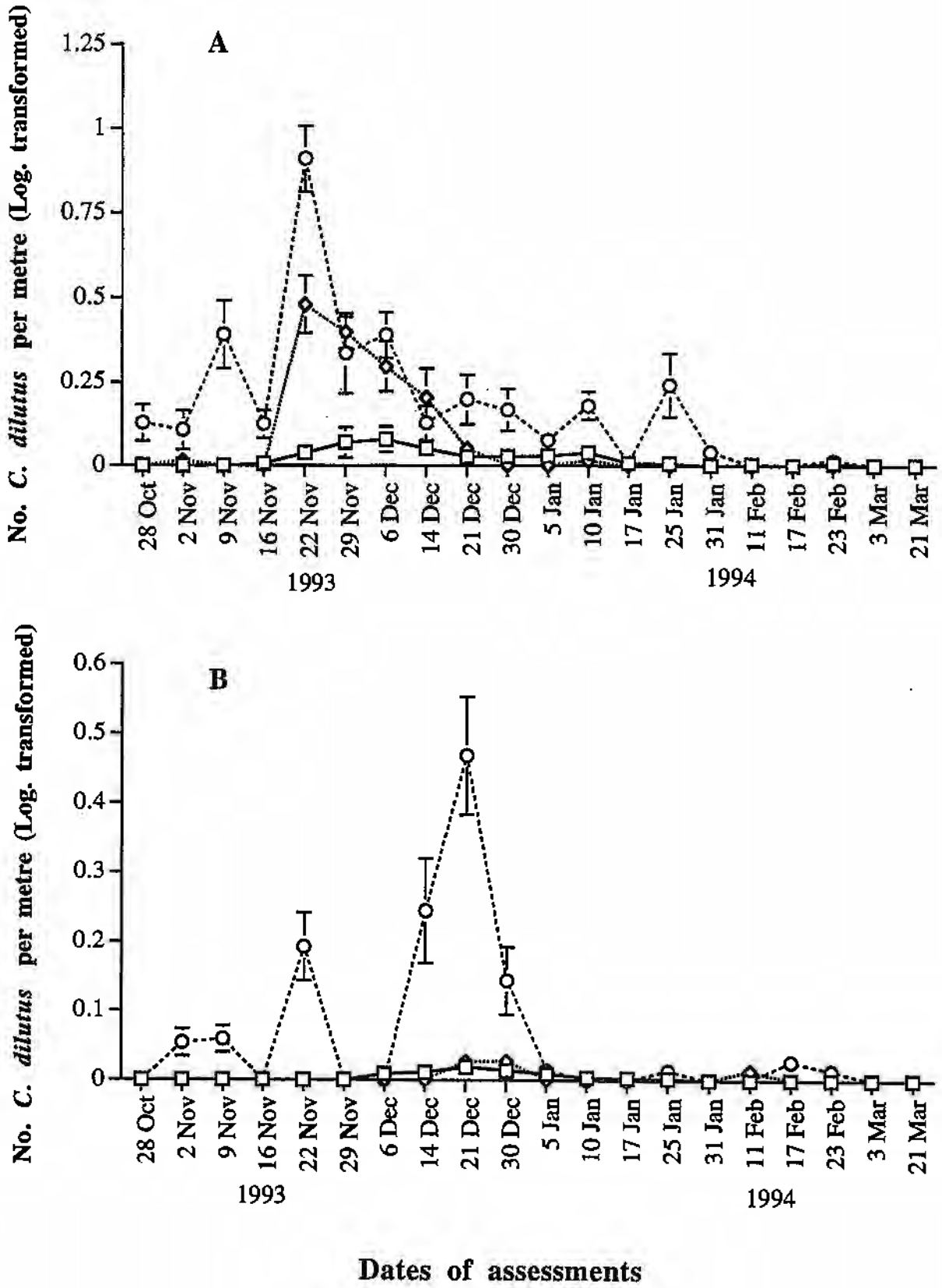

A
B
No. C. dilutus per metre (Log. transformed)
1
0.75
0.5
0.25
0
0.6
0.4
0.3
0.2
0.1
30 Nov
10 Dec
17 Dec
22 Dec
31 Dec
6 Jan
13 Jan
18 Jan
24 Jan
1 Feb
7 Feb
14 Feb
21 Feb
1 Mar
11 Mar
17 Mar
1993
1994
Dates of assessments

Figure 3. Number of Creontiades dilutus *adults (A) and nymphs (B) in lucerne (--O--) and cotton under conventional (—◇—) and IPM (—□—) regimes at Auscott in Nassrrabri, 1993-94. Error bars represent standard errors.*


A
B
No. C. dilutus per metre (Log. transformed)
1.25
1
0.75
0.5
0.25
0
0.6
0.4
0.3
0.2
0.1
28 Oct
2 Nov
9 Nov
16 Nov
22 Nov
29 Nov
6 Dec
14 Dec
21 Dec
30 Dec
5 Jan
10 Jan
17 Jan
25 Jan
31 Jan
11 Feb
17 Feb
23 Feb
3 Mar
21 Mar
1993
1994
Dates of assessments

References

ADAMS, R. M. and PYKE, B., 1982. Sap sucking bugs, are they pests ? *Australian Cotton Grower*, **3**, 49-50.

BISHOP, A. L., 1980. The potential of *Campylomma livida* Reuter and *Megacoelum modestrum* Distant (Hemiptera : Miridae) to damage cotton in Queensland. *Australian Joumal of Experimental Agriculture* , **20**, 229-233.

CHINAJARIYAWONG, A., PYKE, B. and WALTER, G. (1988). Sap sucking bugs, pest status and threshold research. *Australian Cotton Grower*, **9**, 31-32.

HASEMAN, L. (1918). The tarnished plant-bug and its injury to nursery stock. *Missouri Agricultural Experimental Station Research Bulletin*, **29**, 1-26.

HOKKANEN, H. M. T. (1991). Trap cropping in pest management. *Annual Review of Entomology*, **36**, 119-138.

HORI, K. and MILES, P. W. (1993). The etiology of damage to lucerne by the green mirid, *Creontiades dilutus* (Stål). *Australian Journal of Experimental Agriculture*, **33**, 327-331.

MENSAH, R. K. and Harris, W. (1996). Envirofeast® IPM in cotton: Part 2. Use of lucerne crop as refugia for beneficial insects in cotton. *Proceedings of the Australian Cotton Conference*, **8**, 229-236.

TAYLOR, T. H. C. (1945). *Lygus simonyl* Reut. as a cotton pest in Uganda. *Bulletin of Entomological Research*, **36**, 121-148.

STERN, V. M., MUELLER, A., SEVACHERIAN, V. and WAY, M. (1969). Lygus bug control in cotton through alfalfa interplanting. *Ibid*, **23**, 8 - 10.

SEVACHERIAN, V. and STERN, V. M. (1974). Host plant preferences of lygus bugs in alfalfa-interplanted cotton fields. *Environmental Entomology*, **3**, 761-766.

Suppression of *Helicoverpa* spp. (Lepidoptera : Noctuidae) Oviposition by Use of the Natural Enemy Food Supplement Envirofeast®

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Abstract The deterrent activity of a newly developed food product, Envirofeast® and other food sprays viz. sugar, Envirofeast 2 and petroleum oil plus kelgum mixture on *Helicoverpa* spp. oviposition on cotton crops was investigated by mesh house choice and no-choice tests and large scale field trials at the Australian Cotton Research Institute at Narrabri, Norwood near Moree and Alcheringa near Boggabilla in New South Wales from 1992-95. Envirofeast® treated plants received significantly fewer eggs than did any other treatment and control (water-sprayed) plants, both in the mesh house choice and no-choice tests and in field plots sprayed at fortnightly intervals and exposed to natural populations of *Helicoverpa* spp. The deterrent effect on oviposition by Envirofeast® spray in the mesh house was greater on *Helicoverpa punctigera* (Wallengren) than *H. armigera* (Hubner) but this effect was partially offset by increased *H. armigera* infestations in the field. This was evident in the 1992-93 and 1993-94 field trials at Norwood when the number of eggs laid on Envirofeast® treated plots was significantly lower than any other treatments tested to peak in February when the moth populations were dominantly *H. armigera*. Despite the species difference in the response, the study demonstrates oviposition deterrence by the Envirofeast® product towards *Helicoverpa* spp. on cotton which indicates that Envirofeast® may be used in an integrated approach in cotton systems to reduce *Helicoverpa* spp. numbers. This effect would modify the predator to prey ratios so as to enhance levels of biological control.

