VG97040

Trichogramma wasps in vegetable IPM Programs

Richard R Llewellyn
BioResources Pty Ltd

HAL

Know-how for Horticulture™

VG97040

This report is published by the Horticultural Research and Development Corporation to pass on information concerning horticultural research and development undertaken for the vegetable industry.

The research contained in this report was funded by the Horticultural Research and Development Corporation with the financial assistance of the Vegetable Industry.

Cover price: $22.00 (GST Inclusive)
HRDC ISBN 0 7341 0137 6

Published and distributed by:
Horticultural Research & Development Corporation
Level 6
7 Merriwa Street
Gordon NSW 2072

Telephone:	(02) 9418 2200
Fax:	(02) 9418 1352
E-Mail:	hrdc@hrdc.gov.au

HRDC
HORTICULTURAL RESEARCH & DEVELOPMENT CORPORATION

Partnership in horticulture

HRDC Project Number: VG97040
31 Aug 2000

Trichogramma wasps in vegetable IPM programs

Richard R. Llewellyn
BioResources Pty Ltd

HRDC Project Number: VG97040 (31 Aug 2000)

Trichogramma wasps in vegetable IPM programs

Richard R. Llewellyn
BioResources Pty Ltd
PO Box 578
Samford Qld 4520
Ph. (07) 3289 4919
Fax (07) 3289 4918
Email: richard@bioresources.com.au

Final Report to HRDC on research conducted between September 1997 and August 2000.

Funded by Australian Vegetable Industry Levies and HRDC

31 August 2000

Contents

Media Summary

Trichogramma are tiny wasps that lay their eggs into moth eggs using them to rear their own young. In this way, wasps emerge from the moth egg rather than caterpillars. The presence and extent of these important insects has not been widely studied. Grower and crop consultant knowledge has consequently, with a few exceptions, been low.

This project investigated a number of related issues:

- Levels of parasitism in some horticulture districts and identification of the species involved.
- Collaborative field trials comparing biological insecticides (which do not harm the wasp) with conventional chemical insecticide practices.
- The ability to mass release and establish in crops *Trichogramma pretiosum*, a highly active and competitive species.
- Release rates and methods of field delivery of mass reared Trichogramma.
- Preliminary work field observations of the impact of methomyl and spinosad on Trichogramma.

This project has established that:

- Trichogramma and other moth egg parasitoids are common in most growing districts.
- In some situations their activity has a significant impact of heliothis larvae populations and combined with biological insecticides can provide as good as or better control of heliothis than conventional chemical insecticides.
- *Trichogramma pretiosum* can under suitable conditions be released and become established in some growing districts.
- Mass releases of 90,000 to 120,000 *T. pretiosum* per hectare in sweet corn typically increase parasitism in a crop from nil to 60-70% in one release.
- Manually applied capsules each containing 1,000 wasps is a reliable method of releasing Trichogramma but they can also be applied using mechanised liquid application methods.

In some areas, most notably the Lockyer Valley, Sydney Basin and central west NSW, control strategies have already been modified to take advantage of this natural resource resulting in better control of heliothis as well as reduced costs. These strategies included monitoring egg parasitism in crops, use of biological insecticides and reductions in the use of chemical insecticides. An IPM field guide, "Sweet corn pests and their natural enemies" was compiled, produced and printed as part of this project.

Trichogramma pretiosum has been identified as a very effective parasitoid and is now mass reared for introduction into crops. The establishment of *T. pretiosum* in other districts was deemed a priority by growers and researchers at the National Sweet Corn Project Workshop held in Bowen in June 2000. This parasitoid also attacks a range of other important pests including diamond back moth, loopers, lucerne leaf roller, cabbage cluster caterpillar, cabbage centre grub and others. New biological and "soft" insecticides make it more practical to utilise natural enemies than in the past. Further, where natural enemies are conserved they play an important part in resistance management strategies.

Technical Summary

The problem

Devising means and strategies for the control of major caterpillar pests, like heliothis and diamondback moth is an ongoing task. The development of resistance to insecticides is both a real and potential problem while the desire to reduce chemical inputs is a goal of industry, government and the public alike. Natural enemies of pests are often talked about as a component in these strategies but only limited work has been done in Australia in vegetable crops. Vegetable crops are invariably sprayed with chemical insecticides so that it is difficult to assess the potential impact of natural enemies in a commercial situation. Some new biological insecticides that are harmless to natural enemies have made it possible to consider natural enemies as a component of IPM programs.

