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

SELECTED PUBLICATIONS

COTTON RESEARCH AND DEVELOPMENT CORPORATION

FUNDED PROJECT (DAN 98 C) (July 1995 to June 1998)

DR ROBERT KOFI MENSAH

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

Tel: (067) 991500
Fax: (067)931186

NSW AGRICULTURE

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

ISBN 0 - 7313-1549-9

DECLARATION

This addendum of the final report (DAN 98C) to the best of my knowledge contains no copy or paraphrase of materials previously published by any other person. The studies contained in this report were conducted by myself under the project Code DAN 98C funded by the Australian Cotton Research and Development Corporation (CRDC) and NSW Agriculture.

Dr Robert Mensah
(Senior Research Entomologist)

NSW Agriculture
Australian Cotton Research Institute
Narrabri, NSW 2390, Australia

TABLE OF CONTENT

TABLE OF CONTENT

PLAIN ENGLISH SUMMARY

Cotton crops in Australia are attacked by a wide range of pests, the key ones being the larvae of *Helicoverpa* spp., green mirids and mites. To sustain production, the cotton industry currently relies heavily on synthetic insecticides for the control of these pests. A major focus of the cotton industry is to reduce the dependence on insecticides and maximise the long term sustainability of the industry. One way this can be achieved by developing an alternative pest control strategy which minimises insecticide use and places much more emphasis on the role of beneficial insects. This project has developed methods for conservation, augmentation and utilisation of beneficial insects in an integrated pest management (IPM) program in cotton. It has described the numerical and functional responses of beneficial insects and determined some of the factors operating in cotton and other crops that influence the efficacy of beneficial insects. Studies to conserve and utilise beneficial insects particularly predators in the cotton agroecosystem for integrated pest management (IPM) strategies in normal and transgenic cotton were carried out between July 1995 and June 1998.

The study examined habitat diversity and its implications for the conservation and use of predatory insects of *Helicoverpa* spp. in cotton systems. The utility of crops such as sunflower, safflower, sorghum, lucerne and tomato as refugia for predatory insects and as trap crops for other cotton pests such as green mirids were examined. The lucerne crop was found to serve as a refugia for predatory insects and trap crop for green mirids when interplanted with cotton. The refugia function of interplanted lucerne was attributed to the abundance of floral nectar, alternate prey, shelter, mating and oviposition sites in the lucerne crop. Thus given the abundance of food resources, shelter, oviposition and mating sites in the lucerne, higher numbers of predators were not inclined to move from the lucerne strips to forage the adjacent cotton crop. Envirofeast® product applied at the rate of 2.5 kg/ha to the cotton crop was found to attract the beneficial insects from the lucerne to the cotton. The optimum size and the length of lucerne/cotton interplants required to effectively manage green mirids and generate beneficial insects in cotton was 8 or 12 metres of lucerne for every 300 metres of cotton. Lucerne crops planted as borders to a cotton crop were found to generate beneficial insects but were not effective in managing green mirids in cotton blocks which had more than 300 rows.

The IPM program developed in this project integrated Envirofeast® sprays, lucerne strips, gemstar virus, tracer and synthethic insecticides. The IPM program has reduced synthetic insecticide sprays and achieved a similar level of control of cotton pests and lint yield to that of conventional insecticide managed transgenic and normal cotton. In the IPM strategy, 50-80 per cent of synthetic insecticides were replaced by biological sprays. When the IPM strategy was used without Envirofeast® sprays on both normal and transgenic cotton, the cotton crop suffered a yield loss of 1.24 - 4.57 bales per hectare in the case of normal cotton and 0.74-1.24 bales per hectare on transgenic cotton.

The numbers of beneficial insects per metre were found to be significantly higher ($P<0.001$) and green mirids per metre significantly lower ($P<0.0001$) in the IPM managed plots with lucerne strips than on the conventional insecticide managed transgenic and normal cotton crops.

Studies to determine the consumption rate per day and factors affecting predatory beetles showed that *Helicoverpa* spp. or prey densities can affect their consumption rate through competition. Increasing prey density from 5 to 60 *Helicoverpa* spp. eggs increased the consumption rate of transverse ladybirds from 2.5 to 25 eggs per day. Higher predator densities can also affect their consumption rate. Some of the other factors affecting the consumption rate of predatory beetles were the use of synthetic insecticides particularly pyrethroids, food resource, rainfall, relative humidity, temperature, irrigation, soil cultivation.

Field studies to assess the efficacy of *Beaveria bassiana* (Naturalis®) against green mirids showed that the product had no effect on green mirid adults and beneficial insects; it caused 51.9 - 64.4 per cent mortality of green mirid nymphs 2-5 days after application. The product, therefore, cannot be used as a stand alone product for mirid management but can be used successfully in conjunction with other IPM strategies.

INTRODUCTION

Commercial cotton crops in Australia are attacked by a wide range of insects, the major ones being *Helicoverpa* spp. larvae, green mirids, two-spotted mites and thrips. The management of these pests depends almost exclusively on synthetic insecticides; natural enemies of the pests are neglected due to lack of techniques to maximise their abundance and effectiveness. Cotton production in Australia rely on within-field monocultures and this practice discriminate against and reduce the activity of predatory insects because they lack ecological diversity. The lack of ecological diversity could be the major cause of pest problems because the food, hosts, prey and hibernating or overwintering sites of most of the natural enemies of the pests are reduced thereby limiting natural biological control. This can result in pest outbreaks because abundant food is available to the pest and they need not waste time searching for food or a mate or unduly expose themselves to their natural enemies. The development of a strategy that may conserve and maximise the abundance and effectiveness of natural enemies of cotton pests particularly *Helicoverpa* spp. in cotton will be crucial to enhance the development of an integrated pest management (IPM) program in cotton. For a successful conservation and utilisation of beneficial insects as a base of an IPM program, it is important that the industry gain a detail knowledge of predator responses to prey, predator/prey interactions, factors limiting their efficacy and the utility of other crops as refugia for beneficial insects. It is also important for the industry to gain knowledge in the utility of other pest management or insect behaviour modifying tools that can attract beneficial insects or suppress oviposition of pests or control the pest with minimal disruption to the efficacyof the beneficial insects in cotton systems.

The aim of this study was to (1) improve our understanding of predator responses to prey, predator/prey interactions and factors limiting their efficacy in cotton systems, (2) improve the performance of Envirofeast® product developed in DAN 68 and 89C (3) develop strategies to attract, conserve and utilise beneficial insects as basic components of IPM in cotton and (4) manage green mirids and aphids through conservation of beneficial insects.

A SELF-INSTRUCTION MANUAL FOR ENVIROFEAST® INTEGRATED PEST MANAGEMENT PROGRAM FOR COTTON PESTS

By

Robert Mensah

NSW Agriculture, Australian Cotton Research Institute, PMB, Myall Vale, Narrabri, NSW, Australia

Introduction

The Australian cotton production system is monoculture (i.e. one crop grown in a large area). It lacks diversity and as such the food, hosts, prey and overwintering or hibernating sites of natural enemies are reduced. Natural enemies have to move in and out of the monocultural system to look for food and other needs in order to survive, whereas the pests need not waste time searching for food or mates. Insect pests such as *Helicoverpa* (Heliothis) spp. through migration can rapidly infest plants and lay their eggs with little opposition from their natural enemies which may arrive too late in the monoculture crops to be of much value.

Solution to the problems

Changing the way we grow cotton by planting non-crop plants such lucerne as strips within the cotton crop could provide some of the requisites needed to sustain and maintain beneficial insects in our cotton farms. The lucerne crop could serve as a refuge for beneficial insects and enhance their activity and also serve as a trap crop for the non insect pests such as green mirids which have become pests on the cotton crops because there is no alternative crop on which they can feed. The beneficial insects hiding in the lucerne strips will have to be moved into the cotton to feed on Heliothis pests when required without affecting the green mirids. This can be done by applying Envirofeast® spray onto the cotton crops to attract beneficial insects into the cotton to help control *Helicoverpa* spp. Integrating the lucerne crop refugia, Envirofeast® sprays and selective pesticides forms the package of the Envirofeast® IPM technology. Rhone-Poulenc Rural (Australia) Pty Ltd is the commercial partner of Envirofeast® product and its refugia system.

Growers should be aware that the days when monocultural agroecosystems can be managed with a "quick fix" of pesticides to achieve maximum yield and crop quality are gone. Most insect pests and diseases have developed some levels of resistance to the insecticides or fungicides used against them. For example, Heliothis have developed some levels of resistance to almost all the insecticides used against them in the cotton industry. It will therefore not be long before farmers "hit the wall" if an integrated approach to pest management is not undertaken. In my opinion, *Helicoverpa* spp. is a major pest in cotton because of the heavy reliance on insecticides for its control.

The advent of transgenic or Bt cotton to control pests is not going to solve all the pest problems in our monocultural cotton farms. There is the possibility that insect pests especially Heliothis will soon develop resistance to these transgenic plants looking at the levels of Heliothis damage to some of the transgenic cotton crops during the 1996/97 cotton season. For these transgenic plants to remain durable it should be managed as part of an IPM strategy with support from other control measures including Envirofeast. Growers should therefore consider adopting an integrated approach to pest management for the sustainability of the future cotton industry.

GUIDELINES FOR USE OF ENVIROFEAST® IPM STRATEGY

1.0 SITE SELECTION: Selection of Envirofeast® IPM trial site is very important for the success of the IPM program. The trial site should be situated farther away from or not to be surrounded by conventional insecticide managed plot. Avoid insectide drifts from the conventional plots as much as possible.

2.0 SIZE OF PLOTS: Growers using Envirofeast® IPM for the first time are advised to restrict the Envirofeast® trial plot to about 50 ha. As experience in the use of Envirofeast is gained, management units may be incorporated until a whole farm approach to IPM is achieved.

3.0 PANTING OF LUCERNE STRIPS IN ENVIROFEAST IPM PLOTS

Interplanting of lucerne crop as strips in commercial cotton provide a refuge for beneficial insects and spiders on the farm. Many of these beneficial insects can then be encouraged into cotton with the strategic use of Envirofeast® sprays to help manage Heliothis. Lucerne is also preferred over cotton by the green mirid (*Creontiades dilutus*) and therefore can be used as a trap crop to manage this insect. With the introduction of transgenic cotton, green mirids will become a major pest as they are unaffected by Bt cotton plants. Currently there are no insecticides that can control green mirids without disrupting the activity of beneficial insects. The industry needs all avaible biological control strategies to manage cotton pests into the next century. The following are guidelines for growing lucerne in cotton farms.

3.1 SIZE AND PLACEMENT OF LUCERNE STRIPS

Lucerne strips can be used:

(i) within the cotton field with a maximum width of 8 or 12 rows per 300 rows of cotton (i.e. lucerne area = 2.5% of wbole field)

(ii) as a field border - it is preferable to place lucerne on both sides of the field. In this case, a minimum area of 5% of the whole field should be planted to lucerne (eg 24 rows each side of a 1000 row wide field). Note that this option may be slightly less effective than strips grown within the field for green mirid control.

3.2 Establishment

It is most important to have the lucerne strips established before cotton planting.

Sowing date: For lucerne strips to act as a trap crop, an effective plant stand needs to be established. Seeding rates of around 5 kg/ha should be used in dryland situations and 10 to 15 kg/ha for irrigated crops.

Seed bed preparation: Good seed bed preparation is required to achieve good establishment. For best results with establishment, it is best to obtain advice from an experienced lucerne grower and or contract him to plant it for you.

3.3 Planting windows

Sowing time will vary according to the variety of lucerne selected and the growing district. Autumn and spring are the best periods in which to sow. Avoid winter sowings in colder, wetter locations especially if the variety is winter dormant. Spring sowings should be used only under irrigation or in districts where spring rainfall is reliable. Two planting windows have been used successfully:

(i) ***April/June planting***: This produces a well established lucerne stand by the time the cotton is planted.

(ii) ***July/August planting***: Ensure lucerne is established by the end of August. This is the best option for back-to-back cotton. For crops that will be irrigated, the lucerne strips either 8 or 12-row strips should be made into two equal lucerne beds by joining 4 rows into a bed in the case of an 8 row strip and 6 rows per bed in a 12 row strip. A furrow should be made to run between the beds in each strip from the head to the tail ditch. This will ensure that water runs through the lucerne strip from head to tail end during irrigation. However, if the lucerne is to be planted directly onto the cotton beds, the avoid planting in the furrows as this will create irrigation problems once the crop is established.

3.4 Irrigation Management

A 20-day cycle from September to December and a 10 from December onwards are the recommendations for maximum production of lucerne in Northern NSW. Since cotton growers are not striving for maximum production, a first lucerne watering should be done when the cotton starts to square, all other lucerne irrigations can be applied as the cotton requires.

When the lucerne are no further use as a refuge or trap crop, a situation during the late cotton season when broadspectrum insecticides such as synthetic pyrethroids are used in the farm or neighbouring farms, all the lucerne can be slahed or mowed and given no irrigations. Growers should take note that a good stand of lucerne can contribute about 200 kg N/ha in the soil every year in a crop rotation.

3.5 Management of lucerne within the strips

The lucerne strips should be kept attractive through the cotton growing season especially during the early squaring and flowering period of the cotton crop. Once lucerne begins to flower, vegetative growth is limited and it is less attractive to green mirids. This can be achieved by slashing or mowing half of each lucerne strip (**see recommendations in 6.0**) for slashing or mowing to manage beneficial insects and green mirids). The first cut should be early for example at or just before first square. Subsequent cuts should be just as the other half lucerne strip starts to flower (provided there is sufficient regrowth in the other strips.

4.0 Cotton Management

Agronomic management of cotton crops managed with Envirofeast® IPM should be similar to management practises used for the whole farm. However, growers are advised to avoid high plant stands and planting too late.

5.0 Insect Management

Seed treatments or in-furrow application of granular insecticides to control early season pests is optional and solely rest on individual growers. However, if prone to thrips or mirids the grower may have to consider seed treatment or in-furrow application of granular insecticides. These products may be less disruptive to beneficial insects compared to foliar organophosphates.

5.1 Control of Heliothis on Normal cotton using Envirofeast IPM

5.1.1 Sampling of Heliothis and Beneficial insects

Visual sampling: The grower should carry out visual checks (bug checking) of pests (Heliothis. eggs, very small (VS), small (S), medium (M) and large (L) larvae) and all beneficial insects of whole cotton plants 2 times every week or as required by the grower for the particular farm. For every plot sample at least 60 plants with no less than 3 entry points. Data should be recorded as numbers of Heliothis eggs, very small, small, medium or large larvae per metre and **not** "present" or "absent" method. Each of the beneficials should be recorded as numbers per metre. This is to allow a predator to prey or pest ratio to be determined.

5.1.2 D-vac sampling for beneficial insects

If the consultant or Agronomist decides to use D-vac to assess beneficial insects, then sampling should be done same day as checking. It should be done early in the morning before 10 am. The D-vac machine of the type made by Homelite Textron Inc. with a cone diameter of 120mm should be used. A gauze bag should be inserted into the suction tube to collect insects sucked from the plants. During sampling the tube of the D-vac should be drawn from the top to the base of the plants until a 20 metre row of cotton plants and or lucerne strips randomly taken from 2 different sites in the plot have been sampled. After sampling, the contents of the D-vac should be transferred to a plastic bag and predatory insects counted. Research is still in progress to relate D-vac catches with visual counts. All predatory insects should be counted and the total predators per metre used to determine the predator to prey ratio (refer 5.4.1 and 5.4.2).

5.1.3 Damage assessment

Fruit retention should be assessed based on industry guidelines through the duration of the trial. First position fruit retention ranging from 50-60 per cent will give you a good yield.Retention assessment as per CRDC guidelines.

5.2 Predatory insects identified from cotton farms

The following are a list of some of the predatory insects that occurred most often in commercial cotton farms. If in doubt about beneficial insects identification refer to the Cotton Pest and Beneficial Insect Guide.

Order	Family	Species	Common name
Coleoptera	Coccinellidae	*Coccinella transversalis*	Transverse ladybird
		Micraspis frenata	Striped ladybird
		Harmonia octomaculata	Three banded ladybird
		Diomus notescens	Two-spotted ladybird
		Harmonia conformis	Common spotted ladybird
		Coelophora inaequalis	Variable ladybird
	Melyridae	*Dicranolauis bellulus*	Red and blue beetle
		Chauliognathus pulchellus	Green soldier beetle
	Carabidae	*Calasoma schayeri*	Green carab beetle
Hemiptera	Pentatomidae	*Cermatulus nasalis*	Glossy shield bug
		Oechalia schellenbergii	Predatory shield bug
	Nabidae	*Nabis kinbergii*	Damsel bug
	Lygaeidae	*Geocoris lubra*	Big-eyed bug
	Reduviidae	*Coranus triabeatus*	Assassin bug
		Orius spp.	Pirate bug
Neuroptera	Chrysopidae	*Chrysopa* spp.	Green lacewing
	Hemerobiidae	*Micromus tasmaniae*	Brown lacewing
Araneidae	Lycosidae	*Lycosa* spp.	Wolf spider
	Oxyopidae	*Oxyopes* spp.	Lynx spider
	Salticidae	*Salticid* spp.	Jumping spider
	Araneidae	*Araneus* spp.	Orbweavers

5.3 IPM Tools

At present, the Envirofeast IPM tools are Envirofeast®, Viruses (eg Gemstar virus), *Bacillus thuringiensis* (conventional Bt), Endosulfan, Tracer and any other insecticides used in stage 3 of the insecticide resistance strategy. Envirofeast®, Viruses eg. Gemstar virus) and Conventional Bt should be used to support Envirofeast® from early season until beneficial insect numbers decline naturally or when broad spectrum insecticides such as pyrethroids are used on the farm or neighbouring farms. Endosulfan and Tracer should be used on emergency situations during the periods when Envirofeast® and the biological pesticides are being used to restore predator to prey ratio to normal (i.e. 0.5; see decision making in **5.4**).

5.4 Decision making protocol (Normal cotton)

The decision to control Heliothis should be based on the ratio of predators to pests in the crop as indicated by your visual or D-vac counts.

Pest used in the ratio refers to Heliothis eggs, very small (VS) plus small (S). It does not include Heliothis medium (M) and large (L) larvae since the predatory insects are not effective on these stages.

5.4.1 Predators: Total predators per metre in the above table (**i.e. table 5.2**) should be used in the calculation of the predator to pest ratio. However, to be confident in the ratio, at least 3 insects of the most common predators within the families Coccinellidae, Melyridae, Nabidae, Lygaeidae, Reduviidae, Chrysopidae, Hemerobiidae and Pentatomidae should be present in your 20 metre sample or counts.

5.4.2 Application of the Predator to Prey Threshold

The accepted Predator to prey threshold is 0.5 and above.

i.e. Predator per metre ÷ (Helioths Eggs + larvae (VS + S) = 0.5 and above

- When the ratio is 0.5 and above, it means the IPM system is functioning well.
- When the ratio falls below 0.5, there are several options that should be considered before action is taken.

These options are:

- If the Heliothis numbers in your insect check are more of **eggs** than **larvae**, apply **Envirofeast® spray** to attract beneficial insects into your crop to feed on the eggs.
- However, if Heliothis numbers are more of **larvae** (i.e. very small and small larvae) than eggs, **mix Envirofeast® with either a virus or Bt or any biological insecticide** and spray the crop.

Prior to Envirofeast®/biological insecticide spray, D-vac your lucerne strips to determine numbers of beneficial insects and adult green mirids in the lucerne strips.

- If beneficial insect numbers are high in the lucerrne strips compared to cotton but numbers of adult mirids in the lucerne strips are low (less than 5 per 20 metre D-vac sample), **then slash each half of the lucerne strips after Envirofeast®/biological insecticide mixture**

sprays. This action will enhance the movement of a large number of the beneficial insects from the lucerne strips into the cotton.

• In contrast, if both the beneficial insect and adult mirid numbers in the lucerne strips are high (>5 per 20 metres in the case of mirids), **do not slash or mow the lucerne strips after Envirofeast/biological insecticide mixture spray** since this will force the mirids into the cotton to cause mirid problems.

• If Heliothis larvae levels are still high in your next check after Envirofeast/biological insecticide sprays but there is evidence that **the predator to prey threshold is increasing, but not up to 0.5, repeat Envirofeast®/biological insecticide mixture spray**.

• However, if the ratio continued to decline after the two Envirofeast/biological insecticide mixture sprays reaching 0.40 or lower, treat your crop with a selective insecticide such as Tracer or Endosulfan to reduce neonate numbers before they moult to mediums.

N/B Put on your first Envirofeast® spray of the season when the crop has attractive true leaves and you observe Heliothis moths flying around and the number of Heliothis eggs on your crop reaches 1.0 eggs per metre.

5.5 Decision making protocol (Ingard cotton)

Predator to pest threshold of 0.5 and above as in Normal cotton should also be used on Ingard cotton.

i.e. Predator per metre ÷ (Heliothis Eggs + Larvae (VS + S) = 0.5 and above

• When the ratio is 0.5 and above it means the IPM on Ingard is functioning well. Do nothing

• When the ratio falls below 0.5, there are several options that should be considered before action is taken.

* If the Heliothis numbers are more of **eggs than neonates,** ***apply*** **Envirofeast® spray** to attract beneficial insects into your crop to feed on the eggs.

* However, if pest numbers are more of **neonates than eggs**, then mix Envirofeast® with a biological insecticide (***not a conventional Bt***) and spray the crop.

N/B Slashing or mowing of each half of the lucerne strip after Envirofeast®/biological insecticide application on Ingard cotton should follow the same guidelines recommended for Envirofeast IPM on normal cotton.

* If Heliothis neonate numbers in your next check after the Envirofeast/biological insecticide spray are still too high but the check indicate an improvement in the predator to prey threshold repeat Envirofeast®/biological insecticide mixture spray.

* However, if the ratio continued to decline after the Envirofeast/biological insecticide mixture sprays, reaching 0.40 or lower, intervene with a selective insecticide to reduce prey numbers before they moult to mediums.

5.4.3 Recommended rates of Envirofeast

Envirofeast product should be applied at 2.5 kg per field hectare. It can be applied by groundrig or aircraft. When band spraying, the same total quantity of Envirofeast should be applied to the crop as a more concentrated directed band. There is therefore no rate saving with band spraying. In instances where ground rig cannot be used it is possible to apply by air. The volume of Envirofeast® application using a groundrig is 120 litres/ha and by air 30 litres/ha.

Early season: In early season when using a ground rig, apply as a 33% band to cotton plants. The increased concentration achieved from banding will help attract a starting population of predatory insects. If a ground rig cannot be used you can apply by air at 2.5 kg per hectare.