Introduction

Commercial cotton crops in Australia are attacked by a wide range of insects, the major ones being *Helicoverpa armigera* (Hubner) and *Helicoverpa punctigera* (Wallengren) (Fitt, 1994). Both species are polyphagous and females lay their eggs singly on terminal buds, newly developed leaves and squares, and less frequently on old leaves, stems and bolls. The larvae feed preferentially on young growing tips or reproductive structures resulting in loss of terminal buds, squares and bolls causing considerable yield loss.

The current control strategy for these pests on cotton involves repeated applications of synthetic insecticides. Over-reliance on insecticides with 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 traditional insecticidal approach. A major focus of the cotton industry therefore is to reduce the dependence on insecticides and maximise the long term sustainability of the industry. This can be achieved only through the development of alternative methods of control which have no significant impact on natural enemies.

Research for alternative methods for controlling insects and especially food attractants, oviposition deterrents and antifeedants has progressed greatly in recent years (Hagen *et al.,* 1971; Renwick *et al.,* 1989; Jermy, 1990; Dimock & Renwick, 1991; Hough-Goldstein & Hahn, 1992; Mensah & Harris, 1995). Such compounds, singly or in mixtures, are safer on non target organisms and can/should be integrated into pest management systems. Extensive studies have shown that food attractants or sprays either attract, conserve, augment or increase oviposition of beneficial insects resulting in the enhancement of their efficacy to control pests (Ewert & Chiang, 1966; Schiefelbein & Chiang, 1966; Hagen *et al.,* 1971; Carlson & Chiang, 1973; Hagen, 1986; Evans & Swallow, 1993; Mensah & Madden, 1994), but no studies so far have looked into the effect of these supplementary food sprays on the oviposition behaviour of the adult insect pest on the host plant. Any compound or mixture that can deter *Helicoverpa* spp. oviposition could have a significant effect on the pest's population because the reduced number of eggs on the plant results in lower pest numbers and thus a shift in the predator to prey ratio to favour natural enemies, and thereby enhances biological control. In this study I examined the effect of a newly developed supplementary food product called Envirofeast® on *Helicoverpa* spp. in choice and no-choice tests in a mesh house and commercial cotton crops.

Materials and methods

Sources of supplementary food products, plant and insect materials. Unless otherwise stated all experiments were conducted in a Sarlon mesh house (4 m x 10 m) at the Australian Cotton Research Institute (ACRI) at Narrabri in New South Wales, Australia. The food products evaluated were Envirofeast® and Envirofeast 2 (NSW Agriculture, ACRI, Narrabri, NSW, Australia). Envirofeast products were developed by the author from mixtures of complex carbohydrates and protein supplements. The protein base of Envirofeast 2 differed from that of Envirofeast®. 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°C at 101.33 kpa) and Kelgum (Kelco & Co., San Diego, CA).

The experimental plants used in all studies were potted cotton plants (Sicala VI), 0.5 m high. The plants were grown from seeds in pots in the same mesh house where the experiments were carried out. *Helicoverpa* spp. moths used in all the mesh house experiments were from colonies

established by the ACRI's Insecticide Resistance Management Group. All experimental data were subjected to analysis of variance (Instat 2.03; Graphpad Instat Software Inc., San Diego, California) and Tukey-Kramer Multiple Comparisons tests or the least significant difference (lsd) test were used to separate the means.

Ovipositional responses of *Helicoverpa* spp. to supplementary food sprays

Experiment 1

Free choice preference test. The "free choice" ovipositional preference of *Helicoverpa* spp. among the different food supplements was measured by counting the number of eggs laid by the moths on cotton plants sprayed with each of the food products evaluated. The experiment was conducted in the mesh house in November 1992 when plants were 4 weeks old. A randomised complete block design was used with four treatments and a control. There were 5 replicates of each treatment, with each treatment consisting of 8 plants i.e 40 plants per treatment. The treatments evaluated were 0.03 kg Envirofeast® in 1 L of water, 0.03 kg Envirofeast 2 in 1 L of water, 0.03 kg sugar in 1 L of water, a mixture of 0.5% (vol/vol) Lovis oil and 0.01% (wt/vol) Kelgum, and water (control). Separate experiments were conducted for *H. armigera* and *H. punctigera*. The plants in each treatment were sprayed with approximately 1 L of test solution using a knapsack sprayer and 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 and data expressed as number of eggs/plant/treatment. These data were used to calculate an oviposition deterrent index (ODI) for each treatment as follows: $ODI = 100 \times (C - T)/(C + T)$, where C represents the total number of eggs in the control plot and T the total number of eggs in the treated plot. An ODI significantly greater than zero (repeated measures analysis of variance test) indicates that moths preferred to oviposit on control plants, ODI not significantly different from zero indicates no preference between control and treated plants, and ODI significantly less than zero indicates a preference for ovipositing on treated plants relative to the control (Lundgren, 1975; Renwick & Radke, 1985; Renwick *et al.*, 1989; Dimock & Renwick, 1991).

No choice preference tests. The no-choice preference of *Helicoverpa* spp. among the different food supplements was measured in the mesh house by egg production of the moths enclosed in separate cages with plants sprayed with one of the test products.

The experiment commenced in January 1993 using 4 week old cotton plants as previously described. Eight plants from each treatment were enclosed in a square cage (200 x 10 cm high) and 8 pairs of either *H. armigera* or 5 pairs of *H. punctigera* adults were released into each cage. This was replicated 5 times i.e. 40 plants/treatment. Numbers of eggs on each plant were recorded daily

and data expressed as numbers/plant/treatment and an ODI for each treatment was calculated for each treatment.

Experiment 2

Ovipositional response of *Helicoverpa* spp. to sprays of mixtures of Oil/Envirofeast®. Following the results of experiment 1, a trial was conducted in the mesh house with mixtures of Envirofeast® and oil sprays. The treatments include 0.03 kg Envirofeast® in 1 L of water mixed with each of (1) 0.01% Lovis oil, (2) 0.01% Synertrol oil (3) 0.01% D-C tron oil (4) 0.01% Peppermint oil (5) 0.01% Fish oil and water (control). Separate experiments were conducted for *H. armigera* and *H. punctigera*. There were 5 plants in each treatment and this was replicated 5 times. Under free choice conditions the plants were treated with the test solutions with a knapsack sprayer as in experiment 1 and 60 pairs of *H. armigera* or *H. punctigera* were introduced into the mesh house. The number of eggs/plant/treatment were recorded daily.

Under no choice conditions plants from each treatment were enclosed in separate cages within the mesh house as described in experiment 1 and 5 pairs each of the test insect species were released into each cage. Numbers of eggs/plant/treatment were recorded daily. Egg counts were used in both choice and no-choice tests to calculate the ODI for each treatment.

Experiment 3

Field studies on ovipositional response of *Helicoverpa* spp. to supplementary food sprays. Experiments were conducted in a 15-hectare cotton field at Norwood, near Moree in New South Wales. The treatments evaluated were (1) 3 kg Envirofeast® (2) 3 kg Envirofeast 2 (3) 4 kg sugar (4) a mixture of 0.5% (vol/vol) Lovis oil and 0.01% (wt/vol) Kelgum (5) control (untreated) and (6) conventional insecticide treated plot (treated standard). Plots were arranged in a randomized complete block design with 4 replicates with the size of each replicate measuring 0.5 ha. Four conventional insecticide treated plots were selected from other cotton fields located 400m away from the trial site to avoid insecticide drift. Similarly, a 40 m wide buffer separated food spray plots and untreated controls. Pre-treatment counts of insects were made 24 h before treatment application and then approximately every 7 d until the end of the study. Foliar applications of each treatment were applied on November 4, 1992 and thereafter at fortnightly intervals until the end of February 1993. On each occasion treatments were applied using 120 L water/ha. In all, 8 applications of each treatment were made during the season. The untreated control plot was left unsprayed and the conventional insecticide treated standard plot received 8 applications of synthetic insecticide sprays by means of ground rig in early season (2 applications) and by aircraft mid and late season (6 applications).

Visual counts of *Helicoverpa* spp. eggs on plants were made on cotton plants in 4 randomly selected 1 m lengths of row in each treatment replicate i.e. 4 m/treatment. Data were expressed as numbers of eggs/m for each treatment and used to calculate ODI using the formula given above.