The questions arise: Are natural enemies, in this case Trichogrammatids, at a level which is worth considering in IPM programs? Can mass releases be made to assist or speed up the establishment of Trichogramma? This project focuses on the answering these questions.

Research undertaken

A number of related issues were investigated:

- Field laid moth eggs (primarily *Helicoverpa armigera* but also diamondback moth) were sampled in a range of crops and districts. Percentage parasitism was calculated and the species identified.
- Field trials comparing biological insecticides (which do not harm the wasp) with conventional chemical insecticide practices.
- The ability to establish *Trichogramma pretiosum*, a highly active and competitive species in growing districts using mass releases.
- Release rates for mass reared Trichogramma.
- Methods of field delivery of mass reared Trichogramma.
- Some work on the impact of chemicals on Trichogramma.
- An IPM field guide, "Sweet corn pests and their natural enemies" was compiled, produced and printed as part of this project.

Major findings

The major general finding of this work, is that egg parasitoids (local and mass released) can make a major contribution to control of heliothis and other moth pests in vegetable crops when "hazardous" chemical insecticides are minimised. The findings reinforce the need for more "soft options" to complement natural enemy activity and give cause for optimism in relation to resistance management and long term sustainable pest management systems.

More specific findings of the work are:

- Trichogramma and other moth egg parasitoids are found at various levels in most if not all growing districts.
- In some districts, their activity has a significant impact on heliothis larvae populations and combined with biological insecticides can provide as good as or better control of heliothis than conventional chemical control practices.

- *Trichogramma pretiosum,* a species imported from California over 30 years ago has proved to be a more effective egg parasitoid of heliothis than local species (under certain conditions).
- *Trichogramma pretiosum* is well established in the Lockyer Valley and has reappeared each spring for the last three seasons and increased to high levels each season.
- The pattern of parasitism in sweet corn in the Lockyer Valley has been as follows: Low coming out of winter, increasing to 50%-70% parasitism in tasselling sweet corn by late October with most of this caused by *Telenomus* species. In October, *T. pretiosum* starts showing up and increases rapidly. By December, parasitism is typically around 90% in tasselling corn with 90% of this from *T. pretiosum*. By late January, parasitism in vegetative corn is typically high and is close to 100% in tasselling corn with 100% of this from *T. pretiosum*. Growers have therefore been able to drastically reduce chemical inputs from December onward.
- In the central west NSW (Bathurst, Cowra, Dubbo) local parasitoids - *Telenomus* spp., *Trichogrammatoidea* spp and *Trichogrammanza* spp. are present in significant numbers with typically 60-90% parasitism in tasselling sweet corn.
- *T. pretiosum* has established to a lesser extent in the Sydney Basin and Dubbo and appears to have established in the Lindenow.
- In the Lockyer Valley, in minimum sprayed vegetable crops - capsicum, french beans, lettuce, brassicas - egg parasitism of heliothis by local wasps can be high and of DBM moderate.
- *T. pretiosum's* host range includes: Helicoverpa spp., yellow peach moth, vegetable looper, beet webworm, cabbage cluster caterpillar, cabbage centre grub, diamondback moth and lucerne leaf roller.
- *Trichogramma pretiosum* can under suitable conditions be released and become established in some growing districts.
- Mass releases of 90,000 to 120,000 *Trichogramma pretiosum* per hectare in sweet corn typically increase parasitism from nil to 60-70% in one release.
- A more even increase in parasitism is achieved by two releases a week apart.
- Manually applied capsules, each yielding 1,000 wasps, is a reliable method of releasing Trichogramma but they can also be applied using mechanised liquid application methods. This later method is suitable for inoculative releases in large areas.
- In sweet corn crops not sprayed with chemical insecticides, secondary pests can become a problem. Likewise other natural enemies are also common. These were documented and complied into an IPM field guide now in print.

In some areas, most notably the Lockyer Valley, Sydney Basin and central west NSW, pest control programs have already been modified to take advantage of this identified natural resource resulting in better control of heliothis as well as reduced costs. These strategies include monitoring egg parasitism in crops, greater use of biological insecticides and reductions in the use of broad spectrum chemical insecticides.

An indirect result of this project which has established *Trichogramma pretiosum* as an important parasitoid, is that this wasp is now commercially mass reared for introduction into crops.

Future work

This project has established that moth egg parasitoids make an important contribution to pest management in some districts. More surveys are required in other districts to assess the importance of local parasitoids and to assess the suitability of mass releases. One can waste effort trying to conserve natural enemies that are not there or conversely spend effort controlling pests when high numbers of natural enemies are present. This project has focused on sweet corn but preliminary work in other crops suggests similar gains could be made in tomatoes, capsicum, beans and lettuce as well as non horticultural crops like soy beans, lucerne, sorghum and cotton.