As the cotton grows, increase the band width to 50% when using a ground rig. Direct the spray to the newly developed leaves which are usually very attractive to the moths. It can be sprayed by air at 2.5kg/ha at 30 litre per hectare spray volume.

After the cotton plants have closed their canopy aerial application at the same rate is recommended.

5.4.4 Mixing and Application of Envirofeast®

Envirofeast should be mixed as a slurry using a premix tank with agitation provided by a pipe connected to a water pump. Top up the mixture with water to reach the total volume required. The mixed product should be agitated constantly throughout mixing and transferral to the groundrig or aircraft.

Envirofeast should be applied using flat fan nozzle or any nozzle that can concentrate the product on the top of the leaves. Coverage of the lower surface of the leaves is though not essentional, an additional benefit will be gained from the product if the lower surface of the leaves are covered.

To determine whether you have got the desire or right concentration on the leaves, identify the sprayed leaves after the product has dried to see whether the leaf surface looks muddy.

Use Envirofeast the same day you mix. The product will "go off" or perish if the mixture or solution is left overnight. Clean groundrig, aeroplane, or premix tanks thoroughly with water before and after Envirofeast® spray.

6.0 Management of green mirids

Green mirids prefer lucerne to cotton. Therefore, interplanting lucerne crop as strips in commercial cotton can be used to manage green mirids. There should be at least 8 or 12 rows of lucerne planted between every 300 rows of cotton. Research has shown that larger rows of lucerne (i.e. greater than 16 rows) makes the lucerne act as a separate or independent system of its own. This means beneficial insects are locked up permanently in the lucerne and can be moved only with a higher concentration (greater than 2.5 kg/ha) of Envirofeast® spray. A smaller area of lucerne (less than 8 rows) though will allow beneficial insects to be moved easily into the cotton using Envirofeast® spray, high infestation of green mirids in the lucerne can force the insects into the cotton through overcrowding.

To manage green mirids in the lucerne strips, the lucerne crop should **not** be allowed to hay off. New regrowth of the lucerne should be maintained through the season by slashing or mowing half of each lucerne strip every 4 weeks or when the crop is in flower.

- Poor establishment of lucerne strips may mean reduced ability of the crop to manage the green mirids in cotton. Research is continuing to identify field threshold for the green mirid.
- However, if a grower is using Entomologic threshold it is important to undertake fruit retention counts to confirm mirid damage before applying a mirid spray. Any chemistry used to control green mirids should have minimum impact on beneficial insects. At present there are no soft option for mirids but Endosulfan can be used to suppress their numbers in emergency situation. Mixing Naturalis with Envirofeast® can also help to suppress mirid numbers but Naturalis is not registered to be used on cotton in Australia.

7.0 Mites

My experience in using Envirofeast® IPM shows that mites are not flared up if you adhere strictly to the Envirofeast IPM guidelines. However, the use of broad spectrum insecticides such as pyrethroids early in the season in adjacent farms can disrupt the activity of beneficial insects which may result in mite outbreak. Heavy infestation of mites late season means you have to treat the crop with a miticide.

8.0 Aphids

Aphids infestations come during the late cotton season when insecticides especially the pyrethroids are used frequently to control Heliothis. The drift from these insecticides can affect the activity of beneficial insects resulting in aphids outbreak. Heavy aphids infestation will require the use of synthetic insecticides.

Acknowledgements

I thank Peter Glennie, Kylie May (Norwood), John and Ross O'Brien (Bellevue), David Blow, Kym Rigby (Doreen), Dave Anthony, Stefan Henggeler, Shane Bodiam (Auscott, Narrabri), Chris Hogendyk, Harvey Gaynor, Mathew Seccombe (Auscott, Warren) for co-operating with the field trials; Rhone-Poulenc Rural (Australia) Pty Ltd for providing Envirofeast® products for the large scale trials, and Bruce Pyke, Dallas Gibb and the Envirofeast IPM Support Group for their constructive criticism of the manual. The Australian Cotton Research and Development Corporation (CRDC) provided funding for all my research projects (DAN 68C, 89C, 98C) that has led to the development and commercialization of Envirofeast®.

INTEGRATED PEST MANAGEMENT (IPM) IN COTTON BASED ON ENVIROFEAST® AND LUCERNE TECHNOLOGIES : WHERE ARE WE

ROBERT MENSAH AND ANGELA SINGLETON

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

INTRODUCTION

In agriculture, pest management seeks to achieve the most efficient balance between maximum yield, quality, minimum cost and minimum destruction of the environment and ecosystem. In modern agricultural production particularly cotton production in Australia, the farmer understands clearly the relationship between yield, quality of his produce and the cost of production. The other area which many of our cotton growers have difficulty is incorporating the concept of environmental protection into pest management systems. Many of our cotton farmers like the rest of the world has put maximum crop yields, quality and minimum cost of production above the preservation of the agroecosystem. The overemphasis on yield and quality has led to excessive use of synthetic insecticides that has resulted in insecticide resistance in most pests especially *Helicoverpa* spp., disruption of natural enemies of the pest and environmental pollution.

The major focus of the Australian cotton industry is to reduce the dependence on synthetic insecticides. However, despite widespread use of economic thresholds and the so called "soft option" IPM in the current production systems, little emphasis has been placed on beneficial insects, while the reliance on synthetic insecticides negates the term IPM for such a system. It is obvious that cotton pests particularly *Helicoverpa* spp. are harder to kill with synthetic insecticides than before and at high infestations no insecticide works.

The question is what are the growers doing wrong? There are many things in pest management that growers are doing wrong. One of them is the way we grow cotton in Australia. The cotton fields are strictly monoculture and lacks ecological diversity. In such situations pest populations increase, minor pests become major pests, and non pests become pests. This is because the food, hosts, prey, overwintering sites of the natural enemies are reduced (Beirne, 1967; De Loach 1972, Andow and Risch, 1985; Mensah and Madden, 1994; Mensah 1997; Mensah and Khan, 1997). Natural enemies have to move in and out of the monocultural cotton farm to satisfy their food requirements and other needs in order to survive, whereas the pests need not waste time searching for food or mates, or unduly expose themselves to natural enemies while doing so. The movement of natural enemies in and out of the cotton system could lead to pest outbreaks because *Helicoverpa* spp. through migration can rapidly infest plants and lay their eggs with little opposition from their natural enemies which may arrive too late to be of much value. There is the need now to develop a true or "big picture" IPM strategy which emphasises on techniques or tools that tend to conserve beneficial insects in the cotton farm and utilise them as basic components in the management of these pests.

Since 1992, we have been funded by the Cotton Research and Development Corporation (CRDC) to develop an IPM strategy which places much more emphasis on natural enemies of the cotton pests in order to reduce the cotton industry's dependence on synthetic insecticides. The project has since developed Envirofeast® (food) spray product and lucerne refugia technologies to conserve and enhance the activities of natural enemies in cotton systems. The Envirofeast® product when applied to cotton crops attracts and conserve the natural enemies. The lucerne crop when interplanted in cotton as strips serves as a refuge for the natural enemies and sink for another cotton pest, the green mirid. The total IPM package is being evaluated by Rhone-Poulenc Rural (Australia) Pty Ltd prior to commercialization.

Strickland *et al.* (1998) attempted to exploit the benefit of our technology to develop IPM on cotton in the Ord. They could not achieve the full benefit of using Envirofeast® because of small plot size and close proximity of treatments and also agronomic problems associated to their trials resulting in the delay of Envirofeast® application and the product not applied at the right time. It was a problem of too few people looking after too many trials. The Envirofeast IPM has been developed in stages and currently we have completed stage 7 of the program.

We report here stages 6 and 7 of the program where we compared pest, natural enemy populations and also the yield of normal and transgenic cotton crops managed with Envirofeast IPM to those managed with conventional synthetic insecticides under the Insecticide Resistance Management strategy for 1996/97 and 1997/98 seasons.

STAGE 6 IPM SYSTEM COMPARED IN 1996-97

This stage of the IPM integrated Envirofeast® spray, lucerne refugia with biological and synthetic insecticides. The trial was conducted in irrigated normal and transgenic cotton fields at the Australian Cotton Research Institute in Narrabri, Bellevue near Warren and Norwood near Moree. The cotton crops were interplanted with lucerne to conserve beneficial insects and manage green mirids (Mensah, 1997; Mensah and Khan, 1997). The size of the trials ranged from 2ha (ACRI); 132 ha (Bellevue) and 170 ha (Norwood). All the trials were replicated and compared with cotton crops (normal and transgenic) of similar size but pests managed with synthetic insecticides under the Insecticide Resistance Strategy.

The treatments at each site are summarized in Table 1. All treated plots under Envirofeast IPM strategy were initially sprayed with Envirofeast® and when the predator to prey (*Helicoverpa* spp.) ratio fell below 0.5 (recommended action threshold for Envirofeast® IPM reported elsewhere in this proceedings), some of the plots were treated with either Gemstar virus or Tracer (spinosad, a new selective insecticide produced by Dow Elanco). When all the natural enemy population in the lucerne strips and cotton has been exterminated as a result of insecticide drifts from conventional insecticide managed farms on site or from neighbours, all the treatments were reverted to insecticide sprays when the threshold was exceeded. In this wise the number of synthetic insecticides used on the IPM plots were recorded and compared with those used on plots managed with conventional insecticides.

At the end of the season, the number of synthetic insecticide saved or replaced by biological insecticide through the use of the IPM was determined. Yields barvested from the IPM treatments and the conventional insecticide managed crops were compared to determine any loss in yield.

TABLE 1: STAGE 6 IPM TREATMENTS COMPARED AT NORWOOD, BELLEVUE AND ACRI, 1996-97.

Treatments	Features
1. Sicala V2 + Lucerne strips + Envirofeast® + Envirofeast/Gemstar virus + insecticides	Normal leaf cotton with lucerne strips and managed with predator food attractant, biological and synthetic insecticides
2. Sicala V2 + Lucerne strips + Envirofeast® + Tracer + synthetic insecticides	Normal leaf cotton with lucerne strips and managed with predator food attractant, selective and synthetic insecticides.
3. Sicala V2 + Conventional insecticides	Normal leaf cotton managed with conventional insecticides (Insecticide Resistance Management Strategy)
4. Sicala V2 (Ingard) + Conventional insecticides	Normal leaf cotton (Ingard) managed with conventional insecticides (TIMS Committee Ingard Management Strategy).

RESULTS OF IPM TRIALS, 1996-97

Promising results were achieved at all trial sites. The total number of spray products (biological and synthetic insecticides) applied through the season on IPM and Conventional insecticide managed cotton crops were not different at all sites. But the encouraging aspect of the results was that despite the equal number of products applied, synthetic insecticides were replaced by biological sprays within the IPM strategy. In the trials at Norwood, 50% of the synthetic insecticide sprays were replaced by biological sprays, 80% were replaced at Bellevue and 88% at ACRI. There were no yield loss at Norwood and ACRI but at Bellevue the IPM program consisting of Envirofeast and Gemstar virus and Envirofeast and Tracer had a yield loss of 0.57 bales and 0.20 bales per acre respectively compared to the conventional cotton (Table 2). This means that one or two more insecticide sprays at the expense of biological sprays could have been enough to avert the yield loss. The result of the trial on Ingard cotton showed that the Ingard cotton saved 2 sprays at Norwood and 5 sprays each at Bellevue and ACRI respectively (Table 2). However, at Bellevue site, the trial lost 0.3 bales per hectare on the Ingard compared with the conventional cotton (Table 2). In general, the level of insecticide sprays in these trials reflected the level of *Helicoverpa* spp. infestations on these plots.

Different species of natural enemies (mostly predators) were sampled from the trials at each site (Table 3). The highest number of predators per plot were recorded on the IPM plots treated with Envirofeast/Gemstar virus mixture, followed by Envirofeast® plus Tracer, and then Ingard plus conventional insecticides. The conventional insecticide treated normal cotton plot had the lowest number of beneficial insects which were predominantly spiders. The beneficial insects were abundant early in the season but numbers declined drastically during stage 2 and were completely exterminated in stage 3. The decline in beneficial insect numbers coincided with the periods when synthetic pyrethroids were used by farm neighbours to control *Helicoverpa* spp. and the drift came to the trial plots. The beneficial insect population collapsed completely in February when on site farms also used pyrethroids to control their cotton pests. The decline and subsequent collapse of the beneficial insect population resulted in high densities of *Helicoverpa* spp. larvae and when threshold was exceeded trials were converted to conventional insecticide sprays.

Green mirid numbers were highest in treatments without lucerne strips but lowest in those interplanted with lucerne strips. Within the lucerne/cotton interplants, green mirids were highest in the lucerne strips than the cotton and remained low until the end of the study indicating there was no movement of green mirids into adjacent cotton.

TABLE 2: SUMMARY OF YIELDS (BALES/ACRE) AND IPM TREATMENTS IN TRIALS AT NORWOOD (N*), BELLEVUE (B*) AND ACRI (A*), 1996-97.

Treatments	No. of Envirofeast sprays	No. of Envirofeast +virus sprays	No of Tracer sprays	Synthetic insecticide sprays	Yields (bales/acre)
1. Sicala V2 + Lucerne strips	N*= 3	3	0	4	3.0
+ Envirofeast® + Envirofeast/	B*= 4	4	0	2	2.40
Gemstar virus+ insecticides	A*= 4	4	0	1	3.01
2. Sicala V2 + Lucerne strips	N*= 3	0	3	4	3.20
+ Envirofeast® + Tracer	B*= 4	0	3	2	2.80
+ synthetic insecticides	A*= 4	0	4	0	2.95
3. Sicala V2 + Conventional	N*= 0	0	0	8	3.0
insecticides	B*= 0	0	0	10	3.0
	A*= 0	0	0	9	2.73
4. Sicala V2 (Ingard) +	N*= 0	0	0	6	2.90
insecticides	B*= 0	0	0	5	2.70
Conventional insecticides	A*= 0	0	0	5	3.07

TABLE 3: MAJOR PREDATORS IDENTIFIED FROM STUDY PLOTS IN THE IPM TRIALS, 1996-98.

Order	Family	Species	Group
Coleoptera	Coccinellidae	*Coccinella transversalis* (Fabricius)	Predatory
		Adalia bipunctata (Linnaeus)	beetles
	Melyridae	*Dicranolauis bellulus* (Guerin-Meneville)	
Hemiptera	Nabidae	*Nabis capsiformis* (Germar)	Predatory
	Lygaeidae	*Geocoris lubra* (Kirkaldy)	bugs
	Pentatomidae	*Cermatulus nasalis* (Westwood)	
		Ochelià schellenbergii (Guerin-Meneville)	
	Reduviidae	*Coranus triabeatus* (Horvath)	
Neuroptera	Chrysopidae	*Chrysopa* spp.	Predatory
	Hemerobiidae	*Micromus tasmaniae* (Walker)	lacewings
Araneida	Lycosidae	*Lycosa* spp.	Spiders
	Oxyopidae	*Oxyopes* spp.	
	Salticidae	*Salticidae* spp.	
	Araneidae	*Araneus* spp.	

STAGE 7 IPM SYSTEM COMPARED IN 1997-98 SEASON

Following the results of the stage 6 trials, an Envirofeast IPM strategy consisting of Envirofeast® sprays, lucerne refuge crops, gemstar virus and synthetic insecticides was selected and evaluated on large scale commercial Ingard and normal cotton crops. This was compared with Ingard and normal cotton crops with no Envirofeast spray but managed with gemstar virus and insecticides when the predator to prey threshold was exceeded (control) and also cotton crops managed with synthetic insecticides under the current Insecticide Resistance Management Strategy. The trials were established at Yarral in Narrabri, Norwood near Moree, Bellevue near Warren and ACRI. The cotton crops at each trial site were interplanted with lucerne 12 metres wide and 300 metres apart. The size of the trial at Yarral was 50 ha; Norwood was 170 ha; Bellevue, 132 ha and ACRI, 2 ha. The treatments evaluated at these sites are summarised in table 4.

The Envirofeast IPM plots were initially sprayed with Envirofeast® and when the predator to prey (*Helicoverpa* spp.) ratio fell below 0.5 (recommended action threshold for Envirofeast® IPM reported elsewhere in this proceedings), the plot was treated first with Gemstar virus and selective insecticides as required by the Envirofeast® IPM guidelines.

When all the beneficial insect populations in the lucerne refuge crops were exterminated the plot were sprayed with insecticides when the threshold is exceeded. The no Envirofeast plot though was located in the Envirofeast IPM block, it received no Envirofeast but insecticide sprays when the threshold was exceeded. The number of insecticide saved or replaced by biological insecticide was recorded so was the cotton yields harvested from the treated plots. Yields were measured after harvesting the bulk area of each treatment.

TABLE 4: SUMMARY OF STAGE 7 IPM TREATMENTS COMPARED AT YARRAL, NORWOOD, BELLEVUE AND ACRI, 1997-98.

Treatments	Features
1. Sicala V2 + Lucerne strips + Envirofeast® + Envirofeast/Gemstar virus + insecticides	Normal leaf cotton with lucerne strips and managed with predator food attractant, Gemstar virus and synthetic insecticides
2. Sicala V2 (Ingard) + Lucerne strips + Envirofeast®+ Envirofeast/virus + synthetic insecticides	Normal leaf (Ingard) cotton with lucerne strips and managed with predator food attractant, Gemstar virus and insecticides.
3. Sicala V2 + Lucerne strips + Gemstar virus + insecticides (No Envirofeast)(Control)	Normal leaf cotton managed with Gemstar virus and synthetic insecticides.
4. Sicala V2 (Ingard) + Lucerne strips + Gemstar virus + insecticides (No Envirofeast)(Control)	Normal leaf (Ingard) cotton managed with Gemstar virus and synthetic insecticides.
5. Sicala V2 + insecticides (Conventional cotton)	Normal leaf cotton managed with conventional insecticides under the Insecticide Resistance Management Strategy.
6. Sicala V2 (Ingard) + insecticides (Conventional Ingard)	Normal leaf (Ingard) cotton managed with conventional insecticides under the TIMS Committee Ingard Management Plan.

RESULTS OF STAGE 7 IPM TRIALS AT BELLEVUE, YARRAL, NORWOOD AND ACRI, 1997-98

A huge amount of data on pests, beneficial insects and yield have been collected throughout the season. Most of the data on pests and beneficial insects have not been analysed with the exception of the Yarral trials and the cotton yield data for all the sites. We have summarised the data on yield and the number of insecticide sprays in each treatment which is a reflection of the levels of pest management in the Envirofeast IPM and conventional cotton treatments (Table 5). The results showed that the number of synthetic insecticides used on normal cotton crops managed with Envirofeast IPM was reduced by 57, 42.8, 37.5 and 75 per cent at Bellevue, Yarral, Norwood and ACRI respectively without any yield loss (Table 5). Similarly, Ingard cotton managed with Envirofeast IPM received lower synthetic insecticide sprays than those managed with conventional insecticides with no yield loss (Table 5). There was a reduction of 60 to 67 per cent of insecticide sprays when the Ingard crop was managed with Envirofeast IPM (Table 5).

When the normal cotton crops were managed with IPM tools other than Envirofeast the cotton crops suffered a yield loss of 0.50 bales per acre at Bellevue, 1.4 bales at Yarral, 1.22 bales at Norwood and 0.80 bales at ACRI (Table 5). In Ingard cotton trials, there was a yield loss of 0.50 bales per acre at Bellevue, 0.40 bales at Yarral, 0.30 bales at ACRI but Norwood there was a yield gain of 0.52 bales (Table 5). The reason for the gain of 0.52 bales of no Envirofeast treated Ingard over Envirofeast treated Ingard at Norwood was that we delayed the first application of Envirofeast® on the Ingard which was not the normal strategy used in the other sites because the efficacy of the Ingard was enough to prevent damage. It was only when the first signs of damage was realised that we decided to put the Envirofeast sprays on. Apart from the reduction in synthetic insecticide sprays on cotton crops managed with Envirofeast IPM, the biological insecticides in the IPM reduced the use of endosulfan by 50% at Yarral and 67% at ACRI. At Norwood no endosulfan was used on the Envirofeast IPM plots at all indicating a 100% reduction. The replacement of endosulfan sprays especially early season is very important to the cotton industry considering the industry's focus on limited use of endosulfan in line with NRA position on the chemical.

In terms of green mirids at the Yarral trial site, the Envirofeast IPM managed cotton crops and no Envirofeast® treated plots which were interplanted with lucerne had fewer mirids than the conventional insecticide managed crops (Figure 1). The conventional cotton crops were sprayed against green mirids on 2 January but there was no green mirid sprays on either the Envirofeast IPM managed or no Envirofeast treated crops. The lucerne strips served as sinks for the green mirids preventing them from moving into the cotton.

Beneficial insect numbers per metre viz; predatory beetles, bugs and lacewings were highest in the Envirofeast IPM treated plots than the no Envirofeast and conventional crops (Fig 2). In contrast, number of spiders per metre were highest in the Envirofeast IPM on normal cotton and no Envirofeast treated plots than the Envirofeast IPM on Ingard and conventional cotton crops (Fig 3.).

Helicoverpa spp. numbers are summarized for Ingard and normal cotton in Figs 4 and 5. The most interesting results to note are the dates of appearance of medium and large larvae on the Envirofeast IPM managed Ingard cotton and conventional insecticide managed Ingard cotton (Fig. 4). The results showed that medium and large *Helicoverpa* larvae were recorded on the conventional Ingard crop on 2 January 1998 and on the Envirofeast IPM Ingard crop on 13 January. Also, application of the first insecticide spray against *Helicoverpa* spp. occurred in the conventional insecticide managed Ingard on the 12 January 1998 whereas on Envirofeast IPM managed Ingard, the first insecticide spray was applied on the 28 January 1998. Until this date, Envirofeast was the only product applied to the

Envirofeast IPM Ingard indicating that beneficial insects together with the efficacy of the Ingard crop were managing the *Helicoverpa* spp. population.

TABLE 5: SUMMARY OF YIELDS (BALES/ACRE) AND SPRAYS USED IN IPM TRIALS AT BELLEVUE (B*), YARRAL (Y*), NORWOOD (N*) AND ACRI (A*), 1997-98.