Experiment 4

Large scale evaluation of Envirofeast® spray on *Helicoverpa* spp. oviposition. This study was conducted in irrigated cotton at Norwood, near Moree in 1993-94 and Alcheringa near Boggabilla in 1994-95. In the 15 ha study plot at Norwood 3 ha were sprayed with Envirofeast® and 0.5 ha was left unsprayed (control). This was replicated 4 times. Foliar applications of the Envirofeast® spray was similar to experiment 3 and were done on November 30, 1993 and thereafter at 14 d interval until March 15, 1994. Counts of the number of eggs/m of both treated and control plots were made as described above.

At the 170 ha Alcheringa study site, 40 ha were sprayed with Envirofeast® and 1 ha was left unsprayed as a control since grower was not prepared to leave a large area of cotton unsprayed. These were replicated 4 times. Foliar application of Envirofeast® commenced on November 8, 1994 and thereafter at 14 d intervals until the end of February 1995. Counts of the number of eggs/m in both treated and control plots were made and compared to similar data taken from 4 conventional insecticide treated plots each measuring 100 ha located 200 m from the other treatments.

Results

Ovipositional responses of *Helicoverpa* spp. to supplementary food sprays (Mesh house study)

Free-choice conditions. Significant differences ($P<0.01$) in ovipositional response of *Helicoverpa* spp. were found among the various supplementary food products tested (Table 1). Significantly fewer ($P<0.01$) eggs were found on plants treated with Envirofeast sprays, especially Envirofeast®, than on the other treatments and the control. The ODI of Envirofeast® and Envirofeast 2 treated plants were significantly greater than zero and higher than any other treatments indicating that these products strongly deterred *Helicoverpa* spp. oviposition (Table 1). The suppressive effect of Envirofeast treated plants was stronger on *H. punctigera* than on *H. armigera*. The oil and kelgum mixture spray also more greatly deterred oviposition by *H. punctigera* than by *H. armigera* as indicated by its ODI.

No-choice conditions. Significant differences ($P<0.05$) were also found among supplementary

food products tested with fewer eggs found on Envirofeast® treated plants than the other treatments and the control (Table 2). The oviposition deterrent effect for Envirofeast® as indicated by the ODI, was also higher than the other treatments (Table 2). In all treatments, deterrence of oviposition of *H. punctigera* was more pronounced than that of *H. armigera.*

Ovipositional response of *Helicoverpa* spp. to sprays of mixtures of Oil/Envirofeast®. Under choice conditions, Oil/Envirofeast® mixtures sprayed on plants significantly ($P<0.05$) suppressed oviposition by *H. punctigera*, but results were not significantly different ($P>0.05$) from those plants that received Envirofeast® spray alone (Table 3). However, in the case of *H. armigera,* plants treated with Envirofeast® alone or mixed with either peppermint or fish oils had significantly ($P<0.05$) fewer eggs laid on them compared with the other oil mix sprays (Table 3). In general maximum numbers of eggs/plant were laid on plants treated with water alone. In all cases, the ODI was significantly greater than zero indicating moths prefered to lay on untreated control plants (Table 3). *H. punctigera* was most affected by the oviposition deterrent effect of all treatments. A similar trend was recorded for all treatments under no-choice conditions for both species (Table 4).

Field studies on ovipositional response of *Helicoverpa* spp. to supplementary food sprays. Under field conditions, oviposition by *Helicoverpa* spp. was significantly ($P<0.05$) different among cotton plants treated with the various food products (Table 5). Significantly ($P<0.05$) fewer eggs were found on Envirofeast® and Envirofeast 2 treated plots compared with the other treatments and the control (Table 5). Highest egg numbers occurred on plots treated with oil/kelgum mixture, sugar and conventional insecticide treated and unsprayed control plots respectively. The peak number of eggs laid on Envirofeast® and Envirofeast 2 treated plots were 5 and 10 eggs/m respectively and these occurred on February 18 (Table 5) when moth populations were dominantly *H. armigera*. At the end of the study, plots treated with Envirofeast® spray had 8 times fewer eggs than the sugar, insecticide treated and unsprayed plots.

Large scale evaluation of Envirofeast® spray on *Helicoverpa* spp. oviposition. At the Norwood study site significantly ($P<0.05$) fewer eggs were found on Envirofeast® treated plots compared with the unsprayed plots (Fig. 1A). Egg numbers ranging from 0-1/m were found on the Envirofeast® treated plots from 17 December until 1 February before reaching a peak of 8 eggs/m on 7 February when moths were dominantly *H. armigera* (Fig. 1A). The unsprayed plots however had higher numbers of eggs ranging from 4 - 8.3/m during the same period before peaking at 10.7/m on 14 February (Fig. 1A). At the end of the study 3.1 times fewer eggs were found on the Envirofeast® treated plots compared with the control (Fig. 1A).

Similar results were obtained at the Alcheringa site, with the Envirofeast® treated plots recording a significantly lower ($P<0.01$) number of eggs compared with the conventional insecticide treated and the unsprayed plots (Fig. 1B). The mean number of eggs/m per sample date recorded on the Envirofeast®, insecticide treated and unsprayed plots were 0.72, 1.46 and 1.98 respectively. In this study 2.03 and 2.76 times more eggs had been recorded in the unsprayed and insecticide treated plots respectively compared with the Envirofeast® plot.

Discussion

The results indicate that the oviposition of *Helicoverpa* spp. and especially *H. punctigera* was significantly influenced by treating cotton plants with Envirofeast sprays. Under both mesh house (choice and no-choice trials) and field conditions, Envirofeast sprays suppressed oviposition by *Helicoverpa* spp. on treated plants more than any other treatment assessed. Deterrence of oviposition calculated as ODI in the mesh house study was evidently strongest for the Envirofeast® product (Tables 1- 5). *H. punctigera* oviposition was more significantly suppressed than *H. armigera* indicating that increased infestations of the latter in the field could partially offset the ovipositional deterrent effect of the Envirofeast® product. This was confirmed in the field study during the 1992/93 and 1993/94 seasons at Norwood when the number of eggs laid on Envirofeast® treated plots, though significantly fewer than on any other treatments, peaked in February to coincide with the period when the moth populations were dominantly *H. armigera* (Table 5 and Fig. 1A). The lower number of eggs recorded in the field trials on all treated plots and especially Envirofeast® treatments could be the result of a combination of predation and the ovipositional deterrent effect of the product since Envirofeast® is also known to attract and conserve predatory insects of *Helicoverpa* spp.(Mensah and Harris unpublished data). However the fact that significantly higher numbers of eggs were recorded on the unsprayed plots and the plots treated with sugar which is known to arrest and concentrate predatory insects of these moths (Hagen *et al.*, 1971; Ewert and Chiang, 1966; Ben Saad and Bishop, 1976; Mensah and Madden, 1994) would suggest that the effect of predation in this study was minimal and the ovipositional deterrent effect of the product was mostly responsible for the lower egg numbers on the Envirofeast® treated plots.

The study also indicated that the mixture of oil and kelgum deterred *Helicoverpa* spp. oviposition in the field but this effect was not as pronounced as observed in the mesh house (Table 1 and 5). The deterrent effect of Envirofeast® was reduced when oils were added to increase adherence and persistence on leaves.

In the context of managing *Helicoverpa* spp. in cotton farms, the deterrence of oviposition by Envirofeast® is important as the pest, being highly migratory, can rapidly infest crops from other

sources before natural enemies have time to establish and respond to their numbers. This usually results in a low predator to prey ratio in cotton systems and control is achieved, not by biological, but by chemical means. Any product that deters oviposition and modifies the predator to prey ratio in favour of natural enemies of *Helicoverpa* spp. must enhance the effect of biological control. The Envirofeast® product acts in this instance to deter oviposition on the crop by reducing the numbers of eggs deposited on the crop thus shifting the predator to prey ratio to increase the effectiveness of natural enemies.

Several studies have been conducted in the use of supplementary food sprays in crop systems to attract, arrest and conserve predatory insects to manage pests (Hagen *et al.*, 1971; Ewert and Chiang, 1966; Ben Saad and Bishop, 1976; Mensah and Madden, 1994), but no studies have been conducted on the effect of these food products on the oviposition behaviour of the pest species. The use of behaviour-modifying compounds such as oviposition deterrents to reduce oviposition of many insect pests on crops has been progressed recently (Renwick, 1988; Jermy, 1990; Dimock & Renwick, 1991; Hough-Goldstein & Hahn, 1992) and plants have been the major source of these deterrent compounds (Harbourne, 1982; Klocke, 1987; Renwick *et al.*, 1989; Dimock & Renwick, 1991; Hough-Goldstein & Hahn 1992).