B.t. products and virus products are making it more practical to utilise natural enemies. Some new products in the pipeline will enhance this capacity and it is important that growers and consultants become more aware of the role of natural enemies in the package when using these products. Similarly, when field trials are conducted with "soft" products it is important to monitor the activity of natural enemies as the results may be confusing and even contradictory without this data.

Further, where natural enemies are conserved they play an important part in resistance management strategies. This benefit is perhaps undervalued and requires more attention.

The establishment of *T. pretiosum* in other districts has been deemed a priority by growers and researchers at the National Sweet Corn Project Workshop held in Bowen in June 2000. This parasitoid also attacks a range of other important pests including diamond back moth, loopers, lucerne leaf roller, beet webworm, cabbage cluster caterpillar and others. Numerous and repeated releases into unsprayed crops, (not necessarily vegetable crops e.g. maize, lucerne, sorghum) are desirable and will increase the chances of establishment.

Some further field trials are currently in progress in sweet corn in the Lockyer Valley that compare springtime mass release strategies. This work also needs to be done in other districts.

Area wide management of heliothis in the future is likely to include conservation and encouragement of egg parasitoid populations. A better understanding of alternative hosts and the crops and plants which harbour these hosts is also desirable so that management practices may be expanded to facilitate the reliable overwintering of parasitoids and a rapid build up in spring.

Introduction

Trichogramma are tiny wasps less than 0.5 mm long. The females lay their eggs into moth eggs. The wasp embryos then develop into fully formed wasps inside the moth egg, killing the developing caterpillar in the process. Because of this 'ovicidal' action it prevents caterpillar damage making them a particularly attractive biocontrol agent.

Locally occurring Trichogramma have been used successfully to suppress heliothis in the tomato processing industry in NSW and Northern Victoria (Smith *et al*) and in California since the late 1980's (Hoffman *et al*). Previous work by the author (1997) and McLaren (1981) and Scholz (1994) has demonstrated the ability of mass released Trichogramma to increase parasitism in a wide range of crops.

The initial focus of this project was to be on mass releases of Trichogramma and related issues. However, early findings which identified moderate to high levels of parasitism by local species led to a broadening of the study. During the first field trial in the Lockyer Valley, in processing sweet corn, October 1997, it was found that parasitism of heliothis eggs was already 55%. This situation presented an opportunity to compare conventional chemical insecticide practices with a combination of natural egg parasitism and applications of nucleopolyhedrosis virus (NPV or Gemstar®).

The results revealed significantly greater damage in the chemical block (50 % side damage) than in the NPV block (28% side damage). This was the first commercial scale trial of NPV in sweet corn and raised many issues and questions which led to a widening of the project to include the study of the egg parasitoids already in crops in various districts.

By early 1998, parasitism in tasselling sweet corn through the district was typically over 90% and close to 100% of this was caused by *Trichogramma pretiosum*, a species released in small quantities in the Lockyer Valley three years previous by Brad Scholz, QDPI. This finding was relayed to growers who reduced chemical use in sweet corn in particular. These findings contributed to the registration of Gemstar® for sweet corn.

A mass culture of *T. pretiosum* was then established with the assistance of Bugs for Bugs, Mundubbera and releases were made into sweet corn crops to determine appropriate release strategies, release rates and timing. These trials were followed by a comparison of various release methods, firstly in the laboratory and then in the field. Some observations were also made of the effects of methomyl and spinosad sprays on parasitism.

T. pretiosum was released in the Sydney Basin, Lindenow, Bowen, Bathurst and Cowra. Establishment appears to have occurred in the Sydney Basin and perhaps Lindenow. Parasitism was surveyed to various degrees in these districts and revealed moderate to high levels at some times during the season. Although no releases were made in the Dubbo district, *T. pretiosum* was found in good numbers.

These findings have had implications for the management of sweet corn within the life of the project with significant reductions in chemical use especially in the Lockyer Valley. There is now a greater awareness of the potential of natural enemies in IPM programs. This will help reduce dependence of chemical insecticides, reduce resistance pressures and environmental and public health concerns. Reductions in insecticides will in turn provide more opportunities for natural enemies to increase to useful levels within a district.