Treatments	No. of Envirofeast sprays	No. of Envirofeast +virus sprays	No of selective insecticides	Synthetic insecticide sprays	Yields (bales/acre)
1. Sicala V2 + Lucerne strips	B*= 3	3	2	1	3.50
+ Envirofeast® + Envirofeast/	Y*= 3	2	2	2	4.60
Gemstar virus+ insecticides	N*= 2	3	0	5	4.51
	A*= 3	1	1	1	3.80
2. Sicala V2 (Ingard) + Lucerne	B*= 5	1	2	0	3.70
+ Envirofeast®+ Envirofeast/	Y*= 6	0	1	1	4.40
virus + synthetic insecticides	N*= 3	1	0	5	3.29
	A*= 3	1	1	1	3.60
3. Sicala V2 + Lucerne strips	B*= 0	3	2	1	3.00
+ Gemstar Virus + insecticides	Y*= 0	2	2	2	3.20
(No Envirofeast)(Control)	N*= 0	1	4	4	2.66
	A*= 0	1	1	1	3.00
4. Sicala V2 (Ingard) + Lucerne	B*= 0	1	2	0	3.20
strips + Virus + insecticides	Y*= 0	0	1	1	4.00
(No Envirofeast)(Control)	N*= 0	0	4	4	3.81
	A*= 0	1	1	1	3.30
5. Sicala V2 + insecticides	B*= 0	0	2	5	3.40
(Conventional cotton)	Y*= 0	0	4	3	3.70
	N*= 0	0	4	4	3.77
	A*= 0	0	3	5	3.50
6. Sicala V2 (Ingard) +	B*= No conventional trials at this site				
insecticides	Y*= 0	0	2	3	3.60
(Conventional Ingard)	N*= 0	0	1	6	3.79
	A*= No conventional trials at this site				

GENERAL DISCUSSIONS

The results of this study clearly showed that the Envirofeast IPM program can effectively managed cotton pests to achieve cotton yields similar to or sometimes higher than conventional insecticides. The development of Envirofeast IPM program commenced in 1992 with cotton yields of 1.2 bales per acre. Further development has continued and we are currently in stage 7 where yields from cotton crops managed with the Envirofeast IPM in commercial trials have equalled those managed with conventional insecticides under the Insecticide Resistance Management Strategy. Each of the tools in the IPM program has been tested and shown to have an important role to play. It has been shown in 1992-93 trials at Auscott in Narrabri (Field 18) and Norwood near Moree (Field 20) that cotton crops sprayed with Envirofeast® product alone yielded 2.5 times more cotton than unsprayed cotton crops of similar size. This yield difference masy depend on the season, *Helicoverpa* spp. pressure and the beneficial insects population.

This study has also showed that cotton crops managed with IPM tools without Envirofeast® had a yield loss of between 0.5 to 1.4 bales per acre. Apart from this, Envirofeast® spray also replaced some of the synthetic insecticides used in early and mid seasons for *Helicoverpa* spp. control. Together with the other tools an average of 63.5% of synthetic insecticides were replaced with biological sprays and in some instances most of them were saved. Also about 50-60% of endosulfan use was replaced with biological sprays. This is important considering the cotton industry's push for limited use of endosulfan in line with NRA position on the product. The lucerne strips within the Envirofeast IPM strategy managed green mirids (Mensah and Khan, 1997) and served as a refugia to conserve beneficial insects in cotton (Mensah, 1997, 1998). Most of the cotton farms have no natural refuge for beneficial insects to overwinter. In areas where there are natural refuges around the crops, the beneficial insect populations are affected by the activities of your neighbour in terms of insecticide use against *Helicoverpa* spp. The lucerne strip in your farm enables you to hang onto these insects for some time before you lose them.

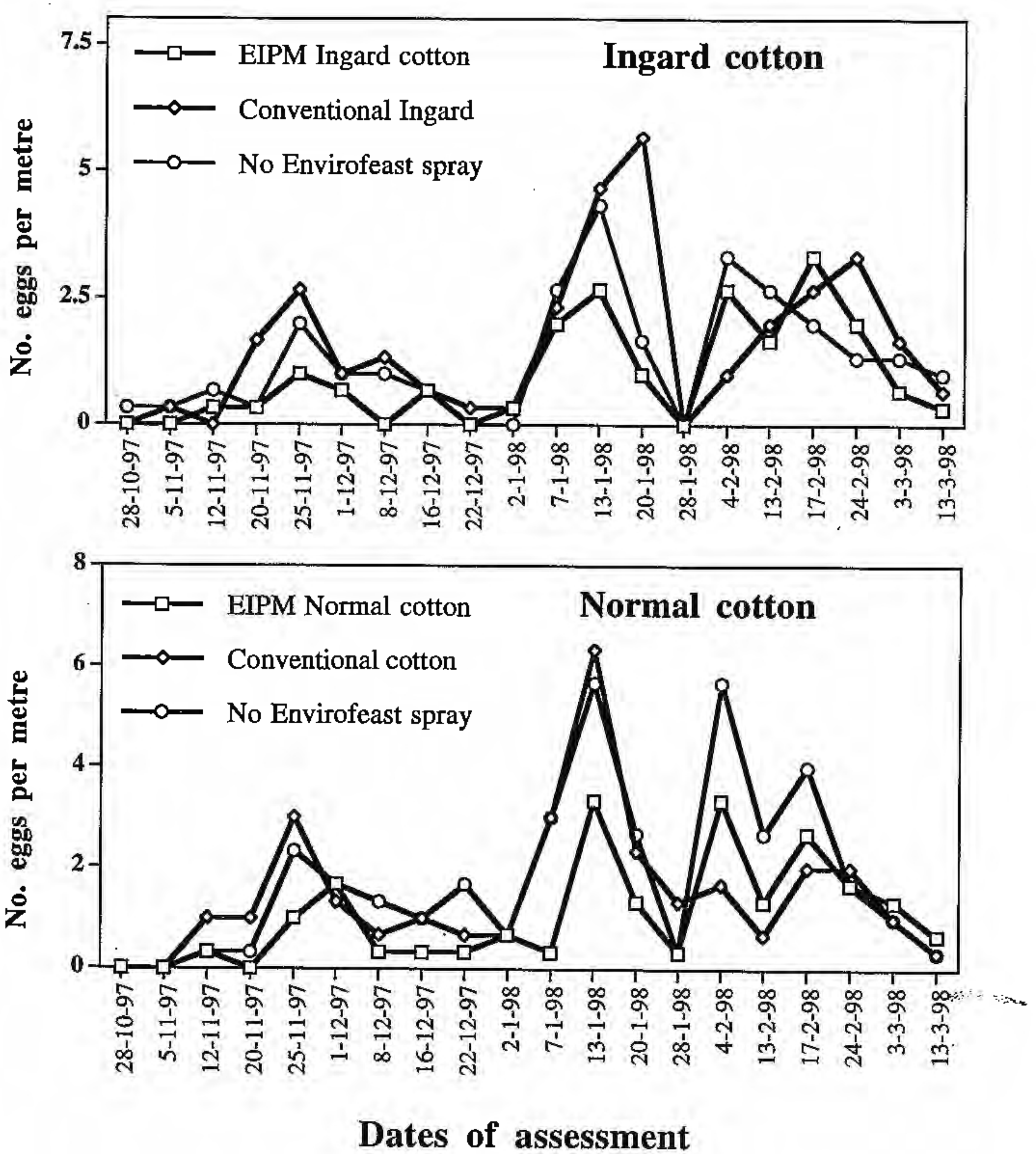
The use of Envirofeast IPM on Ingard cotton reduced synthetic insecticides use drastically. It also enhances the efficacy of the Ingard crops by increasing the activity of the beneficial insects and exposing *Helicoverpa* spp. neonates to multiple mechanisms to die instead of a single mechanism i.e. the Ingard crop. In doing this the IPM strategy is in some way enhancing the durability of the transgenic plants. On normal cotton the Envirofeast IPM is reducing resistance as a result of the reduction in total synthetic insecticide use.

To achieve good results with Envirofeast IPM, it should be used in areas free from insecticides. This can be acheived if farm neighbours come together to form a regional or area wide group and use the strategy. By using it as an area-wide or regional base IPM strategy the effect of synthetic insecticides will be minimised enabling the IPM strategy to succeed. Therefore area-wide or regional based Envirofeast IPM program can be more successful than an individual user within neighbours managing their cotton with synthetic insecticides. Envirofeast IPM users should avoid panic spraying which usually comes about when they use Envirofeast as one of the insecticides and expect *Helicoverpa* spp. larvae to disappear overnight. Envirofeast® product cannot kill an ant. It is a product designed to conserve beneficial insects and the decision to intervene with insecticides within the IPM program is explained in the Envirofeast IPM guidelines and this is based on the predator to *Helicoverpa* spp.(Heliothis) ratio which is calculated from your regular insect sampling or bug checking. Guidelines for use of Envirofeast IPM is available to growers from the Technology Resource Centre at ACRI and Rhone-Poulenc representatives. Envirofeast IPM in my view will work for farmers who does not panic spray, spend time to check their farms correctly and applying the sprays at the right time they need to.

In conclusion, I would like growers to understand that the insects are becoming harder to kill, the old method of spray and kill under the Insecticide Resistance Strategy has curtail resistance for a while but has not reduced insecticide use. For the future sustainability of the cotton industry there should be a change and Envirofeast IPM could be an option or a platform for the development of "big picture IPM" or best pest management practice for the cotton industry.

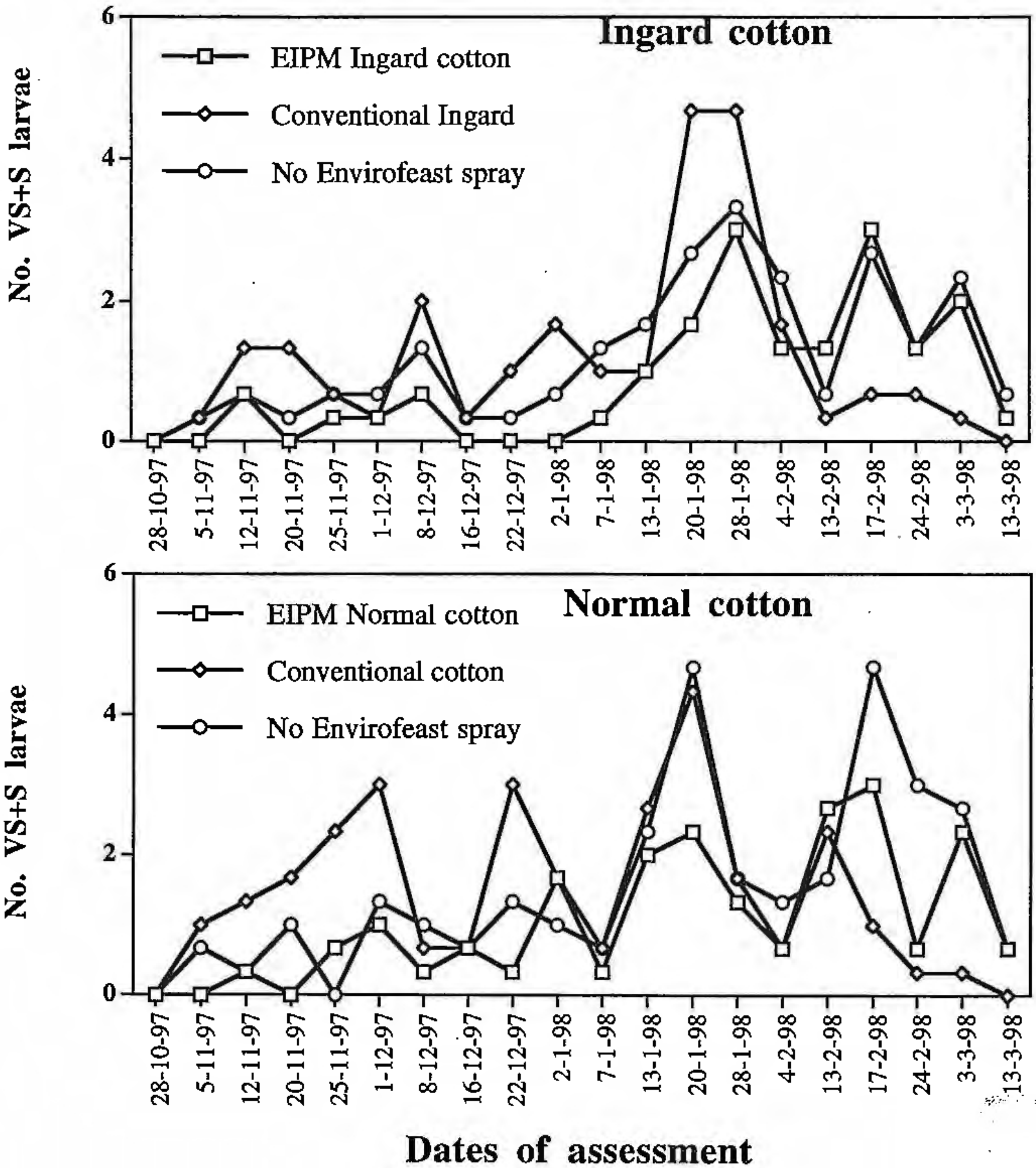
Envirofeast IPM and Conventional:

Number of Eggs per metre, Yarral 1997-98.



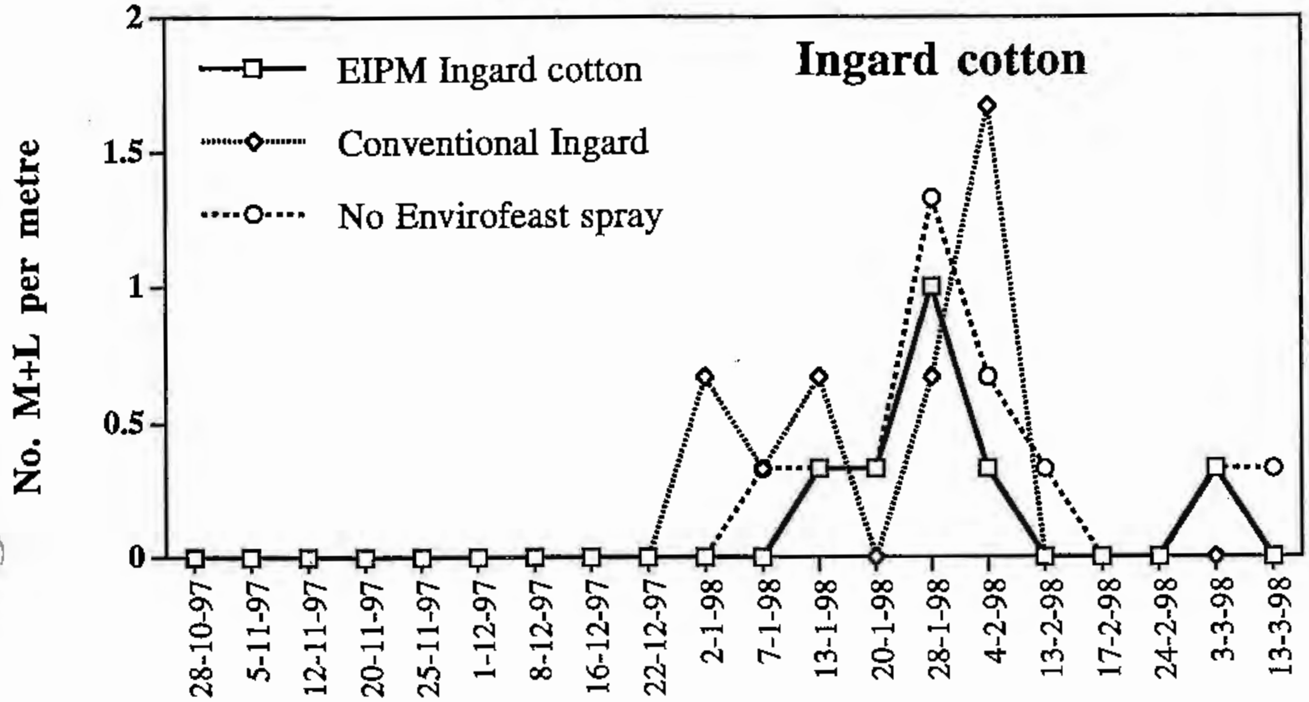
Envirofeast IPM and Conventional:

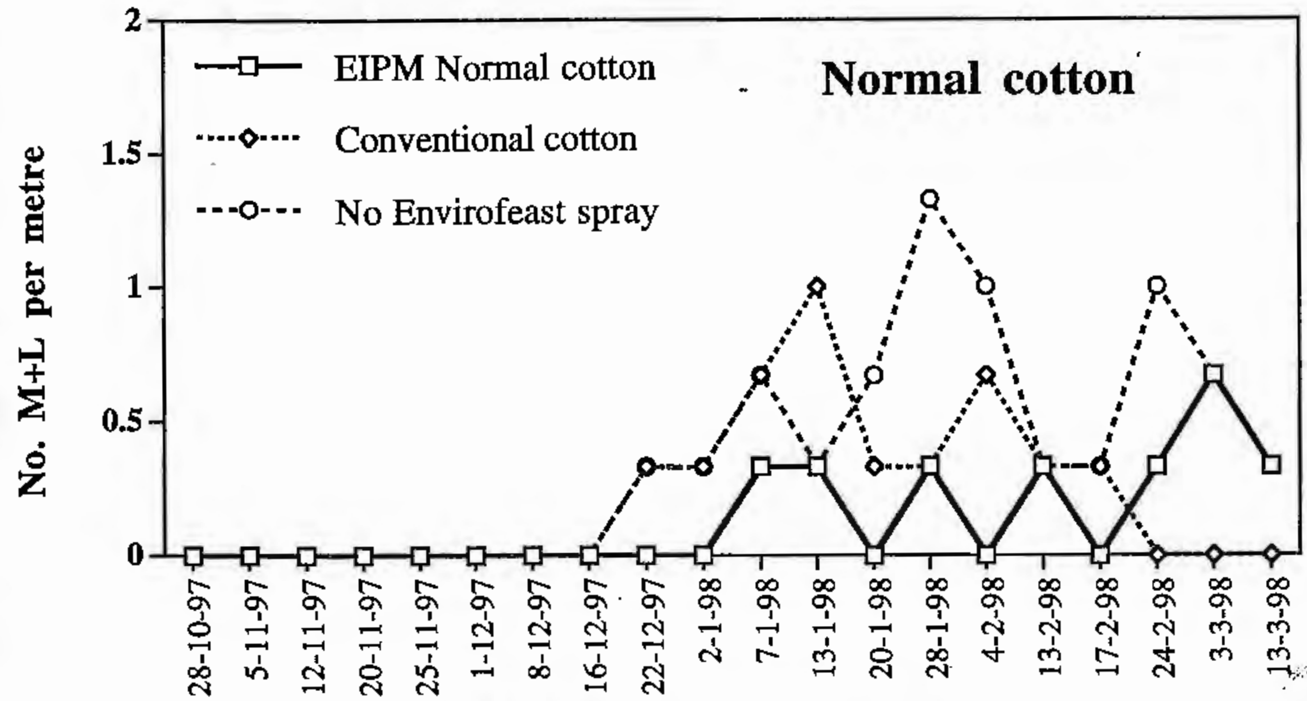
Number of VS + S larvae, Yarral, 1997-98



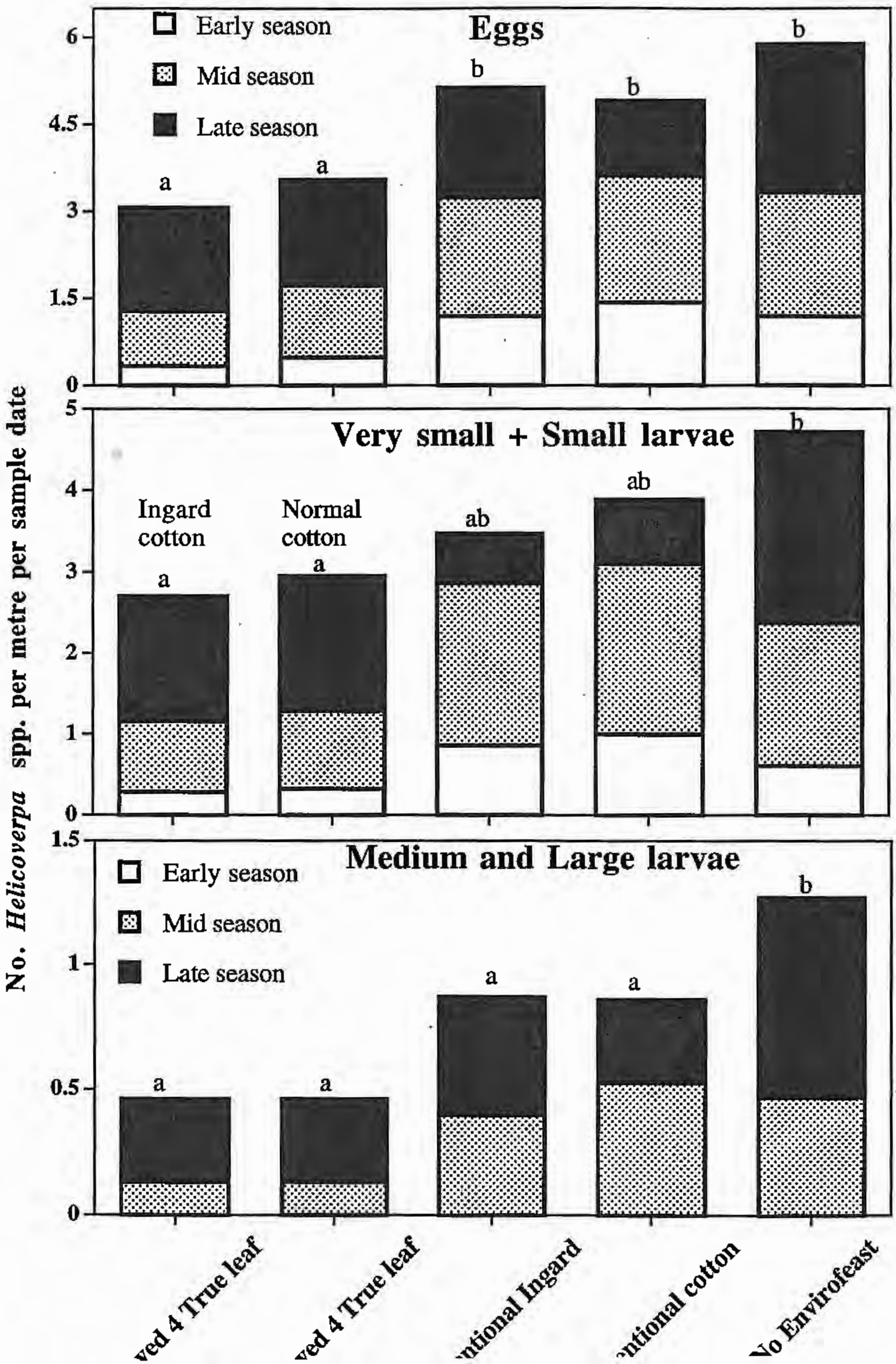
Envirofeast IPM and Conventional:

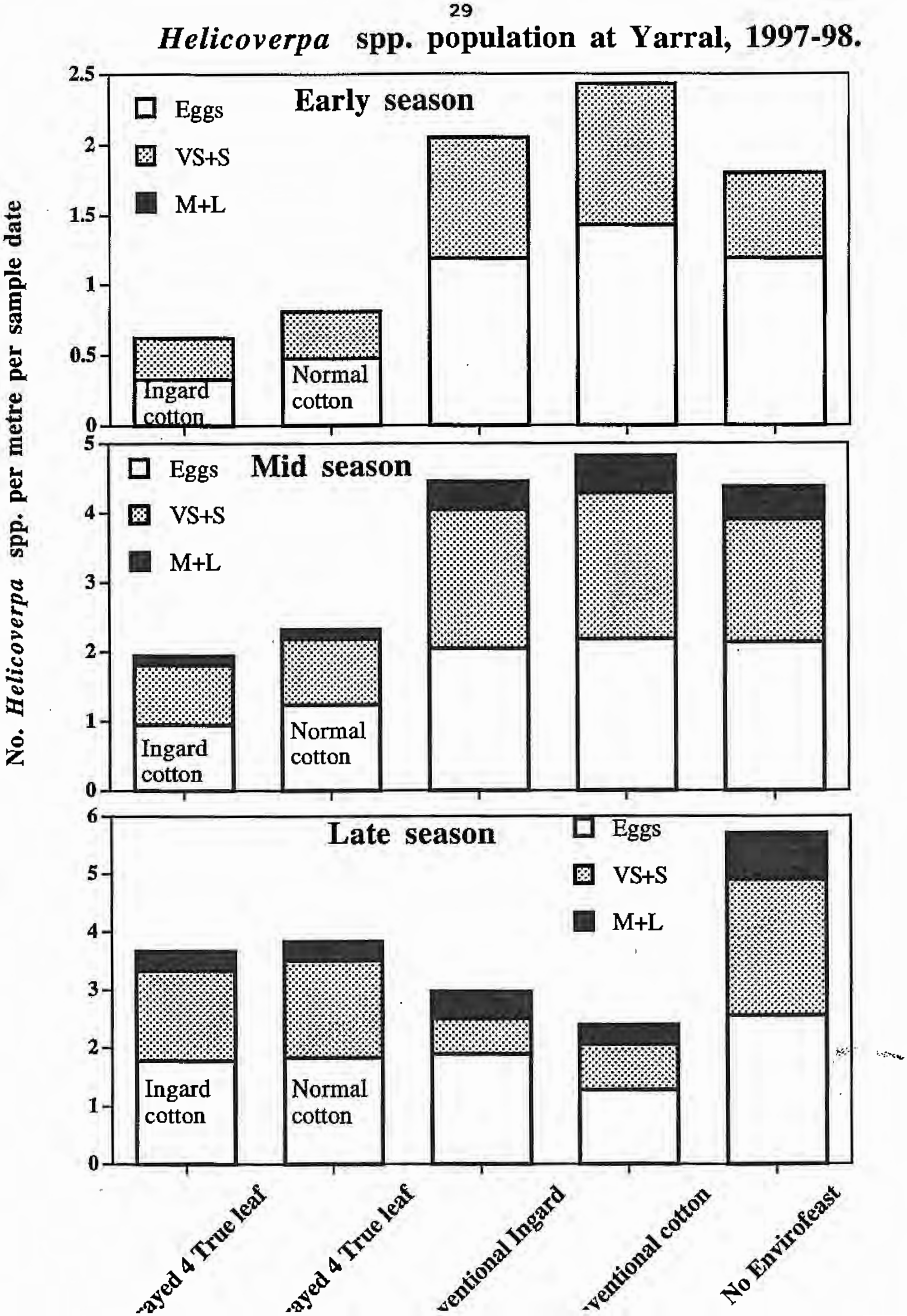
Number of Medium and Large per metre



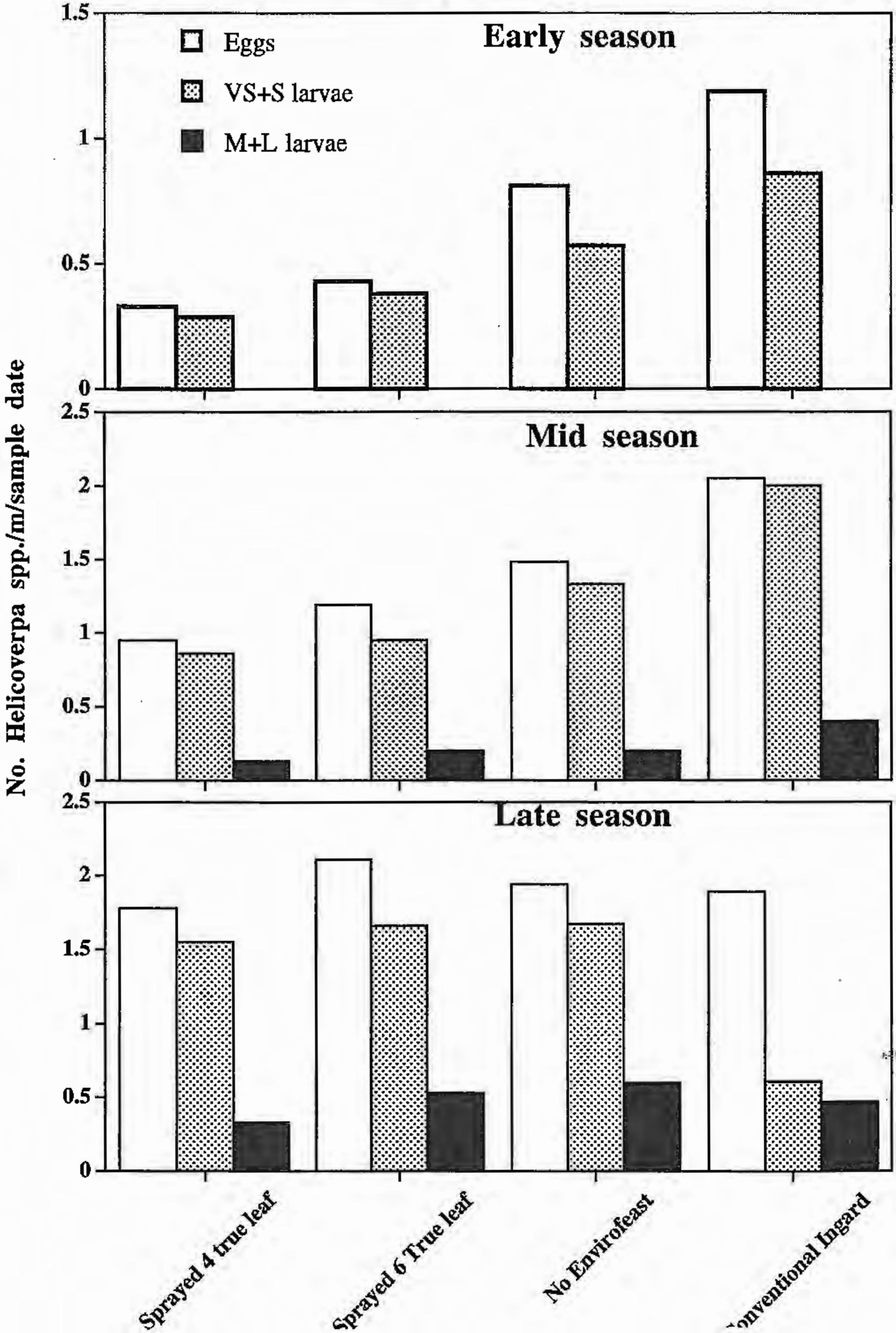


Dates of assessment

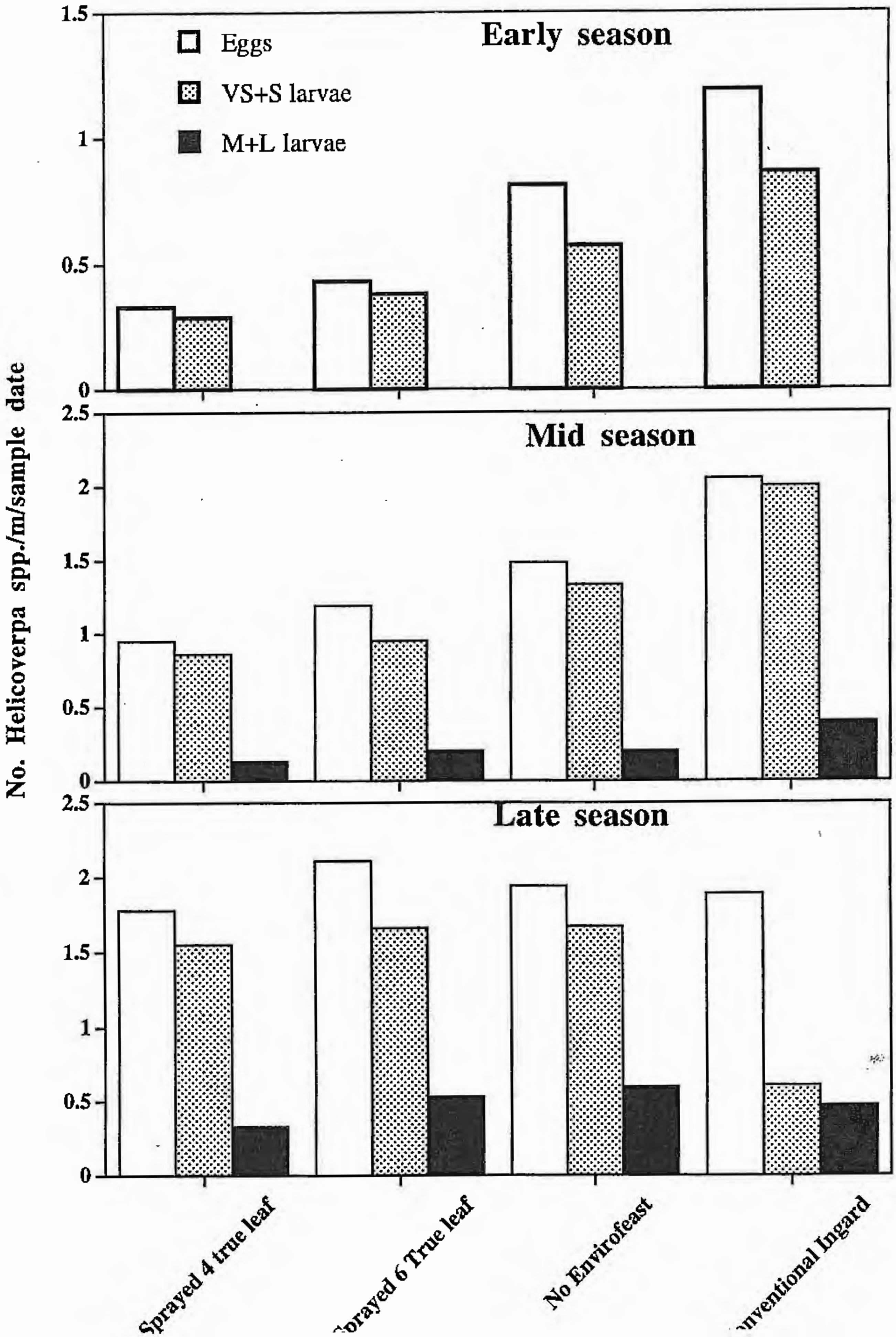

Eggs
Early season
Mid season
Late season
a
a
b
b
b
Very small + Small larvae
Ingard cotton
Normal cotton
a
a
ab
ab
b
Medium and Large larvae
Early season
Mid season
Late season
a
a
a
a
b
No. Helicoverpa spp. per metre per sample date
6
4.5
3
1.5
0
5
4
3
2
1
0
1.5
1
0.5
0
ved 4 True leaf
ved 4 True leaf
ntional Ingard
ntional cotton
No Envirofeast


Helicoverpa spp. population at Yarral, 1997-98.
No. Helicoverpa spp. per metre per sample date
Early season
Eggs
VS+S
M+L
Ingard cotton
Normal cotton
Mid season
Eggs
VS+S
M+L
Ingard cotton
Normal cotton
Late season
Eggs
VS+S
M+L
Ingard cotton
Normal cotton
ayed 4 True leaf
ayed 4 True leaf
ventional Ingard
ventional cotton
No Envirofeast

Numbers of *Helicoverpa* spp. per metre per sample date



Numbers of *Helicoverpa* spp. per metre per sample date



Habitat diversity: Implications for the conservation and use of predatory insects of *Helicoverpa* spp. in cotton systems in Australia

(*KEY-WORDS*: *Helianthus annuus*, *Carthamus tinctorius*, *Sorghum bicolor*, *Medicago sativa*, *Lycopersicon esculentum*, predators, monoculture, habitat, diversity, insect conservation)

R. K. MENSAH
NSW Agriculture, Australian Cotton Research Institute, PMB Myall Vale Narrabri, NSW 2390, Australia

Abstract. Adoption of within-field monocultures of annual crops in modern farming systems is known to discriminate against and reduce the activity of predatory insects. In Australia, cotton fields are strictly monoculture and lack ecological diversity. This lack of diversity could be the major cause of pest problems in these agroecosystems. The utility of crops such as sunflower (*Helianthus annuus*), safflower (*Carthamus tinctorius*), sorghum (*Sorghum bicolor*), lucerne (*Medicago sativa*) and tomato (*Lycopersicon esculentum*) as refugia for predatory insects of *Helicoverpa* spp. when they were planted as strips in cotton fields was evaluated from 1993-1995. Densities of beneficial insects, mainly predatory beetles, bugs and lacewings, were higher in lucerne crops than any other crop tested. In an experiment where lucerne was planted in strips within commercial cotton, the number of predators was highest in the lucerne strip and declined with increasing distance from the lucerne strip to reach their lowest level 300 m away in the cotton crop. At the end of the study, 7.1, 6.1, 5.8 and 1.5 times more predatory beetles, bugs, lacewings and spiders per metre row respectively were recorded on the lucerne strips than on cotton. When lucerne was interplanted with commercial cotton to compare densities of predators on cotton with and without lucerne strips, 2.1, 2.5 and 1.2 times more predators were recorded on cotton with lucerne strips than cotton without lucerne strips. This indicated that the lucerne strips can serve as a refugia for predators which can then be moved into cotton fields. This study supports the findings of previous researchers that increased habitat diversity in monocultural crops by strip-cropping can increase population density of indigenous predators.

1. Introduction

Cotton crops (*Gossypium hirsutum*) in many parts of the world are attacked by a wide range of insect pests, the major ones being *Helicoverpa* spp. (Hardwick, 1965; Fitt, 1989). The management of these pests depends almost exclusively on synthetic insecticides; natural enemies of the pests are neglected due to lack of techniques to maximise their abundance and effectiveness. Modern farming systems which rely on within-field monocultures also discriminate against and reduce the activity of predatory insects because they lack ecological diversity (Hagen and Hale, 1974). Increased habitat diversity of crop systems through strip cropping is known to conserve and enhance the efficacy of natural enemies of crop pests by providing food sources for adults, alternative prey at times of scarcity, and shelter for overwintering or for unfavourable situations within the crop system (De Loach, 1971; Hagen and Hale, 1974).

In Australia, cotton fields are strictly monoculture, and the lack of ecological diversity could be the major cause of pest problems because the food, hosts, prey, and hibernating or overwintering sites of most of the natural enemies of the pests are reduced thereby limiting natural biological control (Beirne, 1967; De Loach, 1971; Hagen and Hale, 1974). This can result in pest outbreaks, because abundant food is available to the pest and they need not waste time searching for food or a mate or unduly expose themselves to their natural enemies (Beirne, 1967; Hagen and Hale, 1974). *Helicoverpa* spp., which are the major pests of cotton crops in Australia, are highly migratory and can therefore rapidly infest cotton crops and lay their eggs. Unless natural enemies are present and well established in high numbers before the pests arrive, they cannot respond rapidly enough to control them (Fitt, 1989; Mensah and Harris, 1994, 1995).

The development of a strategy that may conserve and maximise the abundance and effectiveness of natural enemies of *Helicoverpa* spp. in cotton fields will be crucial to enhance the control of these pests. There are many examples to show that increased habitat diversity in crops can increase population densities of indigenous predators to enhance biological control of pests on different crops ((Risch *et al.*, 1983; Herzog and Funderburk, 1989; Russell, 1989; Andow, 1991; Bugg *et al.*, 1987; Fye, 1972; Corbitt, 1991; Wetzler and Risch, 1984; DeLoach, 1971; Southwood and Way, 1970; Pimentel, 1971; Hagen and Hale, 1974; Van Emden and Williams, 1974; Andow and Risch, 1985; Van Leteren, 1987; Van Emden, 1990; Mensah and Madden, 1994; Way and Heong, 1994; Conlong, 1990, 1994, 1995; Mensah and Khan, 1997). However in Australia, no definitive studies have been undertaken to determine if.increased habitat diversity in and around cotton fields would conserve and maximise the abundance of populations of natural enemies of *Helicoverpa* spp.

The aim of this study was to quantify the impact of habitat diversity by strip-cropping on the abundance of natural enemies of *Helicoverpa* spp. in cotton fields as a step towards the development of strategies to conserve and establish these natural enemies in cotton fields early in the cotton season before the pest arrive. Specifically the objectives were to: (1) evaluate the utility of locally grown alternative crops as refugia for predatory insects of *Helicoverpa* spp. in cotton, (2) determine the best refuge crop for strip-cropping, and (3) determine whether the abundance of natural enemies in commercial cotton fields are greater with strip-cropping present than it would be without it.

2. Materials and methods

2.1. Responses of predatory insects to different alternative crops interplanted in cotton

The study was conducted on a 3 ha irrigated cotton field at the Australian Cotton Research Institute (ACRI)(30^{o} 13'S, 149^{o} 47'E) at Narrabri, New South Wales between September 1993 and April 1994. The alternative crops evaluated were sunflower (*Helianthus annuus* L.), safflower (*Carthamus tinctorius* L.), sorghum (*Sorghum bicolor* L.), lucerne (*Medicago sativa* L.), tomato (*Lycopersicon esculentum* Miller) and cotton. Most of these crops are grown in monoculture in the district. Each of the crops was planted in strips, 8 m (or rows) wide and 100 m long adjacent to and separated by cotton strips 20 m (or rows) wide and 100 m long. In total three strips of each crop were planted across the cotton field. The alternative crops were planted on 5 September 1993 and cotton was planted on 10 October 1993. All crops were irrigated at the same time as cotton; irrigation depended on the soil moisture level.

Predatory insects were sampled from each crop once every week from 3 November 1993 to 11 March 1994 by using a small portable suction sampler, D-vac (Homelite Textron Inc., NC, USA). On each sample date, one sample was taken from each crop strip. The D-vac has a 120 mm diameter cone and a nozzle speed of approximately 10 m per second. A gauze bag (25 cm deep) was inserted into the suction tube to collect insects sucked from the plants. The sample was collected from a single pass of the tube of the vacuum sampler along the tops of the plants in 20 metre of row. After each sampling, the contents of the D-vac were transferred to a plastic bag, chilled, taken to the laboratory, and frozen until the contents were counted and identified.

2.2. *Effect of lucerne strips on numbers of predatory insects on adjacent cotton fields*

Following the results of the above experiment, a study was conducted within lucerne/cotton interplants to determine whether the lucerne strip within the cotton crop is acting as a sink or source of predatory insects to cotton. Experiments were conducted in irrigated cotton fields at Auscott in Narrabri in New South Wales (30° 13'S, 149° 47'E). Lucerne strips 12 m wide and 710 m long, were planted as borders to sandwich 89 ha of cotton. This was repeated 4 times in four cotton fields. One half of the lucerne strips (4 m wide) was slashed alternately every 4 weeks to stimulate new growth and prevent the lucerne from haying or drying off (Mensah and Harris, 1995; Mensah and Khan, 1997).

Predatory insects were sampled weekly from 2 November 1993 to 2 January 1994 by taking a 20 m row vacuum sample from cotton, as previously described at 10, 50, 100, 200 and 300 m away from the edge of the lucerne strip. A sample was also taken in the lucerne at the same time. These were repeated 4 times at each distance. The predators were separated into predatory beetles, bugs, lacewings and spiders and data expressed as numbers per metre per sample date.

2.3. *Abundance of populations of predatory insects in lucerne/cotton interplant*

Based on the results of the above experiments, an experiment was conducted on lucerne/cotton interplants on a 170 ha commercial irrigated cotton field at Alcheringa near Boggabilla (29° 36', 150° 20') in New South Wales in the 1994-95 season. The goal of the study was to determine whether planting lucerne as strips within commercial cotton can conserve predatory insects within the agroecosystem. Lucerne strips 12 m (or rows) wide and 900 m long, were planted in cotton. For every 300 m (or rows) of cotton, one strip of lucerne was planted; this was repeated six times across the field. The lucerne was planted on 7 September 1994 and cotton on 15 October 1994. The lucerne strips were irrigated at the same time as cotton, depending on the soil moisture level. Alternate 6 m wide bands of each lucerne strip were slashed every 4 weeks and the slashings baled as hay. The 4-week slashing sequence stimulates new growth and prevents the lucerne from haying or drying off before the end of the study (i.e. end of the cotton season) (Mensah and Khan, 1997).

Predatory insects of *Helicoverpa* spp. were sampled weekly from 11 November 1994 to 16 January 1995 by taking a 20 m row vacuum sample from lucerne and cotton plants as previously described.

2.4. Comparison of numbers of predatory insects on 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 from 30 October 1995 to 20 December 1995. The sizes of the two cotton fields were 53 ha (field 9) and 60 ha (field 16), respectively, and they were adjacent to each other, separated by 30 m natural vegetation. In the first field (field 9), lucerne strips 12 m (or rows) wide and 709 m long; were planted within the cotton. For every 300 m (or rows) of cotton, one strip of lucerne was planted. In total, six lucerne strips wewre planted across the field. Alternate 6 m wide bands of each lucerne strip were slashed every 4 weeks to stimulate growth and prevent the lucerne from drying off. The second field (field 16) had no lucerne planted within the cotton; the field was divided into six subplots (2a, 2b, 2c, 2d, 2e and 2f), and each subplot (10 ha cotton) was considered as cotton without lucerne strips. The two fields (fields 9 and 16) were left unsprayed with synthetic insecticide until after the early cotton season (i.e. 20 December 1995), when field 16 was sprayed with synthetic insecticides to prevent crop damage by *Helicoverpa* spp. and *Creontiades dilutus* and this resulted in the termination of the trials.