These studies have shown that the suppression effect of Envirofeast® on *Helicoverpa* spp. oviposition could be an important supplement to the beneficial effects of Envirofeast® to attract and sustain natural enemies. In conclusion this product has the potential to be integrated into programmes to assist in the control of major cotton pests.

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Table 1. Ovipositional preferences of *Helicoverpa armigera* (n = 110 pairs) and *H. punctigera* (n = 100 pairs) on cotton plants sprayed with various food supplements in the mesh house at the Australian Cotton Research Institute in Narrabri, November, 1992. (Results of free choice tests)(n= 40 plants per treatment).

Treatments	No. of eggs per plant		Mean Ovipositional Deterrent Index (ODI)	
	H. armigera	*H. punctigera*	*H. armigera*	*H. punctigera*
Envirofeast ®	11.78 a	2.10 a	41.5	83.8
Sugar	17.10 b	19.40 b	25.0	8.9
Envirofeast 2	10.78 a	3.73 a	45.1	72.3
Oil and Kelgum mixture	25.20 c	3.13 a	6.1	76.2
Water (Control)	28.50 c	23.17 b	0	0

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

Table 2. No choice test for oviposition of *Helicoverpa armigera* (n= 8 pairs) and *H. punctigera* (n = 5 pairs) on cotton plants in the mesh house at the Australian Cotton Research Institute in Narrabri, January 1993.

Treatments	No. of eggs per plant		Mean Ovipositional Deterrent Index (ODI)	
	H. armigera	*H. punctigera*	*H. armigera*	*H. punctigera*
Envirofeast ®	1.11 a	0.37 a	74.5	91.7
Sugar	3.82 ab	1.91 bc	33.2	52.7
Envirofeast 2	3.61 ab	0.83 ab	35.7	68.6
Oil and Kelgum mixture	5.33 b	1.99 c	17.6	38.2
Water (Control)	7.61 b	4.45 d	0	0

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

Table 3. Ovipositional response of *H. armigera* and *H. punctigera* (n = 60 pairs each) to Envirofeast/Oil mixtures sprayed on cotton plants in the mesh house at the Australian Cotton Research Institute in Narrabri, May 1993. (Results of free choice tests)(n = 25 plants per treatment).

Treatments	No. of eggs per plant		Mean Ovipositional Deterrent Index (ODI)	
	H. armigera	*H. punctigera*	*H. armigera*	*H. punctigera*
Envirofeast ®	6.85 ± 0.67 a	4.00 ± 0.62 a	53.6	61.1
Envirofeast® + 0.01% Lovis oil	11.70 ± 1.09 b	3.00 ± 0.58 a	31.9	69.3
Envirofeast® + 0.01% Synertrol oil	8.09 ± 0.81 c	3.67 ± 1.67 a	47.4	63.7
Envirofeast® + 0.01% D-C tron oil	12.45 ± 0.70 b	2.67 ± 0.76 a	29.1	72.2
Envirofeast® + 0.01% Peppermint oil	5.82 ± 1.18 a	8.00 ± 4.58 a	59.1	34.8
Envirofeast® + 0.01% Fish oil	6.00 ± 0.82 a	2.33 ± 0.33 a	58.1	75.3
Water (Control)	22.65 ± 1.00 d	16.54 ± 1.68 b	0	0

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

Table 4. Ovipositional response of *H. armigera* and *H. punctigera* (n = 5 pairs each) to Envirofeast/Oil mixtures sprayed on cotton plants in the mesh house at the Australian Cotton Research Institute in Narrabri, May 1993. (Results of No choice tests)(n = 25 plants per treatment).

Treatments	No. of eggs per plant		Mean Ovipositional Deterrent Index (ODI)	
	H. armigera	*H. punctigera*	*H. armigera*	*H. punctigera*
Envirofeast ®	9.00 ± 2.05 ab	1.98 ± 0.32 a	43.3	81.0
Envirofeast® + 0.01% Lovis oil	12.25 ± 1.89 b	1.30 ± 0.28 a	30.0	87.1
Envirofeast® + 0.01% Synertrol oil	14.50 ± 1.55 b	1.05 ± 0.60 a	22.2	89.4
Envirofeast® + 0.01% D-C tron oil	11.00 ± 0.91 b	0.63 ± 0.23 a	34.8	93.5
Envirofeast® + 0.01% Peppermint oil	9.25 ± 1.03 ab	0.43 ± 0.22 a	42.2	95.5
Envirofeast® + 0.01% Fish oil	5.00 ± 1.78 a	1.12 ± 0.62 a	64.0	88.8
Water (Control)	22.75 ± 3.52 c	18.84 ± 1.94 b	0	0

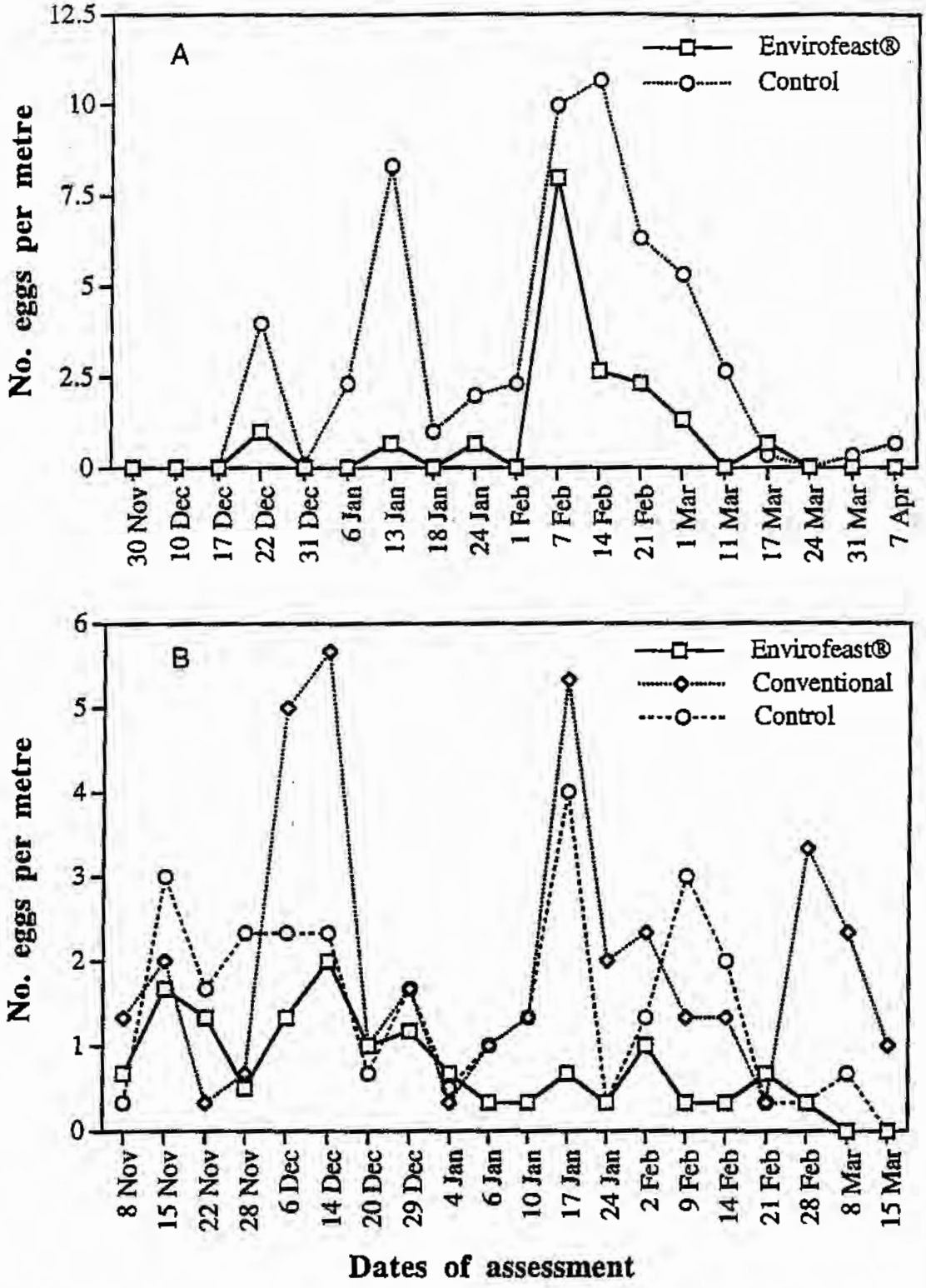
Means within a column followed by the same letter are not significantly different (P>0.05) (Least significant difference).