The project has also identified other vegetable crops which are likely to benefit from a better utilisation of egg parasitoids in combination with the "soft" products already available. These include suppression of heliothis in lettuce, beans, capsicum and tomatoes; of diamondback moth in brassicas and beet webworm in beetroot. This capacity will be further enhanced when more Lepidoptera specific insecticides become available.

In the course of the work in sweet corn, it was soon evident that secondary pests could be a problem in crops not sprayed with broad-spectrum insecticides. Information was collected on these pests as well as other natural enemies and placed on a web site for easy access to growers and consultants. At the 1999 National Sweet Corn Conference it was proposed that the information collected be expanded and printed in a pocket field guide. The project was subsequently extended and 2,000 copies were printed in June 2000. Distribution is being handled by the QDPI Bookstore.

Materials and Methods

Numerous surveys and laboratory and on farm trials were conducted in the course of the project with the direction of the research influenced by the results of previous trials. The work was of various levels of complexity, from simple measurements of egg parasitism to determine the activity of local parasitoids, to more complex replicated trials. The work can be divided into the following headings:

Surveys of egg parasitoids and releases of *T. pretiosum*

Work in sweet corn:

- Field trials comparing NPV and local parasitoids with conventional practices.
- Sampling for parasitism of heliothis eggs in sweet corn crops in Lockyer Valley and releases of *T. pretiosum* in those districts.
- Egg parasitism in other Districts:
  - Sydney Basin, Central West NSW and Dubbo, Bowen.
- Summary of egg parasitoids found in sweet corn.

Work in other crops:

- Egg parasitism of moth pests in brassica crops in the Lockyer Valley.
- Crossing trial to verify the identity of *T. pretiosum* in the Lockyer Valley.
- A comparison of three egg parasitoids of diamond back moth.
- Egg parasitism of heliothis in various vegetable crops in the Lockyer Valley.
- Parasitism through winter and the host range of *Trichogramma pretiosum.*

Issues relating to the mass release of *Trichogramma pretiosum*

- A comparison of release rates for *T. pretiosum* in sweet corn.
- Evaluation of field delivery methods for Trichogramma.
- Preliminary field observations of the effects of chemicals on *T. pretiosum.*

In the course of the trials important observations were made unrelated to the focus of a specific trial. For instance, trials that were aimed at comparisons of release systems also served as observations of the background levels of local parasitoids as well as the capacity of *T. pretiosum* to establish in a crop under competitive situations. Some of these findings will be related in the results and discussion of the individual trials.

"Sweet corn pests and their natural enemies" field guide

- Compilation of an IPM field guide for sweet corn.

General information about the materials and methods

Where possible pre release samples were taken before any mass release was made. This provided an indication of the relative importance of local parasitoids and the species active. Field trials and observations endeavored to utilise untreated and/or unsprayed controls. However, in a commercial situation this was not always possible.

Sampling for egg parasitism
Two methods were used for sampling parasitism. Where field laid eggs were plentiful parasitism was measured by collecting "brown ring" stage eggs and growing them out to see if a larvae or wasps emerges. Where field laid eggs were unreliable, fresh heliothis egg sentinel cards were placed in the crop at regular intervals and collected two days later. The processes and the pros and cons of these methods are discussed below:

Field laid eggs
Collecting field laid eggs and growing them out in microtitre trays is a practical and efficient method of measuring parasitism when eggs are easy to find. It also minimises handling and makes identification of the wasps that emerge relatively easy. The steps are as follows and these are the guidelines that have been distributed to crop consultants and other researchers:

- Collect at least 20 eggs from across each block/plot/treatment.

- Select "brown ring" stage eggs if possible, these are usually two to three days old. Pure white eggs may have just been laid and may not have had time to be parasitised.

- Punch out discs of leaf containing the egg with single hole paper punch.

- Use fine tipped tweezers to place the leaf disc into a multi cell tray.

- Cover the tray with strips of clear, wide sticky tape. Make a very small hole with a very fine needle (an acupuncture needle is ideal) in the tape over each cell to allow moisture to escape to prevent mould developing.

- Label the tray with date, site, plant stage etc. Keep in a warm place (around 25-30°C if possible) but out of direct sun.

- Eggs not parasitised will darken and produce a small caterpillar within about 3 days (depending on temperature).

- Mark the cells with larvae - these cells will not need further inspection. A rough % parasitism can be calculated at this stage and this may be all the information that is required for crop monitoring purposes.

- The eggs that have been parasitised will go a coal black colour in about 4 to 5 days and the wasps will emerge from black eggs 7-10 days after collection.