Predatory insects were sampled from 30 October 1995 to 13 December 1995 by taking a 20 m row vacuum sample, as previously described, separately from each of the six lucerne strips and the cotton in field 9 and also from each of the subplots in field 16.

2.5. 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 = log (X+1). Treatment and sample dates were the independent variables. Tukey-Kramer Multiple Comparisons tests were used to separate means. Arithmetic rather than transformed means are given in the text.

3 Results

3.1. Responses of predatory insects to different alternative crops interplanted in cotton

Predators of *Helicoverpa* spp. identified from the study plots are given in Table 1. Significant differences ($P<0.001$) in numbers of predators were found among the crops tested (Figs 1 - 3). Significantly higher ($P<0.001$) numbers of predatory beetles were found on lucerne than any of the crops with the exception of *Adalia bipunctata* (Fabricius) where numbers recorded on the lucerne crops were the same as those on sunflower, safflower and sorghum (Fig. 1). The lowest numbers of predatory beetles were recorded on cotton and tomato crops (Fig. 1). Among the predatory bugs sampled, *Geocoris lubra* (Kirkaldy), *Nabis capsiformis* (Germar) and *Cermatulus nasalis* (Westwood) were most abundant on lucerne, whereas *Oechalia schellenbergii* (Guerin-Meneville) and *Coramus triabeatus* (Horvath) were more abundant on safflower and sunflower respectively (Fig. 2). There were greater numbers of predatory lacewings on safflower, and the highest numbers of spiders were recorded on lucerne crops (Fig. 3). Overall, more predators were recorded on the lucerne crop than any of the crops (Figs. 1-3).

3.2. Effect of lucerne strips on numbers of predatory insects on adjacent cotton

Populations of predatory beetles, bugs and lacewings recorded on the lucerne strips were significantly higher ($P<0.001$) than on the adjacent cotton and seemed to decline with increasing distance from the lucerne strip to reach their lowest level 300 m away (Fig. 4). A similar trend was shown by spiders, but numbers recorded on the lucerne strips and the cotton crops 50 m away were not significantly different ($P>0.05$) (Fig. 4). In general, the predator numbers recorded on cotton at different distances away from the lucerne strip were lower and not significantly different ($P>0.05$) from each other with the exception of the predatory bugs and spiders, indicating that the lucerne strip with higher number of predators was acting as a reserviour or refugia to conserve the insects (Fig. 4).

3.3. Abundance of populations of predatory insects in lucerne/cotton interplant

Predatory beetles, bugs and lacewings were more abundant on lucerne than cotton with the exception of spiders where populations on both crops were the same (Fig. 5). Predatory beetle numbers recorded on lucerne from 25 November 1994 until 6 January 1995 were significantly higher ($P<0.01$) than cotton, but after 6 January numbers on both crops were not significantly different ($P>0.05$) (Fig. 5). Populations of predatory bugs were higher on lucerne than cotton from 11 November through to 16 December and again from 23 December until 6 January 1996, thereafter populations on both crops were not significantly different ($P>0.05$)(Fig. 5). Predatory lacewing numbers were significantly higher ($P<0.05$) on lucerne than on cotton on all the sample dates with the exception of 28 November, 23 December, 29 December and 6 January where the lacewing numbers recorded on both crops were not significantly different (P>0.05) (Fig. 5). In contrast, numbers of spiders recorded on both lucerne and cotton were not significantly different (P>0.05) on most of the sampling dates with the exception of 25, 28 November and 5th December when spider numbers were significantly different (P<0.05). At the end of the study 7.1, 6.1, 5.8 and 1.5 times more predatory beetles, bugs, lacewings and spiders per metre row respectively were recorded on lucerne strips than on cotton (Fig. 5).

3.4. Comparison of numbers of predatory insects on cotton crops with and without interplanted lucerne

Significant diferences (P<0.01), with the exception of spiders, were found between the numbers of predatory beetles, bugs and lacewings recorded on cotton with and without lucerne strips (Fig. 6). The highest numbers of predatory beetles, bugs and lacewings were recorded on the lucerne strips, followed by cotton with lucerne strips with the least on cotton without lucerne strips (Fig. 6). In contrast, the number of spiders recorded from the lucerne strips and cotton with and without lucerne strips were not significantly different (P>0.05) (Fig. 6). At the end of the study 2.1, 2.5 and 1.2 times more predatory beetles, bugs and lacewings per metre row respectively, were recorded on cotton with lucerne strips, in comparison with cotton without lucerne strips. Also, within the lucerne/cotton interplanting, 1.7, 2.2 and 2.4 times predatory beetles, bugs and lacewings per metre row respectively, were recorded on the lucerne strips compared with the cotton.

4. Discussion

The study clearly showed that interplanting lucerne in cotton fields by strip-cropping can conserve and increase the densities of predatory insects of *Helicoverpa* spp. in cotton.

In an experiment where lucerne was planted within cotton field as strips, the densities of predators were higher in the lucerne crop than in cotton. In another study where lucerne was planted as borders to cotton fields, the number of predators in the lucerne crop were again higher in the lucerne crop than in cotton with predator numbers declining with increasing distance from the lucerne strip to reach their lowest level 300 metres into the cotton crop. This could mean that within a lucerne/cotton interplant, the lucerne crop may act as a refugia or reserviour to conserve predatory insects. However, when lucerne was interplanted with commercial cotton, to compare densities of predators on cotton with and without lucerne strips, 2.1 and 2.5 times more predatory beetles and bugs per metre row respectively were recorded on cotton with lucerne strips than cotton without lucerne strips. This indicated that the interplanted lucerne crop may be acting as a source of the predators to the cotton crop. The refugia or source 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 (Bugg *et al.* 1987), compared to the monocultural cotton. These resources may have enhanced the establishment of the predators within the lucerne strips. The magnitude of these effects will depend on whether the lucerne strips were well established and colonized by predatory insects long before the cotton crop germination and also the mobility of the predators themselves (Corbett and Plant, 1993). According to Corbett and Plant (1993), an interplanted vegetation may act as a source of natural enemies when natural enemies colonize strip vegetation before crop germination, but may act as a sink when crop and interplanted vegetation germinate at the same time. In this study though, the lucerne crop was established before the cotton crop germinated, the role of the lucerne strip as a source of predators to the cotton crop, however, was minimal looking at the higher numbers of predators recorded in the lucerne strip compared with the numbers in the cotton crop within the lucerne/cotton interplant. Thus given the abundance of food resources, shelter, mating, oviposition sites etc within the lucerne strips (Bugg *et al.* 1987), higher numbers of the predators may not have been inclined to move from the strips to forage the adjacent cotton crop. The movement of the predators can be improved by either applying natural enemies food attractants to the cotton crop to attract predators especially the predatory beetles, bugs and lacewings onto the cotton (Mensah and Harris, 1994, 1995; Mensah, 1997) or by using smaller lucerne strips less than 12 m wide or slashing all the lucerne strips or allowing the lucerne crop to hay off (Mensah and Harris, 1995). The last three options may also force *C. dilutus* another pest of cotton which found mostly in the lucerne strips to move from lucerne to cause damage in cotton (Mensah and Khan, 1997).

The use of lucerne as strips in cotton to generate beneficial insects in cotton systems especially early in the season as indicated in this study, is very important to the management of *Helicoverpa* spp.(Fitt, 1989; Mensah and Harris 1995). This is because *Helicoverpa* spp. can rapidly infest cotton crops through migration from other sources, especially early season, and unless natural enemies are present and well established before the pest arrives they cannot respond rapidly enough to achieve control (Fitt, 1989; Mensah and Harris, 1995). The presence of the lucerne crop within the cotton system will enable the establishment of a high population of beneficial insects in the cotton fields on time prior to the arrival of *Helicoverpa* spp.

However, the study did indicate that planting lucerne crop 300 metres apart within cotton could increase the abundance and spread of predatory insects in cotton systems.

In conclusion, increased habitat diversity in cotton fields using lucerne strips can be a useful tool in using indigenous predators in an integrated pest management program in cotton in Australia.

Acknowledgements

I thank Angela Singleton, Wendy Harris, Ray Morphew, Diana Owers (NSW Agriculture, Narrabri), for their technical assistance. Special thanks to Dave Anthony, Stefan Henggeller and Merrill Johnson (Auscott, Narrabri), Peter Glennie and Kylie May (Norwood, Moree), David Coulton and Iain Macpherson (Alcheringa, Goondiwindi), John O'Brien and Ross O'Brien (Bellevue, Warren), Chris Hogendyk, Shane Bodiam and Harvey Gaynor (Auscott, Warren) for their co-operation. I also thank Dr Richard Spurway (NSW Agriculture, Orange) for reviewing the manuscript. The Australian Cotton Research and Development Corporation provided funding for this project (grant DAN 98C) for which I am grateful.

Table 1. Major predators identified from study plots within commercial cotton farms at all study sites, 1993-96.

Order	Family	Species	Group
Coleoptera	Coccinellidae	*Coccinella transversalis* (Fabricius)	Predatory
		Adalia bipunctata (Linnaeus)	beetles
	Melyridae	*Dicranolauis bellulus* (Guerin-Meneville)	
Hemiptera	Nabidae	*Nabis capsiformis* (Germar)	Predatory
	Lygaeidae	*Geocoris lubra* (Kirkaldy)	bugs
	Pentatomidae	*Cermatulus nasalis* (Westwood)	
		Ochelia schellenbergii (Guerin-Meneville)	
	Reduviidae	*Coranus triabeatus* (Horvath)	
Neuroptera	Chrysopidae	*Chrysopa* spp.	Predatory
	Hemerobiidae	*Micromus tasmaniae* (Walker)	lacewings
Araneida	Lycosidae	*Lycosa* spp.	Spiders
	Oxyopidae	*Oxyopes* spp.	
	Salticidae	*Salticidae* spp.	
	Araneidae	*Araneus* spp.	

This will enhance the efficacy of the beneficial insects and enable their use as basic components in a practical integrated pest management system. The beneficial arthropods also may aid in the management of spider mites and other pests (Corbett et al. 1991; Godfrey and Leigh, 1994) provided the lucerne strips are not sprayed with synthetic insecticides which may disrupt the activity of the beneficial arthropods resulting in the resurgence of the spider mite population (Mensah and Singleton, Unpublished data). The lucerne strips also serve as trap crop for the green mirid, *Creontiades dilutus* Stål which are major pests of cotton (Mensah and Khan, 1997). It should therefore be managed to remain attractive to the green mirids by maintaining new regrowth throughout the cotton season (Mensah and Khan, 1997). This could be done by slashing half of each strip every 4 weeks (Mensah and Khan, 1997).

Several studies have indicated that increased habitat diversity in crops leads to increase population densities of indigenous predators and other arthropods and this can enhance biological control. For example, Conlong (1995) intercropped sugarcane with sorghum and maize and this increased the population density of indigenous predators and arthropods in the intercrops as compared to pure stands of sugar cane. Corbett (1991) also found that the predatory mite *Metaseiulus occidentalis* was enhanced in abundance immediately adjacent to alfalfa interplants in cotton. Greenbug populations on strips of sorghum interplanted in cotton were found by Fye (1972) to support large populations of *Hippodamia convergens* and other predators. These studies suggest that the presence of abundant resources can increase the residence time of natural enemies on vegetation providing these resources and by diversifying agroecosystems by adding such vegetation could enhance natural enemy abundance and effectiveness.

Cotton is grown in Australia as a short lived annual monoculture and so the predatory insects fly periodically to new host locations as the crop matures and is then harvested. The surrounding natural vegetation in most of the cotton areas in Australia especially in the Northern New South Wales where most of the cotton is grown is very sparse and sometimes bare with no natural vegetation at all. By artificially increasing the habitat diversity in the cotton system by interplanting the cotton with lucerne strips, the predatory insects were given a permanent refugia for feeding, oviposition and possible overwintering sites during and after the cotton season enabling them to be carried over from one season to another. This study did not seek to determine whether strip cropping with lucerne will produce predators enough to reduce damage of *Helicoverpa* spp.in cotton since cotton growers are reluctant to leave cotton fields unsprayed against *Helicoverpa* spp.

Figure 1. Responses of predatory beetles to alternative crops interplanted in commercial cotton in the Australian Cotton Research Institute farm at Narrabri, NSW, 1993-94 (Means of treatments followed by the same letter are not significantly different (P > 0.05) (Tukey-Kramer Multiple Comparisons Test). Error bars represent standard errors.

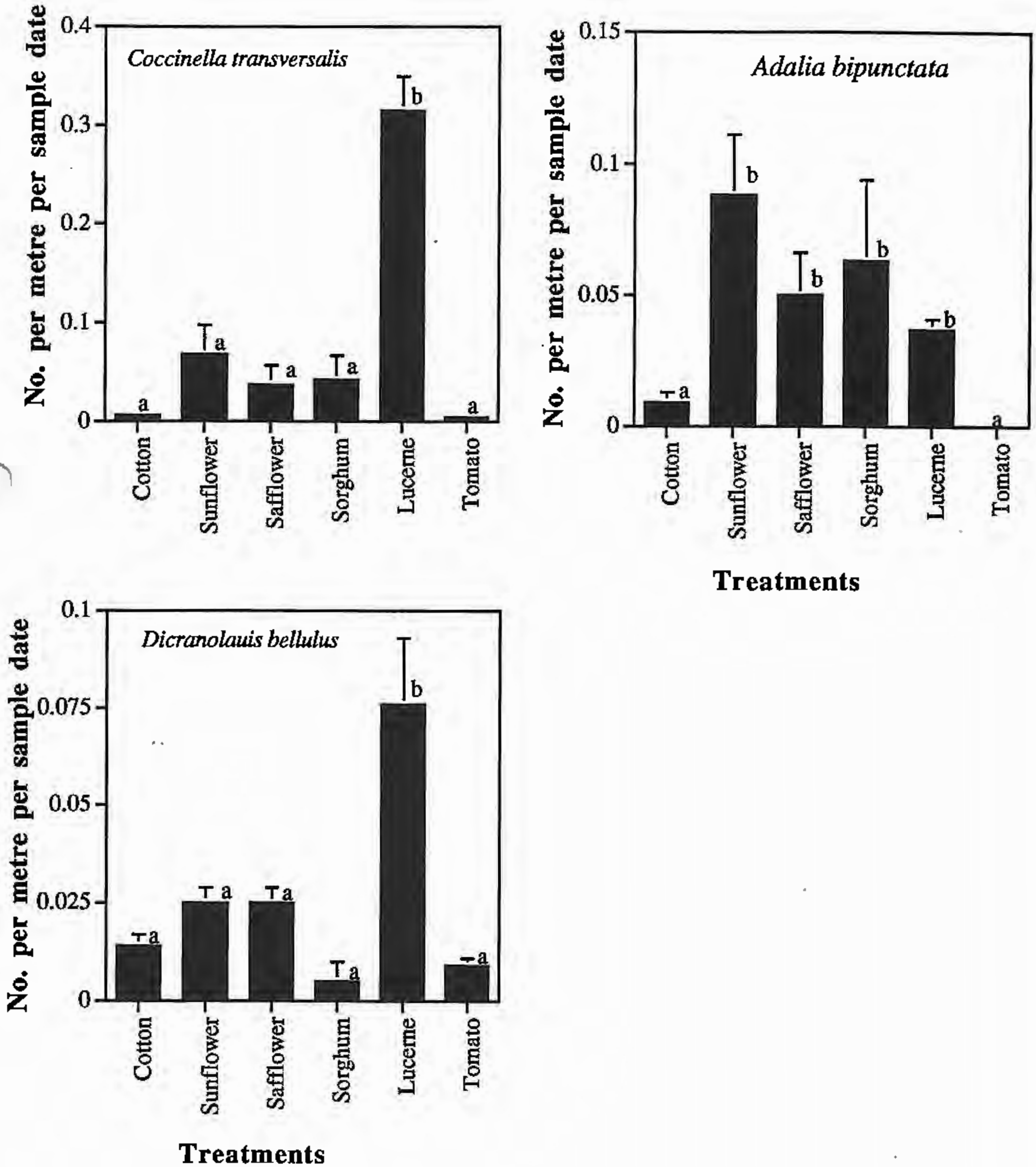

Coccinella transversalis
No. per metre per sample date
0
0.1
0.2
0.3
0.4
Cotton
Sunflower
Safflower
Sorghum
Lucerne
Tomato
a
b
Adalia bipunctata
No. per metre per sample date
0
0.05
0.1
0.15
Treatments
Dicranolauis bellulus
0.025
0.075

Figure 2. Responses of predatory bugs to alternative crops interplanted in commercial cotton in the Australian Cotton Research Institute farm at Narrabri, NSW, 1993-94 (Means of treatments followed by the same letter are not significantly different ($P > 0.05$) (Tukey-Kramer Multiple Comparisons Test). Error bars represent standard errors.

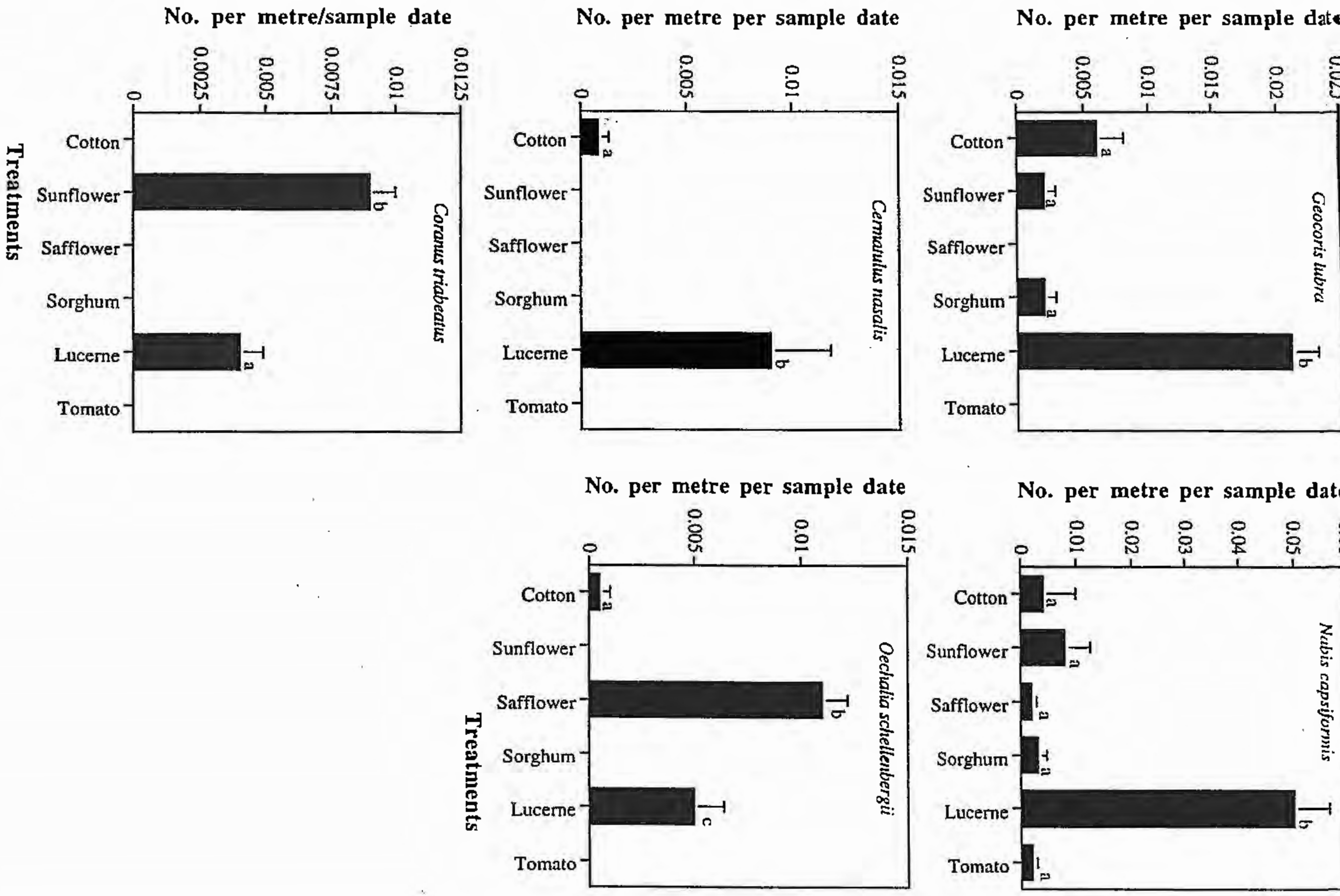
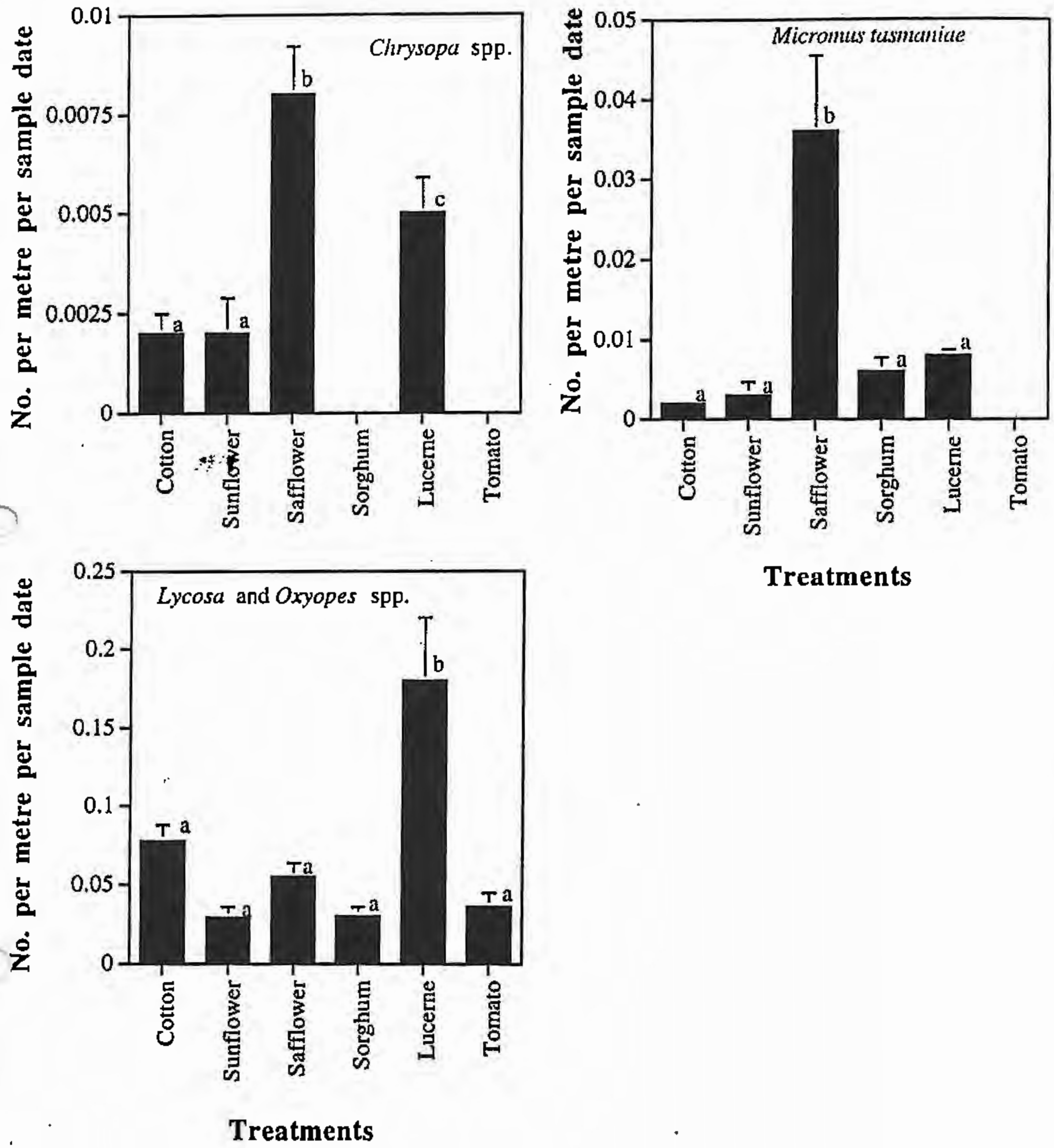

Geocoris lubra
No. per metre per sample date
0
0.005
0.01
0.015
0.02
0.025
Cotton
Sunflower
Safflower
Sorghum
Lucerne
Tomato
a
a
a
b
Cermatulus nasalis
No. per metre per sample date
0
0.005
0.01
0.015
a
b
Coranus triabeatus
No. per metre/sample date
0
0.0025
0.005
0.0075
0.01
0.0125
b
a
Treatments
Nabis capsiformis
No. per metre per sample date
0
0.01
0.02
0.03
0.04
0.05
0.06
a
a
a
a
b
a
Oechalia schellenbergii
No. per metre per sample date
0
0.005
0.01
0.015
a
b
c
Treatments

Figure 3. Responses of predatory lacewings and spiders to alternative crops interplanted in commercial cotton in the Australian Cotton Research Institute farm at Narrabri, NSW, 1993-94 (Means of treatments followed by the same letter are not significantly different (P > 0.05) (Tukey-Kramer Multiple Comparisons Test). Error bars represent standard errors.