Table 5. Responses of field populations of *Helicoverpa* spp. to supplementary food sprays in commercial irrigated cotton at Norwood near Moree in NSW, 1992-93.

	No. of eggs per metre					
Dates of assessment	Envirofeast®	Sugar	Envirofeast 2	Lovis Oil + Kelgum	Control (unsprayed)	Conventional
27 November 1992	0	0	0	0	0	0
4 December	0 a	0.25 ± 0.18 ab	0.25 ± 0.10 ab	0.75 ± 0.27 ab	2.50 ± 0.97 b	2.50 ± 0.67 b
11 December	0.75 ± 0.18 a	5.75 ± 1.20 b	0.75 ± 0.27 a	2.60 ± 0.85 ab	5.25 ± 0.71 b	2.50 ± 0.45 b
21 December	1.00 ± 0.10 a	8.75 ± 2.65 b	1.75 ± 0.18 ac	5.00 ± 1.22 abc	6.50 ± 1.24 bc	8.75 ± 0.91 b
30 December	1.00 ± 0.10 a	12.25 ± 1.97 b	1.75 ± 0.35 a	10.75 ± 1.41 b	13.25 ± 2.76 b	11.95 ± 2.32 b
11 January	1.75 ± 0.18 a	7.75 ± 3.15 bc	3.50 ± 1.23 ab	8.50 ± 2.45 bc	9.75 ± 3.82 c	10.25 ± 3.02 c
21 January	2.25 ± 0.36 a	6.00 ± 0.99 ab	2.00 ± 0.96 a	4.50 ± 1.02 ab	8.25 ± 1.05 b	8.25 ± 1.73 b
28 January	1.75 ± 0.25 a	8.00 ± 1.19 b	4.25 ± 1.09 ab	3.50 ± 0.55 a	6.50 ± 0.65 b	7.00 ± 1.18 b
5 February	1.00 ± 0.14 a	23.75 ± 3.06 b	6.08 ± 1.08 a	5.25 ± 0.90 a	17.50 ± 2.60 b	20.77 ± 3.53 b
12 February	2.75 ± 0.92 a	16.75 ± 2.59 bc	6.50 ± 0.98 a	12.50 ± 2.52 ab	28.50 ± 3.35 c	22.25 ± 3.56 c
18 February	5.00 ± 1.34 a	38.25 ± 3.65 b	10.00 ± 2.40 a	25.00 ± 3.77 c	32.00 ± 3.34 b	32.95 ± 3.99 b
25 February	1.50 ± 0.72 a	18.00 ± 1.57 b	2.75 ± 0.75 a	5.50 ± 1.42 a	19.25 ± 5.06 b	17.50 ± 4.43 b
4 March	0 a	7.75 ± 1.26 b	0 a	2.25 ± 0.55 ab	5.25 ± 0.80 b	4.75 ± 0.75 b
10 March	0	0 a	0.15 ± 0.07 b	0 a	0 a	0 a
Mean	1.44 ± 0.38 a	11.79 ± 2.89 b	3.05 ± 0.82 a	6.62 ± 1.84 c	11.85 ± 2.73 b	11.74 ± 2.57 b

Means between treatments within rows followed by the same letter are not significantly different (P>0.05) Tukey - Kramer Multiple Comparisons Test.

Fig. 1. Effect of supplementary food (Envirofeast® spray on *Helicoverpa* spp. oviposition on commercial cotton at (A) Norwood near Moree, 1993-94 and (B) Alcheringa near Boggabilla, 1994-95.


A
Envirofeast®
Control
No. eggs per metre
12.5
10
7.5
5
2.5
0
30 Nov
10 Dec
17 Dec
22 Dec
31 Dec
6 Jan
13 Jan
18 Jan
24 Jan
1 Feb
7 Feb
14 Feb
21 Feb
1 Mar
11 Mar
17 Mar
24 Mar
31 Mar
7 Apr
B
Envirofeast®
Conventional
Control
No. eggs per metre
6
5
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8 Nov
15 Nov
22 Nov
28 Nov
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8 Mar
15 Mar
Dates of assessment

References

BEN SAAD, A. A. and BISHOP, G. W. (1976). Effect of artificial honeydews on insect communities in potato fields. Environ. Entomol. 5: 453-457.

CARLSON, R. E. and CHIANG, H. C. (1973). Reduction of an *Ostrinia nubilalis* population by predatory insects attracted to sucrose sprays. Entomophaga 18: 205-211.

DIMOCK, M. B. and RENWICK, J. A. A. (1991). Oviposition by field populations of *Pieris rapae* (Lepidoptera: Pieridae) deterred by an extract of a wild crucifer. Environ. Entomol. 20: 802-806.

EVANS, E. W. and SWALLOW, J. G. (1993). Numerical responses of natural enemies to artificial honeydew in Utah alfalfa. Environ. Entomol. 22 (6): 1392-1401.

EWERT, M. A. and CHIANG, H. C. (1966). Dispersal of three species of coccinellids in corn fields. Can. Entomol. 98: 999-1003.

FITT, G. P. (1994). Cotton pest management: Part 3. An Australian perspective. Ann. Rev. Ent. 39: 543-562.

HAGEN, K. S. (1986). Ecosystem analysis: plant cultivars (HPR), entomophagous species and food snpplements. In: Interactions of plant resistance and parasitoids and predators of insects, (eds. Boethel, D. J. & R. D. Eikenbary) Wiley New York Press, 151-197.

HAGEN, K. S., SAWALL, E. F. and TASSAN, R. L. (1971). The use of food sprays to increase effectiveness of entomophagous insects. Proc. Tall Timbers Conf. Ecol. Anim. Control Habitat Management. 3: 59-81.

HARBOURNE, J. B. (1982). Introduction to ecological biochemistry, 2nd ed. Academic Press, London.

HOUGH-GOLDSTEIN, J. and HAHN, S. P. (1992). Antifeedant and oviposition deterrent activity of an aqueous extract of *Tanacetum vulgare* L. on two cabbage pests. Environ. Entomol. 21 (4): 837-844.

JERMY, T. (1990). Prospects of antifeedant approach to pest control: a critical review. J. Chem. Ecol. 19: 234-238.

KLOCKE, J. A. (1987). Natural plant compounds useful in insect control. In: Allelochemicals: role in agriculture and forestry, (eds. Waller, G. R.) American Chemical Society Symposuim Series 330, Washington, D. C., 396-415.

LUNDGREN, L. (1975). Natural plant chemicals acting as oviposition deterrents on cabbage butterflies (*Pieris brassicae* (L), *P. rapae* (L), and *P. napi* (L.). Zool. Scr. 4: 253-258.

MENSAH, R. K. and MADDEN, J. L. (1994). Conservation of two predator species for biological control of *Chrysophtharta bimaculata* (Col. : Chrysomelidae) in Tasmanian forests. Entomophaga 39 (1): 71-83.

MENSAH, R. K. and HARRIS, W. E. (1995). Using Envirofeast® (food) spray and refugia for

cotton pest control. The Australian Cotton Grower 16 (2): 30-33.

RENWICK, J. A. A., RADKE, C. D. and SACHDEV-GUPTA, K. (1989). Chemical constituents of *Erysimum cheiranthoides* deterring oviposition by the cabbage butterfly, *Pieris rapae*. J. Chem. Ecol. 15: 2161-2169.

RENWICK, J. A. A. (1988). Plant constituents as oviposition deterrents to lepidopterous insects. In: Biologically active natural products. Potential use in agriculture, (eds. Cutler, H. G.) American Chemical Society Symposuim Series 380, Washington, D. C., 378 -384.

RENWICK, J. A. A., RADKE, C. D. (1985). Constituents of host and non-host plants deterring oviposition by the cabbage butterfly, *Pieris rapae*. J. Insect Physiol. 34: 251-257.

SCHIEFELBEIN, J. W. and CHIANG, H. C. (1966). Effects of spray of sucrose solution in a corn field on the populations of predatory insects and their prey. Entomophaga, 11: 333-339.