- Some eggs may be "unviable" producing neither larvae or wasp. Under normal unsprayed conditions this may account for around 5% of total number of eggs collected.

Soon after the wasps emerge from parasitised eggs an identification is made without removing the wasp from the microtitre cell.

Percentage parasitism alone does not tell us the number of egg parasitoids actually in the crop and can be misleading. By multiplying the average number of eggs per plant by % parasitism by the number of plants per hectare we get the number of parasitised eggs per hectare. This figure provides an indication of the potential level of parasitism in the week ahead and aids the decision whether a mass release is worthwhile. It does not allow for mortality factors like predation, heat, wind or rain.

Sentinel cards

Heliothis egg sentinel cards were used several times and are a useful tool when conducting field trials when egg pressure is very low or unreliable. The cards can be placed in a grid fashion at the same density in the various treatments or replicates. A minimum of three heliothis eggs on cloth or paper towelling are stapled to another strip of paper (about 10 mm x 70 mm) which is then stapled to the plant. The strip of paper can be numbered or used for notes on collection. The cards can all be placed at the same time and collected two days later. This provides an assurance that all the eggs sampled have been in the crop for the same period and are therefore of the same age.

On collection, the cards are carefully inspected and cards with no eggs noted (an indication of predation levels) and any wasps removed to prevent contamination of the other cards. The cards must then be placed in gauze bags to allow emerging caterpillar larvae to move away from the other eggs on the cards as heliothis larvae are cannibalistic. After 5 days at 25°C, cards with parasitised eggs are noted and placed singly into glass vials to enable identification of the wasps. This whole process is more time consuming than the collection of field laid eggs.

Trichogramma used in mass releases

Trichogramma pretiosum were collected out of *Helicoverpa armigera* eggs on sweet corn in the Lockyer Valley and subsequently mass reared on *Sitotroga cerealella* eggs. Each generation is approximately 9 days in the mass rearing facility or 40 generations per year. The culture was renewed at least annually.

Table 1. Trichogramma strains used in mass releases.

Date Collected	Strain Code	Site	Notes
Oct 1997	TPTH1097	Tent Hill	Collected from DBM eggs in brassicas.
Jan 1998	TPLV0198	Gatton	Collected from field laid heliothis eggs in corn.
Sept 1998	TPLV0998	Mulgowie	Release of TPLV0198 and recapture on heliothis sentinel cards in sweet corn.
Jan 1999	TPLV0199	Gatton	Fresh culture out of field laid heliothis eggs in sweet corn.
Jan 2000	TPLV0100	Gatton	Fresh culture out of field laid heliothis eggs in sweet corn.

Trichogramma release capsules

Unless stated Trichogramma were released via a "capsule" that were assembled and loaded by Bugs for Bugs, Mundubbera. They consist of a piece of cardboard 30 mm x 30 mm and 3 mm thick. A hole 20 mm diameter is punched in the card and sticky paper is fixed on one side. Loose parasitised eggs are spread over the sheet which adhere to the base of the holes. Another sheet of paper is then fixed to the other side. Three small escape holes are punched in the sides. The capsules provide protection from the sun, rain, irrigation and some predators. Other methods used are described in the section on delivery methods.

Identification of species

Accurate species identification of egg parasitoids is a task for a specialist taxonomist. But when conducting trials of this nature it is not possible to make slides of each sample and to obtain expert verification. In one trial hundreds of wasps emerge for identification. Four genera or subgenera are readily observed:

- *Telenomus* spp.
- *Trichogramma* spp.
- *Trichogrammanza* spp.
- *Trichogrammatoidea* spp.

Telenomus spp. are readily distinguished from the Trichogrammatids, as the former is black all over and about 0.7 mm long compared to the Trichogrammatids which range from 0.25 to 0.4 mm.

For the purposes of this research, the Trichogrammatid genera and subgenera were distinguished by either the length of fringes on the wings or the number of segments in the male antennae. See Table A1 in the Appendix for more details.

Trichogramma species encountered are *T. nr brassicae, T. australicum and T. pretiosum,* and these are not easily separated. However, *T. pretiosum,* the species used in the mass releases can be fairly confidently distinguished from the other two by it's two toned appearance - it has a dark abdomen and a pale honey coloured thorax and head while the others are much darker.