Chrysopa spp.
No. per metre per sample date
0.01
0.0075
0.005
0.0025
0
a
a
b
c
Cotton
Sunflower
Safflower
Sorghum
Lucerne
Tomato
Micromus tasmaniae
No. per metre per sample date
0.05
0.04
0.03
0.02
0.01
0
a
a
b
a
a
Cotton
Sunflower
Safflower
Sorghum
Lucerne
Tomato
Treatments
Lycosa and Oxyopes spp.
No. per metre per sample date
0.25
0.2
0.15
0.1
0.05
0
a
a
a
a
b
a
Cotton
Sunflower
Safflower
Sorghum
Lucerne
Tomato
Treatments

Figure 4. Effect of lucerne strips on numbers of predatory beetles, bugs, lacewings and spiders in adjacent cotton crop in Auscott at Narrabri, NSW, 1993-94. (Means between treatments followed by the same letter are not significantly different ($P > 0.05$) (Tukey-Kramer Multiple Comparisons Test). Error bars represent standard errors.

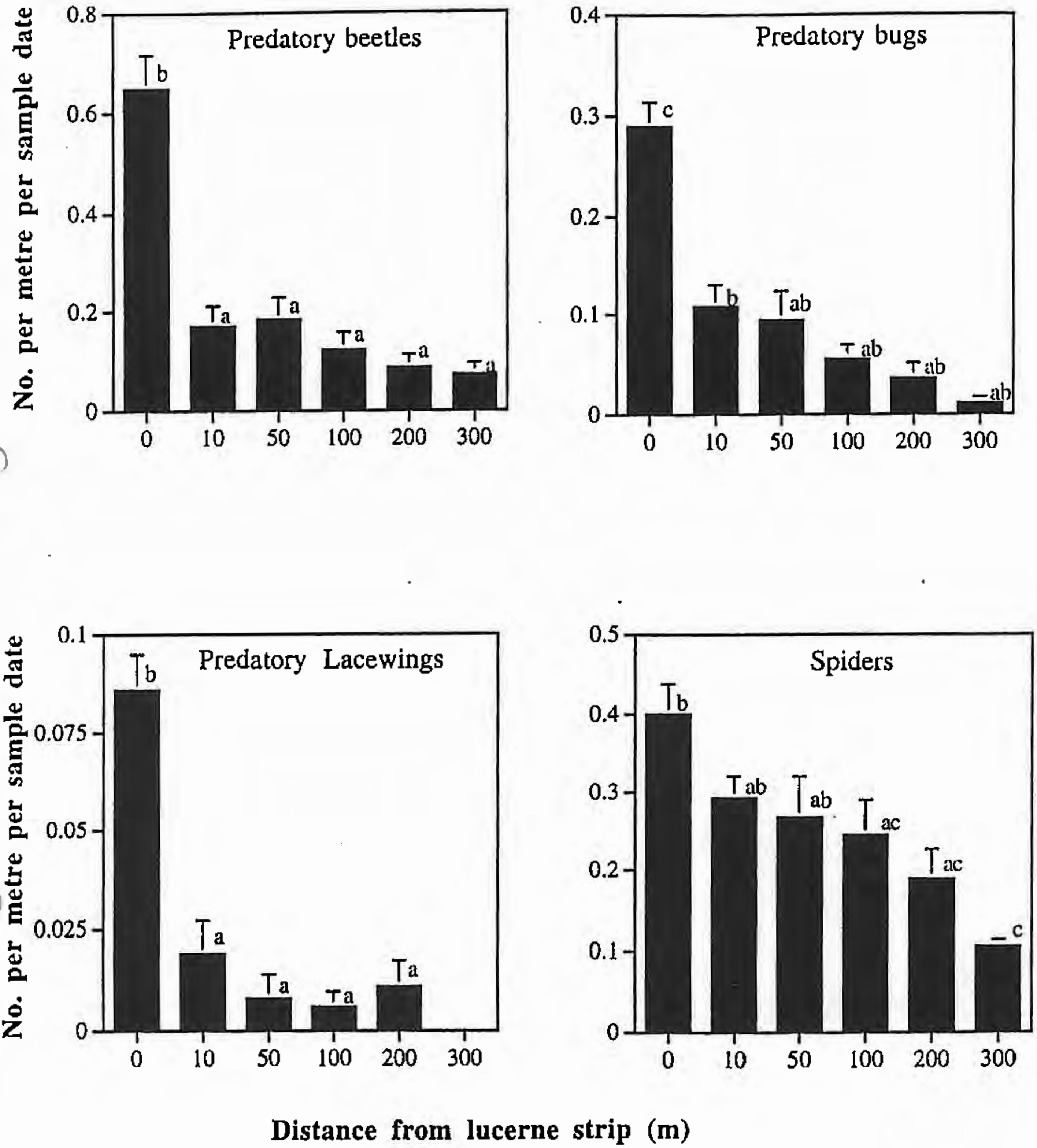

Predatory beetles
Predatory bugs
Predatory Lacewings
Spiders
No. per metre per sample date
No. per metre per sample date
0.8
0.6
0.4
0.2
0
0.4
0.3
0.2
0.1
0
0.1
0.075
0.05
0.025
0
0.5
0.4
0.3
0.2
0.1
0
b
a
a
a
a
c
b
ab
ab
ab
ab
b
a
a
a
a
b
ab
ab
ac
ac
c
0
10
50
100
200
300
Distance from lucerne strip (m)

Figure 5. Comparison of numbers of predatory beetles, bugs, lacewings and spiders in lucerne strips and in cotton at Alcheringa near Boggabilla NSW, 1994-95. Error bars represent standard errors.

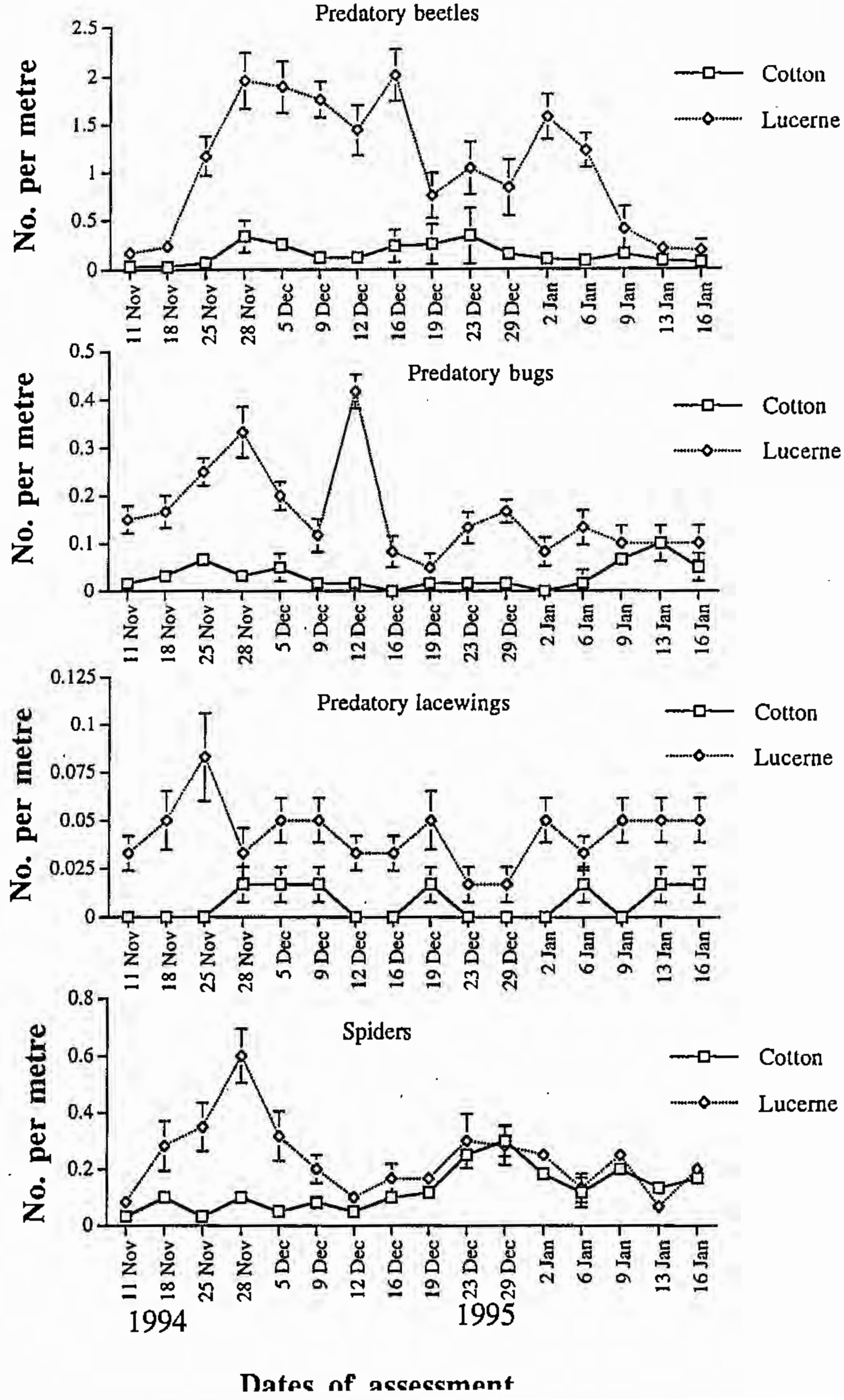
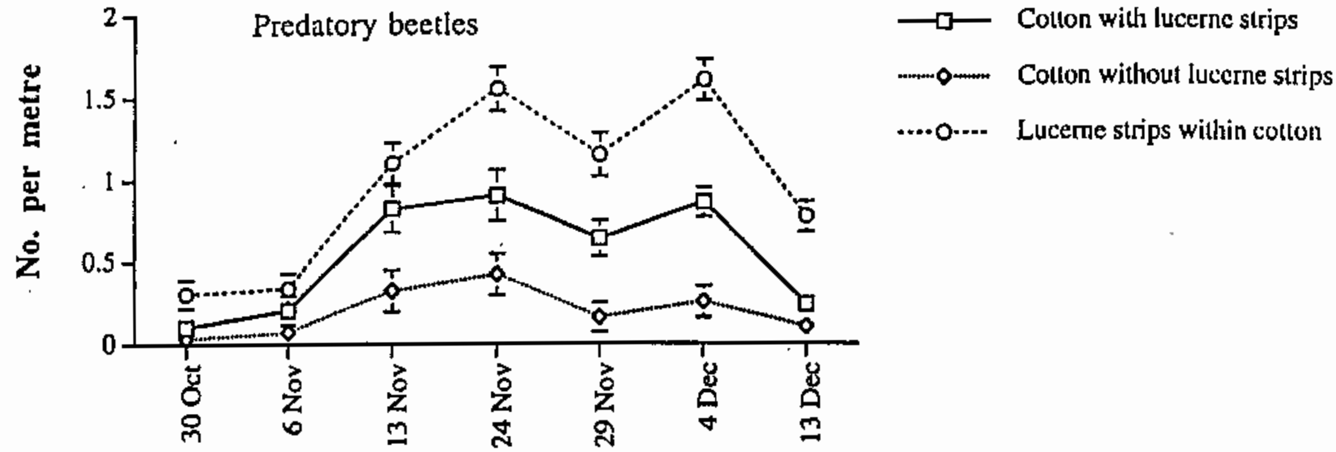
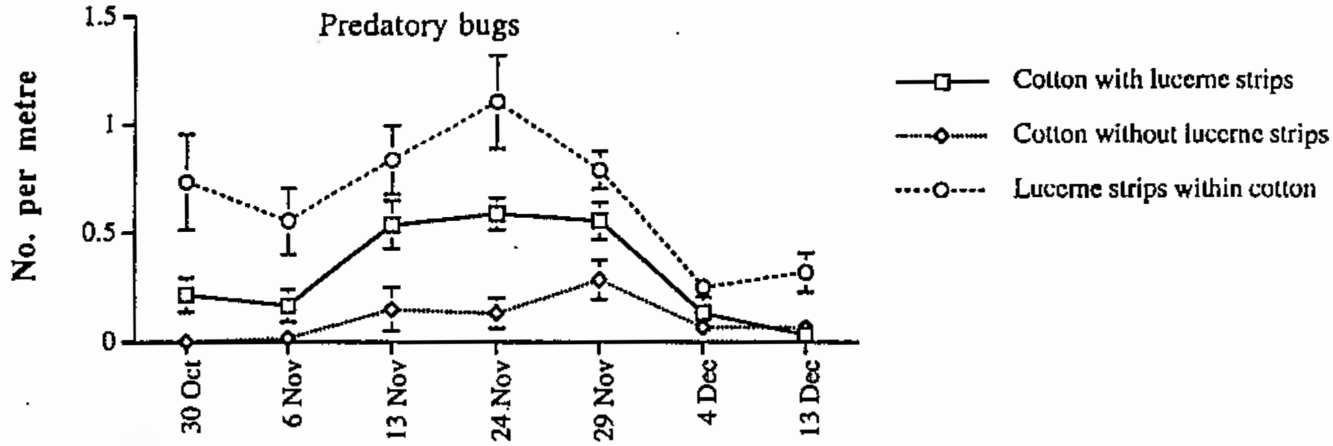
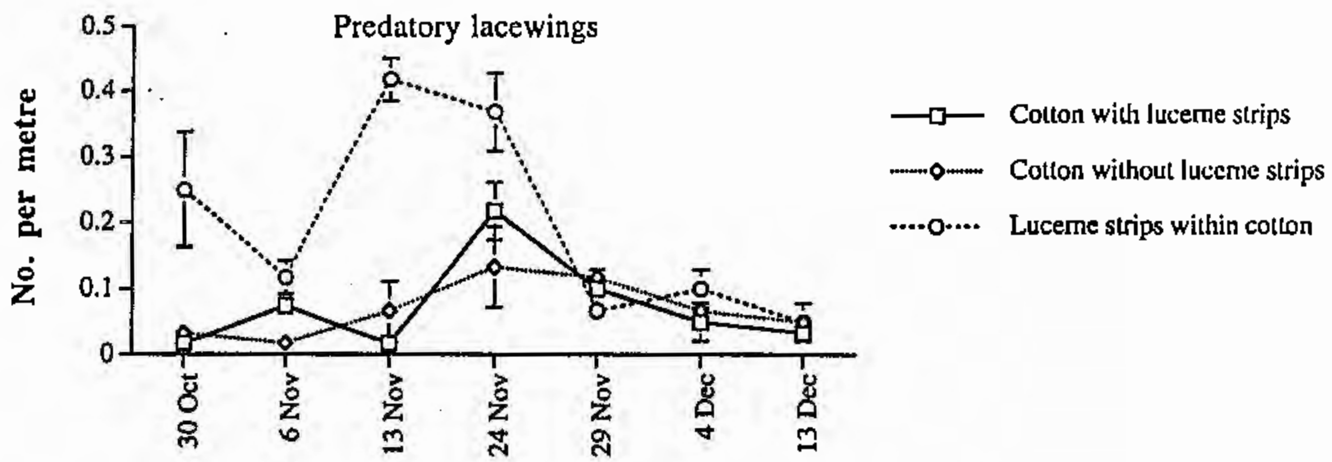
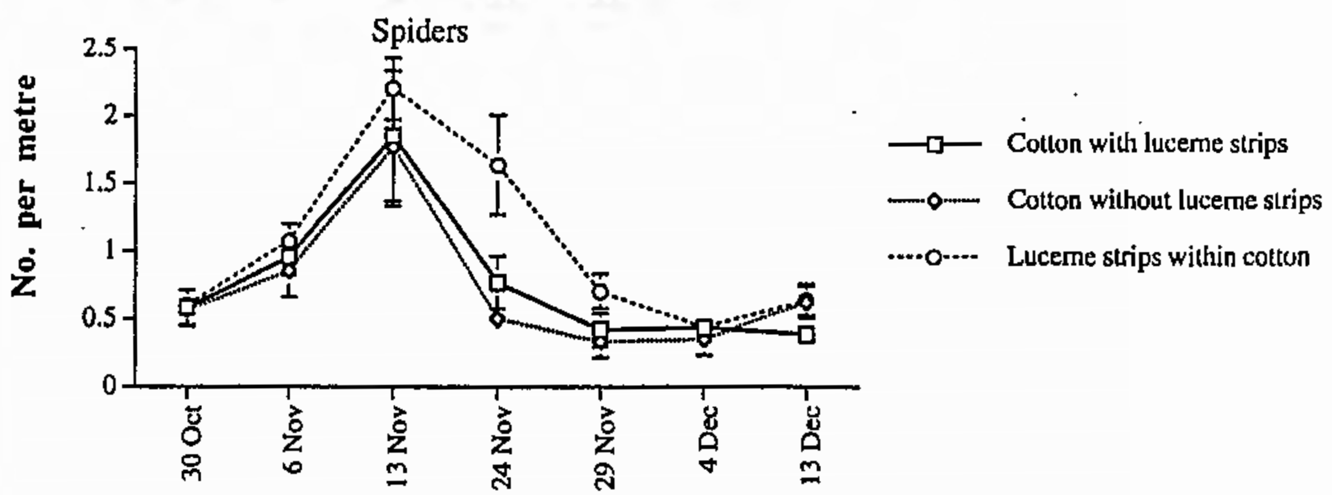

Predatory beetles
No. per metre
2.5
2
1.5
1
0.5
0
Cotton
Lucerne
Predatory bugs
No. per metre
0.5
0.4
0.3
0.2
0.1
0
Cotton
Lucerne
Predatory lacewings
No. per metre
0.125
0.1
0.075
0.05
0.025
0
Cotton
Lucerne
Spiders
No. per metre
0.8
0.6
0.4
0.2
0
Cotton
Lucerne
11 Nov
18 Nov
25 Nov
28 Nov
5 Dec
9 Dec
12 Dec
16 Dec
19 Dec
23 Dec
29 Dec
2 Jan
6 Jan
9 Jan
13 Jan
16 Jan
1994
1995
Dates of assessment

Figure 6. Comparison of numbers of predatory beetles, bugs, lacewings and spiders in lucerne strips, cotton with and without lucerne strips at Norwood near Moree NSW, 1995. Error bars represent standard errors.


Predatory beetles
No. per metre
2
1.5
1
0.5
0
30 Oct
6 Nov
13 Nov
24 Nov
29 Nov
4 Dec
13 Dec
Cotton with lucerne strips
Cotton without lucerne strips
Lucerne strips within cotton


Predatory bugs
No. per metre
1.5
1
0.5
0
30 Oct
6 Nov
13 Nov
24 Nov
29 Nov
4 Dec
13 Dec
Cotton with lucerne strips
Cotton without lucerne strips
Lucerne strips within cotton


Predatory lacewings
No. per metre
0.5
0.4
0.3
0.2
0.1
0
30 Oct
6 Nov
13 Nov
24 Nov
29 Nov
4 Dec
13 Dec
Cotton with lucerne strips
Cotton without lucerne strips
Lucerne strips within cotton


Spiders
No. per metre
2.5
2
1.5
1
0.5
0
30 Oct
6 Nov
13 Nov
24 Nov
29 Nov
4 Dec
13 Dec
Cotton with lucerne strips
Cotton without lucerne strips
Lucerne strips within cotton

References

ANDOW, D. A. 1991. Vegetational diversity and arthropod population response. *Annual . Review of Entomology,* **36**, 561-586.

ANDOW, D. A. and Risch, S. J. 1985. Predation in diversified agroecosystems: relations between a coccinellid predator Coleomegilla maculata and its food. *Journal of Applied Ecology,* **22**, 357-372.

BEIRNE, B. P. 1967. Pest Management. *CRC Press*, Cleveland, Ohio, 123 pp.

BUGG, R. L., EHLER, L. E. and WILSON, L. T. 1987. Effect of common knotweed (*Polygonum aviculare*) on abundance and efficiency of insect predators of crop pests. *Hilgardia,* **55**, 1-51.