Yellow traps can be used to monitor populations of *Coccinella transversalis* (Fabricius) and *Adalia bipunctata* (Linnaeus) (Coleoptera: Coccinellidae) in cotton crops

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ABSTRACT: Squares (30 x 30 cm) sticky traps of various colours were used on a commercial cotton farm to trap adults of *Coccinella transversalis* and *Adalia bipunctata* which are both major predators of *Helicoverpa* spp. during 1992 to 1994. Both insects were attracted most to yellow traps which also reflected the most visible light between 500 nm and 600 nm (where green foliage reflects most light). When yellow was diluted with white to produce yellow-white hues, the light reflected between 500 nm and 600 nm was reduced and the numbers of *C. transversalis* and *A. bipunctata* adults caught on these traps was also significantly reduced. This suggests that *C. transversalis* and *A. bipunctata* adults can discriminate foliage-hues (500 to 580 nm) from non foliage-hues (<500 nm and > 580 nm) and are attracted to colours that suggest the foliage of host plants that may harbour their prey. Yellow sticky traps placed 25 to 50 cm above ground caught significantly more *C. transversalis* and *A. bipunctata* adults than those placed at 75 to 150 cm and are the most appropriate traps to monitor populations of *C. transversalis* and *A. bipunctata* adults in cotton farms.

Introduction

Coccinella transversalis (Fabricius) and *Adalia bipunctata* (Linnaeus) (Coccinellidae) are major predators of *Helicoverpa* spp. (Noctuidae) in cotton in Australia (Room and Wardhaugh, 1979) (Mensah and Harris unpublished data). Both adults and larvae of the coccinellids feed on the eggs and early stage larvae of the noctuids and if high densities of *C. transversalis* and *A. bipunctata,* are established especially early in the cotton season, *Helicoverpa* spp. can be controlled in cotton farms (Mensah & Harris unpublished data). However, *Helicoverpa* spp. are highly migratory and can rapidly infest crops from other sources, so, unless predatory insects are present and well established in high numbers in the

cotton crops early in the season before *Helicoverpa* spp. arrive, they cannot respond rapidly enough to control *Helicoverpa* spp. Currently, cotton growers rely solely on visual observation to determine the presence of *C. transversalis, A. bipunctata* and other predatory insects in cotton, especially early in the cotton season. Therefore, there is a need to develop a quick and effective trapping technique to monitor populations and to help to evaluate the disruptive impact of insecticides on beneficial insects. Developing such a technique requires a better understanding of the role of colour stimuli in the detection of food or host plants that harbour the prey of these coccinellid species. The role of colour stimuli in host detection is becoming more widely recognised (Prokopy and Owens, 1983) and coloured traps have been used to monitor populations of many flying insects, especially phytophagous insects in field crops (Kennedy *et al.* 1961; Ridgway and Mahr, 1986; Adams and Los, 1989; Economopolous, 1989; Mensah and Madden, 1992). However, studies of the responses of entomophagous insects (viz.predators and parasitoids) to different colours are rarer (Weseloh, 1981; Disney *et al.*, 1982; Kirk, 1984) and no studies bave been made of *C. transversalis* and *A. bipunctata.*

The questions to be asked in such a study are:

(1) do *C. transversalis* and *A. bipunctata* adults respond to yellow colour like many other phytophagous insects;

(2) if they do, can yellow sticky traps be used to monitor their population in cotton farms;

(3) what is the optimum height above ground level to place these coloured traps and

(4) can these two coccinellid species discriminate foliage hues from non-foliage hues?

To answer these questions, I tested traps with different colours and shades placed at different heights above ground level in commercial cotton farms.

Materials and methods

Responses of *C. transversalis* and *A. bipunctata* to yellow and other enamel colours. The colour response studies of *C. transversalis* and *A. bipunctata* adults were conducted in a cotton farm at Auscott near Narrabri using field trapping techniques similar to those described by 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 adhesive glue (Bird Tangletrap®, The Tangletrap Company, Grand Rapids, Michigan, USA), and attached to a vertical steel rod in the ground at 50 cms above the ground.

The reflectance characteristics of the colours were measured with a Field Spec™.UV/VNIR

Results

Responses *C. transversalis* and *A. bipunctata* to yellow and other enamel colours. Yellow traps caught significantly more *C. transversalis* and *A. bipunctata* adults than any other trap (Table 1). Green and orange traps were the next most effective and true blue, deep blue, red, magenta and black traps were the least effective (Table 1). There was a significant and positive correlation between the amount of light reflected by each colour between 500nm and 600 nm region and the capture rates of *C. transversalis* ($r^2 = 0.93$; $P<0.001$) and *A. bipunctata* ($r^2 = 0.94$; $P<0.001$) (Table 1).

Responses of *C. transversalis* and *A. bipunctata* to different hues of yellow. Significantly more *C. transversalis* and *A. bipunctata* adults were caught on the full yellow (Y) and 3Y:1W traps than on any of the other hues tested (Fig. 1). The white traps were the least effective. On the yellow traps the most *C. transversalis* adults were caught in November and the most *A. bipunctata* in February. As the same population trends were seen when both species were sampled visually, colour preference was not affected by season.

The maximum reflectances of the yellow and the white and the intermediate shades occurred between 500 nm and 600 nm. The light reflected between 500nm and 600 nm by yellow, white and the three intermediate colours tested was positively correlated with the mean daily trap catches of *C. transversalis* ($r^2=0.68$, $P<0.001$) and *A. bipunctata* ($r^2=0.84$, $P<0.001$) (Fig. 3).

Determination of optimum trap height for maximum capture of *C. transversalis* and *A. bipunctata* adults. Tbe optimum height to place a yellow coloured trap in the field to maximise *C. transversalis* and *A. bipunctata* adult catches was 25 cm or 50 cm above ground (Table 2). At these heights significantly higher numbers ($P<0.05$) of *C. transversalis* and *A. bipunctata* adults were captured than at 75-150 cm (Table 2). Fewest insects were caught at 150 cm above ground.

Discussion

C. transversalis and *A. bipunctata* adults are more responsive to yellow traps than to any of the other colours tested. When full yellow was diluted, the amount of visible light reflected between 500 nm and 600 nm dropped, and presumably, caused the reduction in the number of

C. transversalis and *A. bipunctata* adults captured thus indicating the degree to which these insects respond to light reflected in the 500-600 nm region.

This positive response of both *C. transversalis* and *A. bipunctata* adults to yellow suggests that these insects can discriminate foliage hues (500-580 nm) from other hues (<500 nm and > 580 nm) and would therefore be attracted to the colours of the foliage of host plants that harbour their prey. Leaves, reflect little visible energy below 500 nm and much between 500-600 nm, the yellow range. In northern New South Wales, Australia, where short-lived annual crops, including cotton, are grown seasonally, the habitat provided by these crops for phytophagous insects which are preyed upon by *C. transversalis* and *A. bipunctata* will be ephemeral. Such differences in host permanence means that the coccinellids fly periodically to new host locations when their prey's host plant are harvested and so they may use colour stimuli frequently in flights to distinguish foliage that habours food and thereby ensure their survival.

Many phytophagous insects respond positively to yellow (Wilde 1962; Kring, 1967; Prokopy and Boller 1971, Greany *et al.*, 1977; Ferro and Sychak, 1980; Coombe, 1981; Adams *et al.*, 1983) and yellow coloured traps have been used to monitor their populations (Meyerdirk and Oldfield, 1985; Adams and Los, 1989; Mensah and Madden 1992). Entomophagous insects that are not particularly associated with foliage such as predators and parasitoids would be expected to show the positive response to yellow if this enabled them to locate the leaf-feeding insects on which they prey. The present study has indicated that *C. transversalis* and *A. bipunctata* adults respond to yellow in this way. This could suggest that traps for prey will catch beneficial insects as well and make it possible to monitor populations of both prey and predator using one trap. However, in studies using yellow traps to monitor populations of a specific phytophagous insect where one wishes to avoid the capture of *C. transversalis* and *A. bipunctata* adults, the traps should be located at a height higher than 50 cm above ground.

In conclusion, yellow coloured traps placed between 25 to 50 cm above ground in cotton farms could be used to monitor populations of *C. transversalis* and *A. bipunctata*.

Table 1. Response of *Coccinella transversalis* and *Adalia bipunctata* adults to yellow colours and reflected light emitted between 500-600 nm region on traps in a cotton crop at Auscott, Narrabri 1992-1993.