CONLONG, D. E. 1995. Results of preliminary pitfall trapping trials for potential arthropod predators of *Eldana saccharina*. *Proceedings of the South African Sugar Technologiess Association,* **69**, 79-82.

CONLONG, D. E. 1994. A review and perspectives for the biological control of the African sugarcane stalkborer *Eldana saccharina. Agriculture, Ecosystems and Environment, 48*, 9-17.

CONLONG, D. E. 1990. A study of pest-parasitoid relationships in natural habitats: an aid towards the biological control of *Eldana saccharina* in sugarcane. *Proceedings of the South African Sugar Technologiess Association*, **64**, 111-115.

CORBETT, A. and PLANT, R. E., 1993. Role of movement in the response of natural enemies to agroecosystem diversification: A theoretical evaluation. *Environmental Entomology,* **22**, 519-531.

CORBETT, A., LEIGH, T. F. and WILSON, L. T., 1991. Interplanting alfalfa as a source of *Metaseiulus occidentalis* (Acari: Phytoseiidae) for managing spider mites in cotton. *Biological Control,* **1**, 188-196.

DeLOACH, C. J. 1971. The effect of habitat diversity on predators. *Proceeding Tall Timbers Conference on Ecology Animal Control and Habitat Management,* **2**, 223-241.

FITT, G. P. 1989. The ecology of Heliothis in relation to agroecosystems. *Annual Review of Entomology*, **34**, 17-52.

FYE, R. E. 1972. The interchange of insect parasites and predators between crops. *PANS,* **18**, 143-146.

GODFREY, L. D. and LEIGH, T. F., 1994. Alfalfa harvest strategy on Lygus bug (Hemiptera:Miridae) and insect predator population density: Implications for use as trap crop in cotton. *Environmental Entomology,* **23 (5)**, 1106-1118.

HAGEN, K. S. and HALE, R. 1974. Increasing natural enemies through use of supplementary feeding and non-target prey. *Proceedings Summer Inst. for Biological control of plant insects and diseases.*, Mississippi Univ. Press, Jackson, 647 pp.

HARDWICK, D. F. 1965. The corn earworm complex. *Memoires of Entomological Society of Canada*, **40**, 247 pp.

HERZOG, D. C. and FUNDERBURK, J. E. 1986. Ecological bases for habitat management and pest control. In M. Kogan (ed), *Ecological theory and integrated pest management practice* (Wiley, New York), pp. 217-250.

RISCH, S. J., ANDOW, D. and ALTIERRI, M. A. 1983. Agroecosystem diversity and pest control: data, tentative, conclusions and new research directions. *Environmental Entomology*, **12**, 625-629.

RUSSELL, E. P. 1989. Enemies hypothesis: a review of the effect of vegetational diversity on predatory insects and parasitoids. *Environmental Entomology* **18**, 590-599.

MENSAH, R. K. and HARRIS, W. E. 1994. Making better use of cotton predators. *Australian Cotton Grower*, **15**, 8-11.

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

MENSAH, R. K. and HARRIS, W. E. 1995. Using Envirofeast spray and refugia technology for cotton pest control. *Australian Cotton Grower*, **16**, 30-33.

MENSAH, R. K. 1997. Local density responses of predatory insects of Helicoverpa spp. to a newly developed food supplement 'Envirofeast' in commercial cotton in Australia. *International Journal of Pest Management*, **43**, 221-225.

MENSAH, R. K and KHAN, M. 1997. Use of *Medicago sativa* (L.) interplantings/trap crops in the management of the green mirid, *Creontiades dilutus* (Stål) in commercial cotton in Australia. *International Journal of Pest Management* **43**, 197-202.

PIMENTEL, D. 1971. Population control in crop systems: monocultures and plant spatial patterns. *Proceedings od Tall Timbers Conference on Ecology, Animal Control and Habitat Management.* **2**, 209-221.

SOUTHWOOD, T. R. E. and WAY, M. J. 1970. Ecological background to pest management. In: Rabb, R. L. & Guthrie (eds) *Concepts of pest management. Proceedings Conf. North Carolina State Univ.*, Raleigh, 6-29.

VAN EMDEN, H. F. and WILLIAMS, G. F. 1974. Insect stability and diversity in agroecosystems. *Annual Review of Entomology*, 19, 455-75.

VAN EMDEN, H. F. 1990. Plant diversity and natural enemy efficiency in agroecosystems. In: Mackauer, M. Ehler, L. E. & Roland, J. (eds). *Critical Issues in Biological Control.* Intercept Press. Andover, Hants, 30 pp.

VAN LETEREN, J. C. 1987. Environmental manipulation advantageous to natural enemies of pests. In: Delucchi, V. (ed). *Integrated Pest Management, Quo Vadis? An International Perspective.* __ Parasitis. Geneva, Switzerland, 411 pp.

WAY, M. J. and HEONG, K. L. 1994. The role of biodiversity in the dynamics and management of insect pests of tropical irrigated rice - a review. *Bulletin of Entomological Research*, **84**, 567-587.

WETZLER, R. E. and RISCH, S. J. 1984. Experimental studies of beetle diffussion in simple and complex crop habitats. *Journal of Animal Ecology*, **53**, 1-9.

Local density responses of predatory insects of *Helicoverpa* spp. to a newly developed food supplement 'Envirofeast' in Commercial cotton in Australia

(*Keywords*: *Helicoverpa* spp., *Creontiades dilutus*, *Tetranychus urticae*, supplementary food, coccinellids, predators)

R. K. MENSAH

NSW Agriculture, Australian Cotton Research Institute, PMB Myall Vale, Narrabri 2390, Australia.

ABSTRACT Application of supplementary foods to attract, retain and conserve beneficial arthropods in crop systems has been used for several years on crop plants to enhance biological control of pests. The responses of predatory insects of *Helicoverpa* spp. to sugar and to a mixture of petroleum oil and Kelgum and newly developed food products, Envirofeast® and Envirofeast B, were investigated at a commercial irrigated cotton farm at Auscott in Narrabri in New South Wales from 1992-94. Individual plots received 8 fortnightly applications of each substance dissolved in water and were compared with synthetic insecticide-treated and an unsprayed plots. Adult Coccinellidae, Melyridae, Lygaeidae, Nabidae and Chrysopidae responded more positively and numbers increased more throughout the study on plots sprayed with Envirofeast A than all other treatments. In the presence of Envirofeast A the predatory insects failed to respond consistently or clearly to either sucrose or a protein supplement spray used in Envirofeast B. The conventional insecticides virtually exterminated the predatory insects. In another experiment where predatory insects were sampled at varying distances away from the Envirofeast A sprayed and unsprayed plots, predatory insects (but not spiders) were concentrated around the food sprayed plot. This study supports the findings of previous researchers that application of supplementary food can attract and concentrate entomophagous arthropods to enhance biological control of crop pests.

1. Introduction

Commercial cotton crops in Australia are attacked by a wide range of insects, the major ones being *Helicoverpa spp.*, *Creontiades dilutus* (Stål.) and *Tetranychus urticae* (Koch). The control of these pests depends exclusively on repeated applications of synthetic insecticides. Cotton crops throughout Australia receive on average 12 insecticide and insecticide-mixture sprays each season, although extremes of 18 - 20 sprays still occur (Fitt, 1994). Beneficial insects are neglected in these pest management systems due to the disruptive impact of pesticides. Also, there is no technique available to cotton growers to maximise the abundance and effectiveness of these beneficial arthropods. Recent studies by Mensah & Harris (unpublished data) indicated that interplanted *Medicago sativa* L. (lucerne) in commercial cotton served as refugia for beneficial insects and as a trap crop for *C. dilutus*. However most of the beneficial insects usually remain in the lucerne system and did not move onto the cotton. Mowing of the lucerne resulted in the movement of both beneficial insects and *C. dilutus* onto the cotton, the latter causing significant damage to the crop. A technique that could attract only the beneficial insects from refugia onto cotton would be desirable.

Applications of artificial honeydews to crops have proved useful in attracting and retaining predatory insects in treated crops (Neuenschwander & Hagen 1980; Hagen 1986; Evans & Swallow 1993). Hagen *et al.* (1970) found that artificial honeydew based on protein hydrolysate and sugar applied to alfalfa and cotton significantly increased the number of lacewings and coccinellids and reduced populations of the spotted alfalfa aphid and lepidopterous larvae. Sucrose alone dissolved in water has also been used successfully to concentrate adult coccinellids and lacewings in treated crops (Ewert & Chiang 1966, Schiefelbein & Chiang 1966, Carlson & Chiang 1973, Mensah & Madden 1994). However Hagen *et al.* (1970) found that yeast hydrolysate was highly toxic to cotton; and concentrated sugar solution sprayed on cotton caused stunted growth of the crop in preliminary trials (Mensah & Harris unpublished data). The development of a food product which is non-toxic to cotton and which could attract predatory insects into cotton would be desirable.

The objective of this study was to develop a food product which is non-toxic to cotton and examine its effect on predatory insects of *Helicoverpa* spp. in commercial cotton.

2. Materials and methods

2.1. Sources of supplementary food products.

The food products evaluated were 'Envirofeast A' (now registered as Envirofeast®) and Envirofeast B (NSW Agriculture, Australian Cotton Research Institute (ACRI), Narrabri, NSW, Australia). Envirofeast products were developed by the author from mixtures of complex carbohydrates and protein supplements, but because of commercial considerations it is not possible at the present time to detail the compounds included in the Envirofeast products. However, Rhone-Poulenc Rural Australia Pty Ltd has been selected as commercial partners and the products are currently being evaluated by the company prior to commercialization in 1998. The protein base of Envirofeast A differed from that of Envirofeast B. The other food products evaluated were sugar, and a mixture of petroleum oil (Caltex Lovis, a C_{21} narrow-range oil (50% distillation temperature of 361°C at 101.33kPa) and a polysaccharide composed of a food-grade blend of xanthan and locust bean gums (Kelgum) (Kelco & Co., San Diego, CA).

2.2. Response of predatory insects to different food supplements

Experiments were conducted in a 10-hectare cotton field at Auscott (30° 13'S, 149° 47'E) at Narrabri, NSW in 1992-93 during the 1992-93 season. The treatments evaluated were (1) 3 kg/ha Envirofeast A, (2) 3 kg/ha Envirofeast B, (3) 4 kg/ha sugar (4) a mixture of 0.5% (vol/vol) petroleum oil and 0.01% (wt/vol) Kelgum (5) unsprayed (control) and (5) conventional insecticide treated plot (treated standard). Plots were arranged in randomized complete block design with 4 replicates with the size of each replicate measuring one hectare. Four conventional insecticide treated plots were selected from other cotton fields located 400 m away from the trial site to avoid spray drift. Similarly, a 40 m wide buffer separated food sprayed and unsprayed (control) plots.

Foliar applications of each treatment were applied on November 7, 1992 and thereafter at 14 d 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 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 (3 applications) and by aircraft mid and late season (5 applications).

Pre-treatment counts of insects were made 24h before treatment application and then every 7 d until the end of study. I used two sampling methods sweep net (early season) and D-vac (Homelite Textron Inc., NC, USA) (mid and late season) to assess the impact of the food products on the predatory insects. The reason for this is that cotton plants during early season are small and the dust and dirt are sucked into the D-vac machine, making insect counts difficult. However during mid and late season when cotton plants has developed fruits especially squares, the use of sweep nets usually destroy the fruits hence D-vac was appropriate during this stage. The D-vac sampling technique have so far been developed to a stage where it can be used all season on cotton to evaluate beneficial arthropods. Predatory insects were sampled from cotton plants in each treated plot between 7 am and 10 am on each sample date. They were sampled by taking 50 sweeps (one sweep/plant) of 180^{o} with a sweep net through the canopy of the cotton plant in each plot (from October to December 1992 (early season) and a 20 metre long vacuum sampling using a Dvac (from January to April 1993 (mid and late season). The D-vac is a small portable suction sampler with 120 mm diameter cone and a nozzle speed of approximately 10 m 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 m of row of vacuum sampling in the middle of each treated plot constituted a sample. After each sampling, the contents of the net or D-vac were transferred to a plastic bag, chilled and taken to the laboratory and frozen until later counting and identification. Predators were separated into predatory beetles, bugs, lacewings and spiders and data were expressed as numbers per sampling date per sweep or metre for each treatment. All data were transformed by ($\sqrt{X+0.5}$) and submitted to ANOVA (Graphpad Version 2.03 Instat Software Inc. San Diego California) and least significant difference (lsd) used to separate the means. Arithmetic rather than transformed means are given in the results.

2.3. Attraction of predatory insects to Envirofeast A

Based upon the results of experiment 2.2, Envirofeast A was selected for further studies to determine whether the responses of the predatory insects to this food product in experiment 1 were due to a positive attraction or arrestment. Experiments were conducted on cotton field at Norwood (29^{o} 28'S, 149^{o} 50'E), near Moree, NSW from December 1993 to March 1994. In this study a one hectare plot was sprayed with Envirofeast A only and another hectare situated 400 m in line but opposite to Envirofeast A sprayed plot was left unsprayed (control). Fifty sweeps using a sweep net (from October to December 1993) and a 20 metre vacuum sampling using a D-vac (from January to April 1994) were made on cotton plants as in experiment 1 at 20 m, 50, 100, 200 and 400 m away from the border of Envirofeast A and the unsprayed plot (which is 0 metres). These were replicated 4 times for the treated and unsprayed plots at each distance. Data were expressed as numbers per sampling date/sweep or m at each distance away from treated and control plots. All data were transformed by ($\sqrt{X+0.5}$) and submitted to ANOVA and least significant difference (lsd) used to separate the means. Arithmetic rather than transformed means are given in the results.

3. Results

3.1. Response of predatory insects to different food supplements

The most important predators identified from the plots, are given in Table 1. Numbers of coccinellids (*C. transversalis, H. arcuata* and *A. bipunctata*) were higher throughout this study on plots sprayed with Envirofeast A than with any other treatments (Fig. 1). Similar numbers of *C. transversalis* were recorded on sugar, Envirofeast B and Oil and Kelgum sprayed plots indicating little or no difference in response of the insect to these food products. Envirofeast B, which had same complex carbohydrate as Envirofeast A but different protein base, had lower coccinellid numbers than the latter indicating quality of these food products are important in attraction or arrestment studies. Numbers of *C. transversalis* on the sucrose sprayed plot did not differ significantly (P>0.05) from the Envirofeast B and Oil and Kelgum mixture plots but were significantly different (P<0.05) from the insecticide sprayed and the unsprayed plots (Fig. 1). The plots treated with conventional insecticides had the lowest number of coccinellids at each sampling date (Fig. 1).

The Melyridae, *D. bellulus* and the predatory bugs, *G. lubra* and *N. capsiformis* also responded positively to the application of Envirofeast A (Fig. 2). Their numbers were significantly higher (P<0.05) in the Food A sprayed plot than all other treated plots, with the conventional insecticide plots recording the least (Fig. 2). Response of *G. lubra* to sugar in this study was significantly lower (P<0.05) than the Envirofeast A and Envirofeast B products but in *N. capsiformis* the response to sugar was similar to Envirofeast B (Fig. 2).

Other results summarized in Fig. 3, indicated that green lacewing numbers were significantly greater (P<0.05) in the Envirofeast A treatment plot than the Envirofeast B, sugar, unsprayed and oil plus Kelgum plots. Other predators found in all treated plots but not significantly increased by food spray were spiders (Fig. 3). Spider numbers were similar in all the food-sprayed and unsprayed plots, indicating that these arthropods are not responding to the food sprays. The spider numbers were, however, significantly reduced in the insecticide treated plots (Fig. 3). In general, predatory insects were virtually exterminated by the insecticide treatments (Fig. 1, 2 and 3). Numbers of predatory insects early season were higher than mid and late season.

3.2. Attraction of predatory insects to Envirofeast A

Predatory insect numbers were higher on the Envirofeast A plot than the unsprayed (control) plot and declined with increasing distance to reach their lowest level 400 m away (Figs 4 and 5). A similar trend was not shown in the unsprayed control plot (Figs 4 and 5), indicating that the response of the predatory insects of *Helicoverpa* spp to Food A spray could probably be either attraction, arrestment or both.

4. Discussion

The results of this study indicate that natural enemies (i.e. predatory beetles bugs and lacewings) which are important predators of *Helicoverpa* spp. (Fitt, pers. comm.) responded positively to the provision of supplementary food, especially Envirofeast A. In an experiment where predatory arthropods were sampled from varying distances away from the Envirofeast A treated plot it was shown that all the predators except spiders were concentrated around the sprayed plot. This attraction, arrestment and conservation of predatory insects in cotton fields, especially early in the season, as indicated in this study is important for the management of *Helicoverpa* spp in cotton in Australia. This is because *Helicoverpa* spp. can rapidly infest crops through migration from other sources, especially in the early season, and unless natural enemies are present and well established before the pest arrives they cannot respond rapidly enough to achieve pest control. Any product or technique that could establish natural enemies in cotton farms early in the season before the major pest (*Helicoverpa* spp.) arrives will be beneficial to cotton production in Australia in terms of pest management.

Several studies have been done in the use of protein supplements and sucrose sprays to attract and arrest predatory insects in alfalfa, potatoes, corn, maize, cotton and eucalypts (Hagen *et al* 1971, 1976; Butler and Ritchie 1971; Calson and Chiang 1973; Ewert and Chiang 1966; Ben Saad and Bishop 1976a; Nichols and Neel 1977 and Mensah and Madden 1994) but results so far has been limited to ladybird beetles and lacewings except those of Evans & Swallow (1993), who have reported on other predators in field studies with artificial honeydew. All these studies have shown that ladybird beetles and lacewings respond positively to sucrose and protein supplement sprays on their respective treated crop plants. This study indicated that the new product Envirofeast A could attract other predatory insects in addition to ladybird beetles and lacewings including red and blue beetles, big-eyed bugs and damsel bugs. Also, in the presence of Envirofeast A, coccinellids and lacewings failed to respond positively to sugar and Envirofeast B sprays in contrast to previous studies. This indicates that there is a variation in the degree of attraction of entomophagous insects by different food products based on protein supplements, and that the type of protein base may determine the degree or numbers of entomophagous insects a particular food product may attract or concentrate in field crops. We did not detect any local density response of spiders to any of the food supplement sprays and this supports the findings of Evans & Swallow, 1993.

Although this study supports those of previous researchers that supplementary food when applied to field crops can be used to manipulate populations of entomophagous insects that could be utilised in pest control, the strength of such manipulation may be dependent in part on the type of protein supplement in the food product. In conclusion, the method of spraying Envirofeast A on commercial cotton as shown in this study could possibly be a useful tool in integrating predatory insects as basic components in pest management programmes in cotton in Australia.

Acknowledgments

I thank Wendy Harris, Stephen Ryman, Debbie Colless and Ray Morphew for providing technical assistance. I also thank Messrs. Dave Anthony, Stefan Henggeler, Mrs. Sue Parttison (Auscott, Narrabri), Mr. Peter Glennie and Mrs. Kylie May (Peter Glennie & Sons, Norwood near Moree) for co-operating with the field trials, Dr G. A. C. Beattie (Biological and Chemical Research Institute (BCRI), Rydalmere) for providing the Kelgum product and Caltex oil (Australia) Pty Ltd for the Lovis oil, Dr Allan Clift (BCRI, Rydalmere, Australia) for reviewing the manuscript. The Australian Cotton Research and Development Corporation (CRDC) provided funding for this project (DAN 68C, 89C and 98C).

References

BEN SAAD, A. A. and BISHOP, G. W. 1976a. Effect of artificial honeydews on insect communities in potato fields. *Environmental Entomology,* **5**, 453-457.

BUTLER, Jnr., G. D. and RITCHIE, Jnr., P. L. 1971. Feed wheast and the abundance and fecundity of *Chrysopa carnea*. *Journal of Economic Entomology* **64**, 933-934.

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

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

EWERT, M. A. and CHIANG, H. C. 1966. Dispersal of three species of coccinellids in corn fields.*Canadian Entomology*, **98**, 999-1003.

FITT, G. P. 1994. Cotton Pest Management: Part 3. An Australian Perspective. *Annual Review of Entomology*, **39**, 543-562.

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

HAGEN, K. S., SAWALL, J. R. and TASSAN, R. L. 1970. Some ecophysiological relationships between certain *Chrysopa*, honeydews and yeasts. Boll Laboratory Entomological Agriculture "Filippo Silvestri" Portici 28: 113-134.

HAGEN, K. S., SAWALL, Jnr., E. F. and TASSAN, R. L. 1971. The use of food sprays to increase effectiveness of entomophagous insects. *Proceedings Tall Timbers Conference on Ecology, Animal Control and Habitat Management.,* **3**, 59-81.

HAGEN, K. S., SAWALL, Jnr., E. F. and TASSAN, R. L. 1976. Tryptophan in artificial honeydews as a source of an attractant for adult *Chrysopa carnea. Environmental Entomology* **5**: 458-468.

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.

NICHOLS, P. R. and NEEL, W. W. 1977. The use of food wheast as a supplemental food for *Coleomegilla maculata* (De Geer) (Coleoptera : Coccinellidae) in the field. *Southwest Entomology* 2: 102-105.

NEUENSCHWANDER, P. and HAGEN, K. S. 1980. Role of the predator *Hemerobius pacificus* in a non-insecticide treated artichokes field. *Environmental Entomology*, **9**, 492-495.

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.

Fig. 1. Effect of provision of food supplements on numbers of predatory beetles on commercial cotton during early, middle and late cotton season in Auscott at Narrabri, NSW, 1992-93. (Means between treatments followed by same letter are not significantly different (P>0.05, LSD test). Error bars represent standard errors.