Colour enamels	Mean catch per trap per day [1]		Per cent total reflected light emitted in the 500-600 nm region
	C. transversalis	*A. bipunctata*	
Yellow	0.35 a	0.23 a	26.8
Orange	0.17 b	0.08 b	13.9
Green	0.23 b	0.11 b	17.1
Red	0.09 c	0.03 c	11.8
Deep blue	0.10 c	0.02 c	7.0
Magenta	0.08 c	0.02 c	5.2
True blue	0.11 c	0.03 c	8.7
Black	0.06 c	0.02 c	7.7

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

Means between treatments within rows followed by the same letter are not significantly different (P> 0.05) using the least significant difference test (LSD).

Table 2. Yellow trap captures of *Coccinella transversalis* and *Adalia bipunctata* adults at different heights between 25-150 cm above ground level in a cotton crop at Auscott in Narrabri, 1992 - 1993.

Trap height (cm)	Mean catch per trap per day [1]	
	C. transversalis	*A. bipunctata*
25	4.64 a	2.37 a
50	3.08 ab	1.79 b
75	2.74 bc	0.92 c
100	1.22 c	0.55 cd
125	0.82 c	0.32 d
150	0.53 c	0.13 d

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

Means between treatments within rows followed by the same letter are not significantly different (P>0.05) using the least significant difference test (LSD).

Fig. 1. Captures of *Coccinella transversalis* and *Adalia bipunctata* adults on different hues of yellow coloured traps in commercial cotton at Auscott in Narrabri from November 1993 until April 1994. (Means between treatments for each coccinellid species followed by the same letter are not significantly different (P>0.05) using the least significant difference (LSD) test).

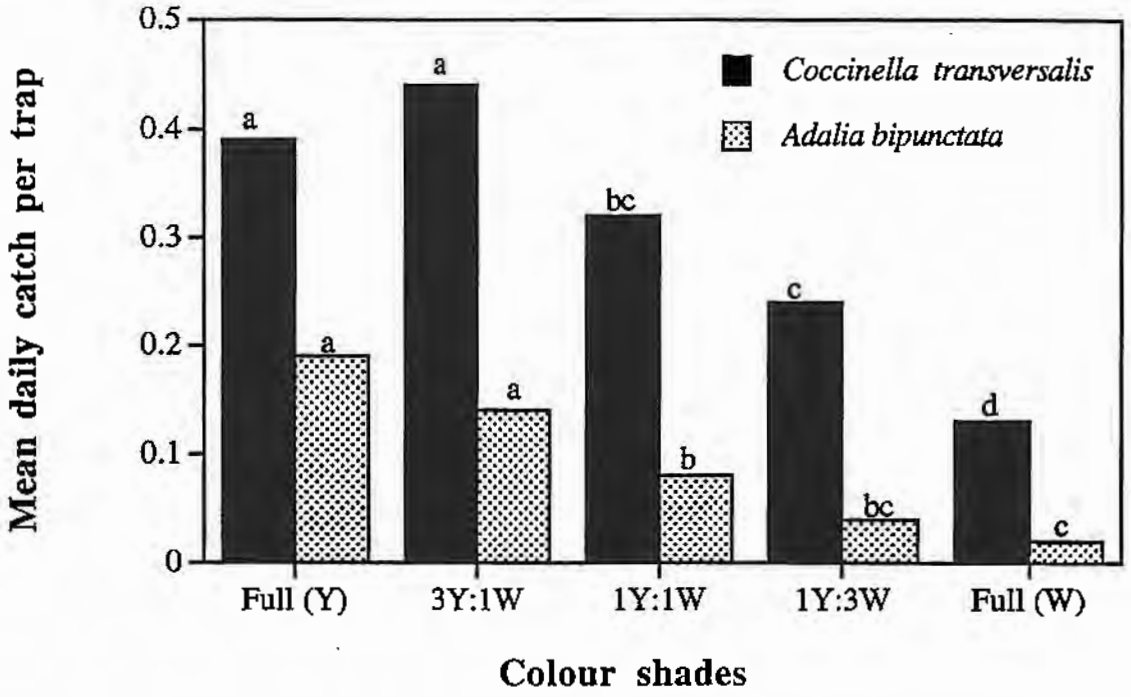

Mean daily catch per trap
0.5
0.4
0.3
0.2
0.1
0
Coccinella transversalis
Adalia bipunctata
a
a
a
a
bc
b
c
bc
d
c
Full (Y)
3Y:1W
1Y:1W
1Y:3W
Full (W)
Colour shades

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

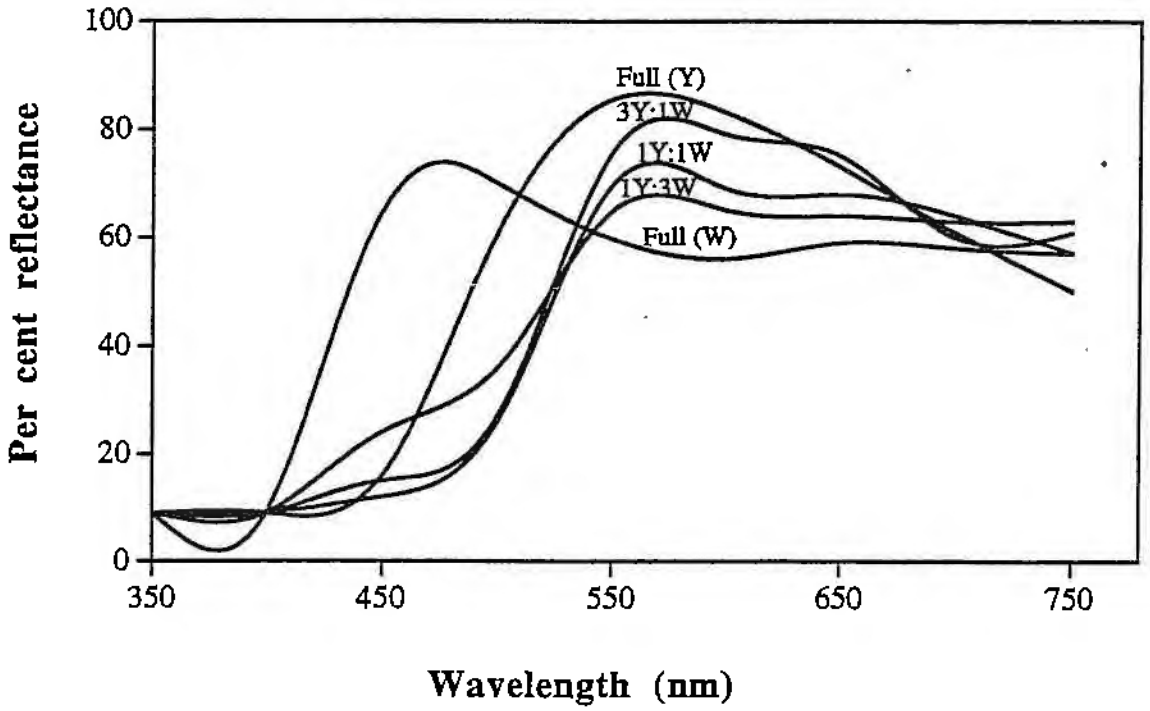
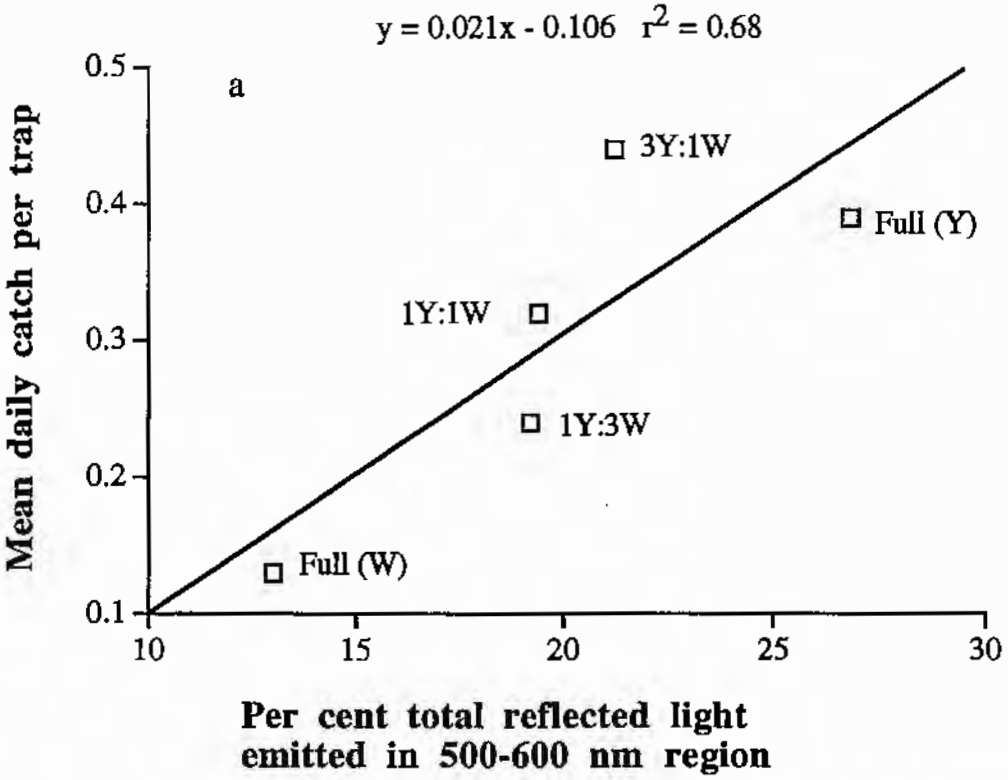
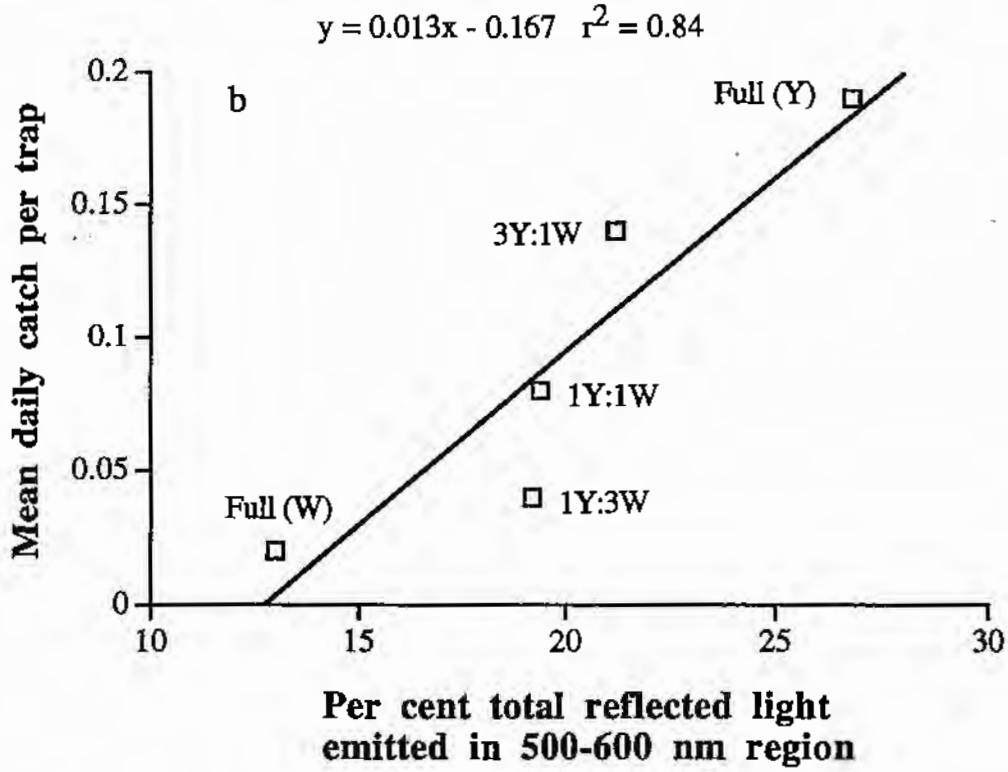