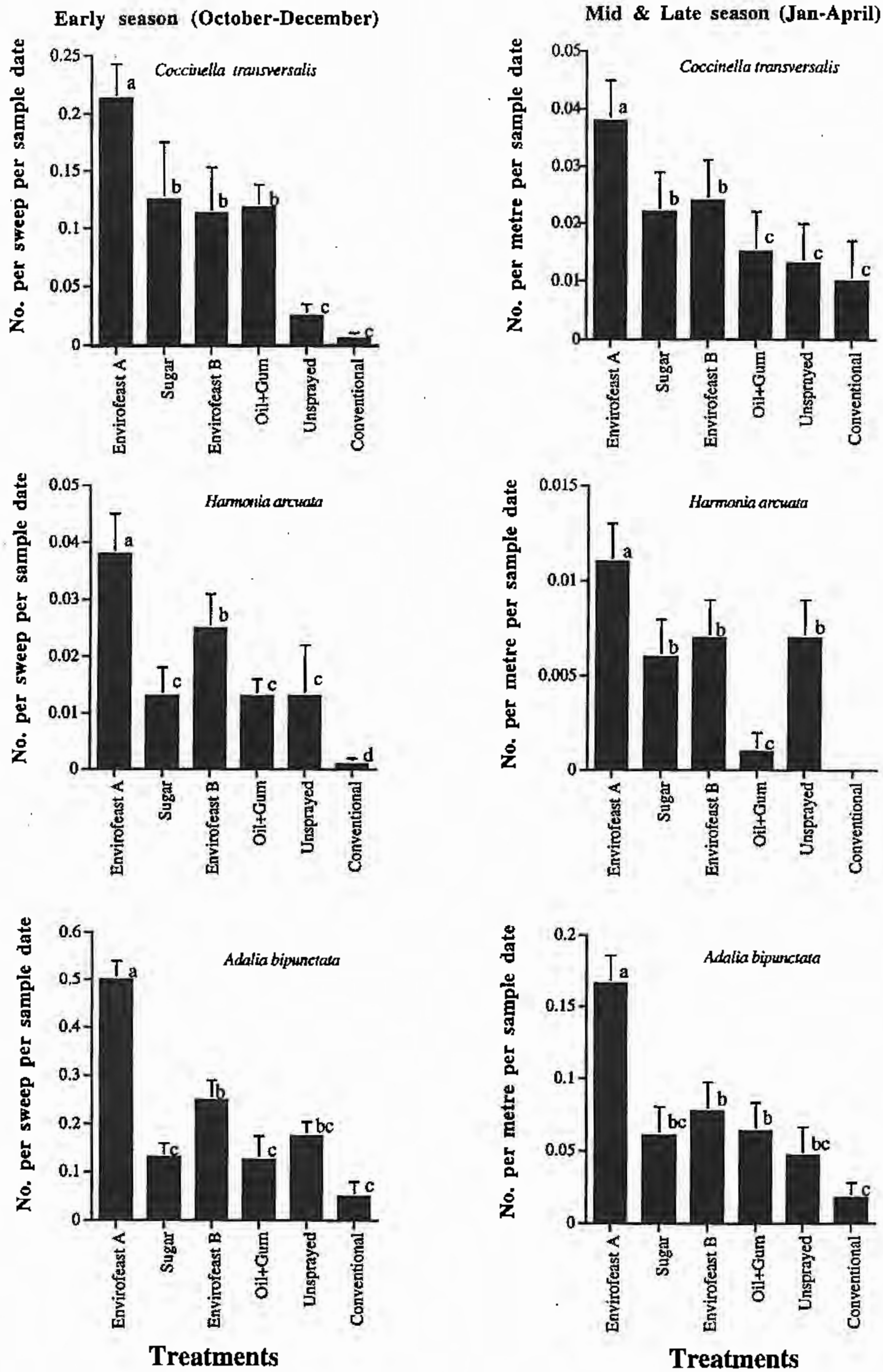

Early season (October-December)
Mid & Late season (Jan-April)
Coccinella transversalis
Harmonia arcuata
Adalia bipunctata
No. per sweep per sample date
No. per metre per sample date
Envirofeast A
Sugar
Envirofeast B
Oil+Gum
Unsprayed
Conventional
Treatments

Fig. 2. Responses of *Dicranolauis bellulus* (A), *Geocoris lubra* and *Nabis capsiformis* (B) to food supplement sprays on commercial cotton in Auscott at Narrabri, NSW, 1992-93. (Means between treatments followed by the same letter are not significantly different (P>0.05, LSD test). Error bars represent standard errors.

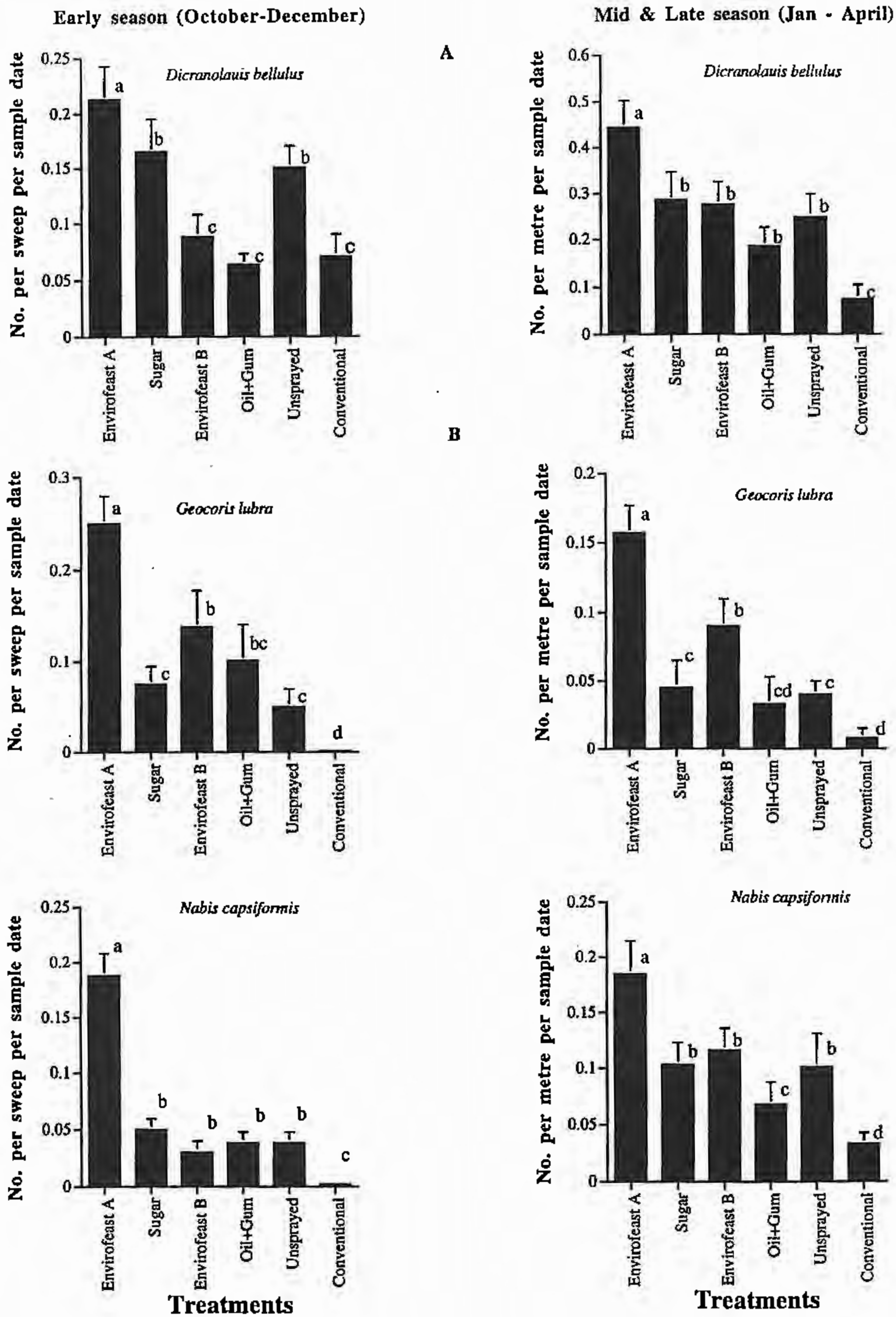

Early season (October-December)
Mid & Late season (Jan - April)
A
B
Dicranolauis bellulus
Geocoris lubra
Nabis capsiformis
No. per sweep per sample date
No. per metre per sample date
Envirofeast A
Sugar
Envirofeast B
Oil+Gum
Unsprayed
Conventional
Treatments

Fig. 3. Responses of *Chrysopa* spp. (green lacewing) (A), *Lycosa* and *Oxyopes* spp. (spiders) to food supplement sprays on commercial cotton in Auscott at Narrabri, NSW, 1992-93. (Means between treatments followed by the same letter are not significantly different (P>0.05, LSD test). Error bars represent standard errors.

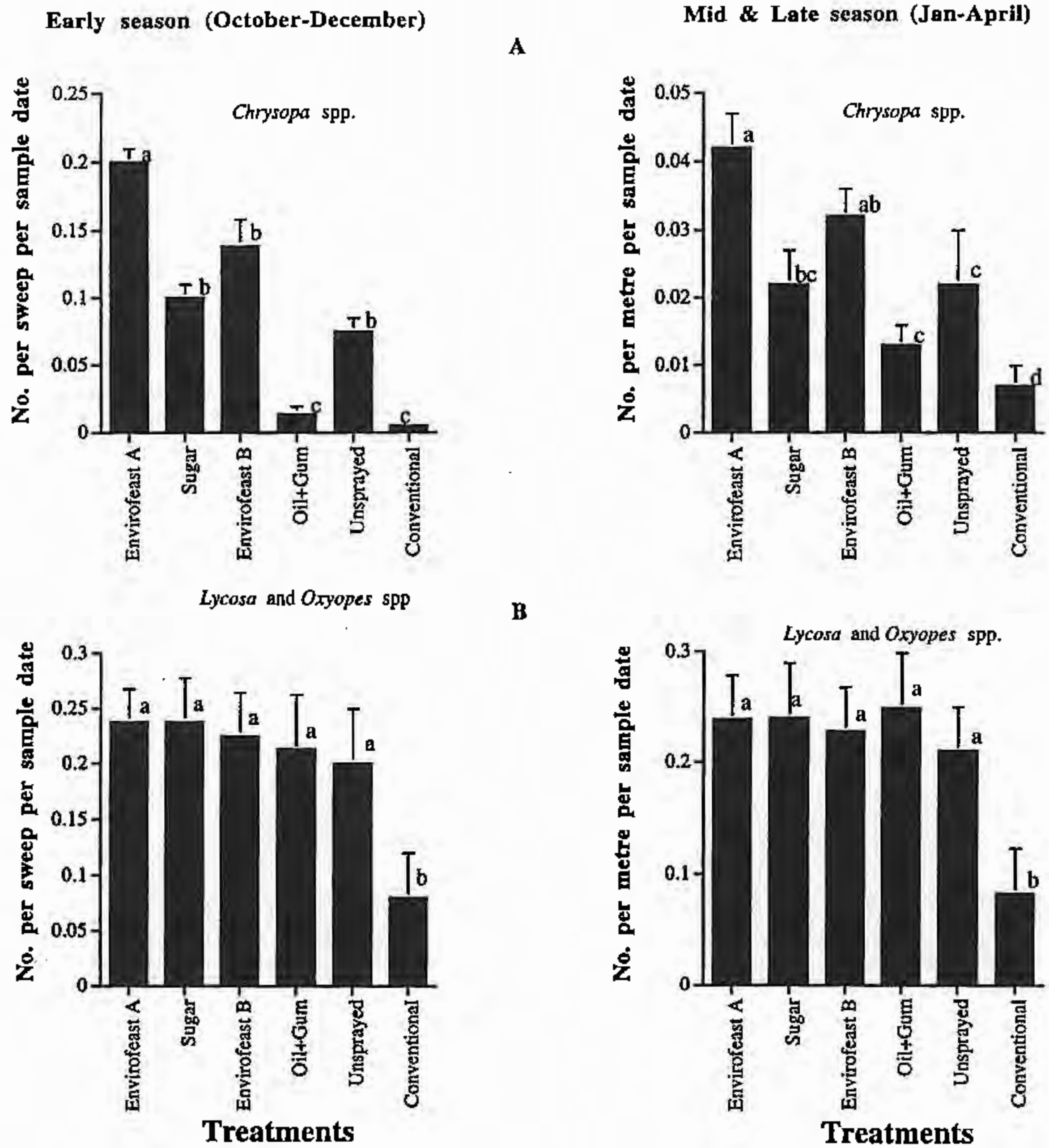

Early season (October-December)
Mid & Late season (Jan-April)
A
Chrysopa spp.
No. per sweep per sample date
No. per metre per sample date
B
Lycosa and Oxyopes spp
Lycosa and Oxyopes spp.
Envirofeast A
Sugar
Envirofeast B
Oil+Gum
Unsprayed
Conventional
Treatments

Fig. 4. Responses of predatory beetles to food supplement sprays on commercial cotton at Norwood near Moree, NSW 1993-94. Error bars represent standard errors.

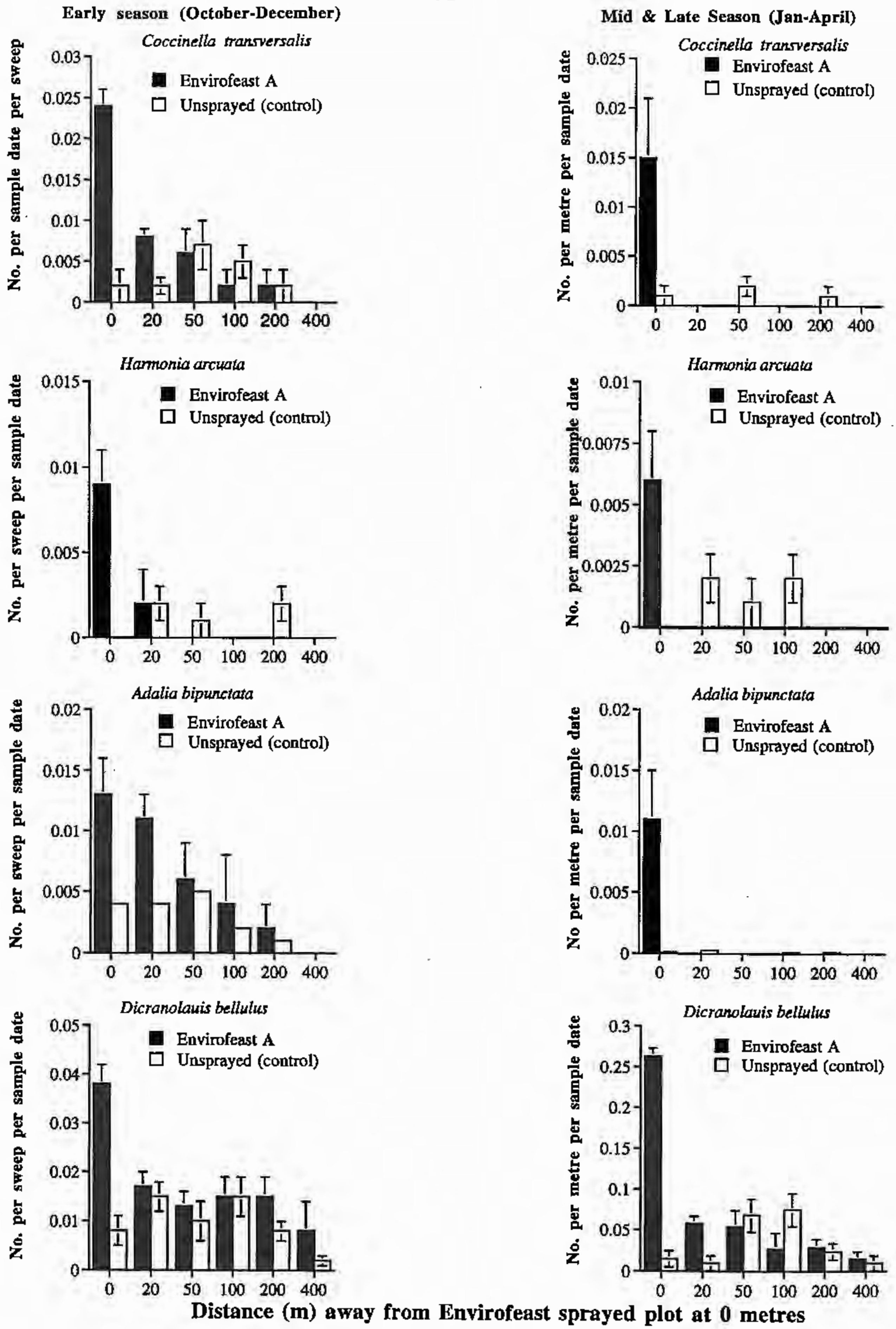
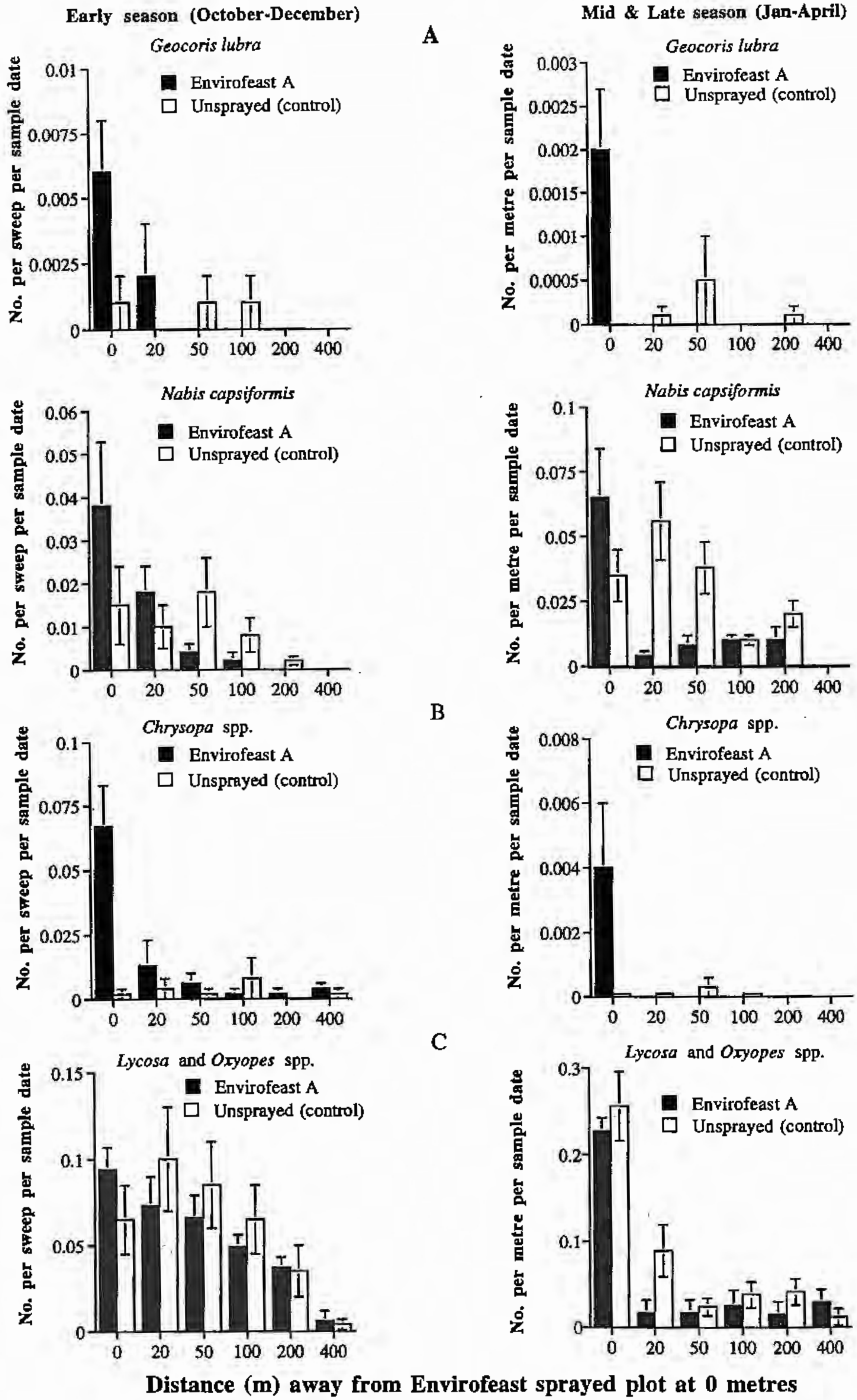

Early season (October-December)
Mid & Late Season (Jan-April)
Coccinella transversalis
Harmonia arcuata
Adalia bipunctata
Dicranolauis bellulus
Envirofeast A
Unsprayed (control)
No. per sweep per sample date
No. per sample date per sweep
No. per metre per sample date
No per metre per sample date
0 20 50 100 200 400
Distance (m) away from Envirofeast sprayed plot at 0 metres

Fig. 5. Responses of predatory bugs (A), lacewings (B) and spiders (C) to food supplement sprays on commercial cotton at Norwood near Moree, NSW, 1993-94. Error bars represent standard errors.


Early season (October-December)
Mid & Late season (Jan-April)
A
Geocoris lubra
Envirofeast A
Unsprayed (control)
No. per sweep per sample date
No. per metre per sample date
Nabis capsiformis
B
Chrysopa spp.
C
Lycosa and Oxyopes spp.
0 20 50 100 200 400
Distance (m) away from Envirofeast sprayed plot at 0 metres

Use of *Medicago sativa* (L.) interplantings/trap crops in the management of the green mirid, *Creontiades dilutus* (Stål) in commercial cotton in Australia

(*Keywords*: *Creontiades dilutus*, Hemiptera, Miridae, interplanting, trap crop, *Medicago sativa*)

R. K. MENSAH and M. KHAN†

New South Wales Agriculture, Australian Cotton Research Institute, PMB Myall Vale, Narrabri, NSW 2390 Australia.

†*Co-operative Research Centre For Sustainable Cotton Production, Department of Agronomy and Soil Science, University of New England, Armidale 2350*

Abstract. The green mirid, *Creontiades dilutus* (Stål) is one of the most serious early-season pests of cotton in Australia. The cotton industry currently relies on broad spectrum insecticides targeted against *Helicoverpa* spp. to control this pest, which in turn disrupts biological control of other major cotton pests. Field experiments to evaluate the use of lucerne, *Medicago sativa* L., in the management of green mirids on cotton were conducted under mesh house free/no choice and commercial farm conditions at Norwood near Moree, and at Auscott and the Australian Cotton Research Institute at Narrabri in New South Wales from 1992 - 94. In the mesh house choice tests and under field conditions, lucerne was preferred over cotton by *C. dilutus* adults for oviposition. However, under no-choice tests, oviposition on lucerne and cotton and also the survival of mirid nymphs on these plants were not significantly different. This indicates that green mirid adults have a distinct preference for lucerne over cotton but in the absence of lucerne the female will not restrain oviposition, but will deposit the same number of eggs on cotton. In an experiment where lucerne was planted as strips within commercial cotton crops, 15 and 35 times fewer mirid adults and nymphs respectively were recorded on cotton compared with cotton without lucerne strips. When lucerne was interplanted with commercial cotton under an IPM regime which had no insecticide sprays against *Helicoverpa* spp., mirid numbers were reduced to levels similar to those achieved by nine conventional insecticide sprays. We conclude that lucerne could be incorporated into an integrated pest management (IPM) system to control green mirids on cotton.