100
80
60
40
20
0
350
450
550
650
750
Full (Y)
3Y:1W
1Y:1W
1Y:3W
Full (W)
Per cent reflectance
Wavelength (nm)

Fig. 3. Relationship between the per cent total reflected light emitted in the 500-600 nm region by each of the test colours and the mean daily trap catch of *Coccinella transversalis* (a) and *Adalia bipunctata* (b) in commercial cotton at Auscott in Narrabri from November 1993 until April 1994.


y = 0.021x - 0.106 r2 = 0.68
a
Mean daily catch per trap
0.5
0.4
0.3
0.2
0.1
3Y:1W
Full (Y)
1Y:1W
1Y:3W
Full (W)
10
15
20
25
30
Per cent total reflected light
emitted in 500-600 nm region


y = 0.013x - 0.167 r2 = 0.84
b
Mean daily catch per trap
0.2
0.15
0.1
0.05
0
Full (Y)
3Y:1W
1Y:1W
1Y:3W
Full (W)
10
15
20
25
30
Per cent total reflected light
emitted in 500-600 nm region

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References

ADAMS, R. G., DOOMEISEN, C. H. and FORD, L. G. (1983). Visual trap for monitoring pear psylla adults on pears. Environ. Entomol. 12: 1327-1331.

ADAMS, R. G. and LOS, L. M. (1989). Use of sticky traps and limb jarring to aid in pest management decisions for summer populations of the pear psylla (Homoptera : Psyllidae) in Connecticut.J. Econ. Entomol. 82: 1448-1554.

COOMBE, P. E. (1981). Wavelength specific behaviour of the whitefly, *Trialeurodes vaporariorum* (Homoptera : Aleurodidae). J. Comp. Physiol. 144: 83-90.

DISNEY, R. H. L., ERZINCLIOGLU, Y. Z., HENSHAW, D. J. C., HOWSE, D., UNWIN, D. M. WITHERS, P. and WOODS, A. (1982). Collecting methods and the adequacy and attempted fauna surveys, with reference to the Diptera. Field Studies 5: 607-621.

ECONOMOPOULOS, A. P. (1989). Use of traps based on colour and or shape. *In* Rohinson, A. S. and Hooper, G. (eds.) World Crop Pests, Fruit Flies, their biology, natural enemies and control 3B: 315-328. Elsevier Sci. Publs. B. V.: Amsterdam.

FERRO, D. N. and SYCHAK, G. J. (1980). Assessment of visual traps for monitoring the asparagus miner, *Ophiomyia simplex*. Entomol. exp. appl. 28: 177-182.

GREANY, P. D., AGEE, H. R., BURDITT, A. K. and CHAMBERS, D. L. (1977). Field studies on colour preferences of Carihbean fruit fly, *Anastrepha suspensa* (Diptera : Tephritidae).Entomol. exp. appl. 21: 63-70.

KENNEDY, J. S., BOOTH, C. O. and KERSHAW, W. J. S. (1961). Host finding of aphids

in the field. III. Visual attraction. Ann. Appl. Biol. 49: 1-21.

KIRK, W. D. J., (1984). Ecologically selective coloured traps. Ecol. Entomol. 9: 35-41.

KRING, J. B., (1967). Alighting aphids on coloured cards in a flight chamber. J. Econ. Entomol. 60, 1207-1210.

MENSAH, R. K. and MADDEN, J. L. (1992). Field studies on colour preferences of *Ctenarytaina thysanura* in Tasmanian boronia farms. Entomol. exp. appl. 64: 111-115.

MEYERDIRK, D. E. and OLDFIELD, G. N. (1985). Evaluation of trap colour and height placement for monitoring *Circulifer tenellus* (Homoptera : Cicadellidae).Can. Entomol. 117: 505-511.

PROKOPY, R. J. (1972). Response of apple maggot flies to rectangles of different colours and shades. Environ. Entomol. 1: 720-726.

PROKOPY, R. J. and BOLLER, E. F. (1971). Response of european cherry fruit flies to coloured rectangles. J. econ. Ent. 64: 1444-1447.

PROKOPY, R. J. and OWENS, E. D. (1983). Visual detection of plants by herbivorous insects. Ann. Rev. Entomol. 28: 337-364.

RIDGWAY, N. R. and MAHR, D. L. (1986). Monitoring adult flight of *Pholetesor ornigis* (Hymenoptera : Braconidae), a parasitoid of the spotted leafminer (Lepidoptera : Gracillariidae). Environ. Entomol. 15: 331-334.

ROOM, P. M. and WARDHAUGH, K. G. (1979). Seasonal occurrence of insects other than *Helicoverpa* spp. feeding on cotton in the Namoi Valley of New South Wales. J. Aust. Ent. Soc. 16: 165-174.

WESELOH, R. M. (1981). Relationship between coloured sticky panel catches and reproductive behaviour of forest tachinid parasitoids. Environ. Entomol. 10: 131-135.

WILDE, W. H. A., 1962. Bionomics of the pear psylla, *Psylla pyricola* in pear orchards of Kootenay Valley of British Columbia.Can. Entomol. 94: 845-849.