In the Lockyer Valley where *T. pretiosum* is common it is not possible to determine the effect of releases without untreated controls. In most other districts there was no problem in determining the effect of the release as there were no or very low numbers of any *Trichogramma* species present before the release. At a few sites in Bowen in 2000, another *Trichogramma* species was present in high numbers and it was difficult to separate this species from *T. pretiosum.*

Measuring mortality of larvae from NPV infection

Several trials were performed which included measuring mortality of larvae after applications of nucleopolyhedrosis virus, NPV (Gemstar®). Larvae of various sizes were placed directly in the field into vented cups containing heliothis diet (provided by QDPI Toowoomba). The size of larvae was noted on collection. Cups were then held at 25°C and inspected daily and dead grubs noted. Mortality from larval parasitism was also noted. Larvae were kept until pupation.

Surveys of egg parasitoids and releases of *T. pretiosum in* sweet corn

NPV and local parasitoids versus conventional practices

The field work started by monitoring egg parasitism in sweet corn in the Lockyer Valley in mid October 1997. This was to be followed by mass releases of Trichogramma. However, surprisingly, the sampling revealed moderate levels of parasitism and led to the running of an opportunistic trial which was to have significant consequences:

Trial 1 Processing sweet corn Tent Hill SE Qld mid October 1997.
A week before tasselling the egg pressure was 2 per plant. Egg parasitism was higher than expected for this time of year at 41% with all this the result of *Telenomus* spp.

It was clear that to apply a "soft" chemical at this stage would be preferable to the application of a broad spectrum chemical insecticide. A small quantity of an old stock of Gemstar® (Nucleopolyhedrosis Virus, NPV) was obtained from the QDPI and the first commercial scale trial of NPV in sweet corn was underway.

There were two crops planted about 200 m apart. One crop had two NPV sprays and the other had two applications of a broad spectrum insecticide mix of methomyl and a synthetic pyrethroid from the air. NPV applications were also made from the air at 4.5 litres Gemstar® over 5.7 ha. Equal to 780 ml/ha. Applied in 30 litres per ha.

Three days after the first application of the NPV, larvae of various ages were collected into diet cups and grown out and assessed for NPV infection. The first NPV spray produced a low mortality of larvae: 19%, 28% and 29% for 2nd, 3rd and 4th instar larvae respectively (n=69) with 3.4% mortality in the Standard Insecticide Block (n=29).

Samples taken after the second application showed much higher levels of mortality: 100%, 89% and 82% for 2nd, 3rd and 4th instar larvae respectively (n=60).

An in field harvest assessment (100 cobs per treatment inspected) revealed considerably less damage in the NPV block with "side damage" being the most important factor in a processing crop:

Table 2. Harvest assessment, Tent Hill Rd Site, Oct 1997.

Treatment	% cobs with Nil damage	% cobs silk damage only	% cobs tip damage only	% cobs with side damage	% cobs with tip and side damage	% cobs with grubs at harvest
NPV	37	2	33	28	61	17
Standard	21	3	26	50	76	42

Egg parasitism in the NPV block increased to 56% by silking. The proportion caused by *Telenomus* dropped from 100% on 18 Oct to only 14% by 7 Nov with *Trichogrammatoidea* spp. and *Trichogramma* spp. accounting for the remainder but the proportions and species were not recorded. At this stage of the project we were not aware that *T. pretiosum* could have been present.

The data from this trial showed that a program using NPV and local egg parasitoids resulted in less damage than standard practices and set the course for further observations and trial work of various levels of complexity.

Trial 2 Seed sweet corn Lowood SE Qld. Nov 1997

This seed sweet corn crop was grown under very hot conditions (mid to high 30's) and failed to pollinate successfully. However, the egg sampling data was useful in showing that *Trichogramma* were still very active at high temperatures with parasitism at 100% on one occasion. On another occasion parasitism dropped to 29% after an application of mancozeb. NPV was applied but the low number of grubs present prevented an assessment.

Trial 3 Fresh market sweet corn Mulgowie SE Qld. Dec 1997

Larvae samples were taken at another site to assess the efficacy of NPV applications. The crop had NPV applied at 500 ml /ha from the air. Results were: 82%, 71% and 53% mortality for 2nd, 3rd and 4th instar larvae respectively (n=67).

Egg parasitism was monitored and increased to 88% by silking with egg pressure around 5 to 6 per plant. In a nearby planting that had conventional chemical treatments, parasitism fell as soon as spraying started. The graphs below illustrate just how many more larvae then need to be killed by the insecticide applications, up to 5 larvae per plant on 5th Jan at early silk. Both crops had around 80% tip damage but detailed harvest assessments were not conducted.

Figure 1. Trial 3, Percent Parasitism, NPV Block, Mulgowie, Dec 1997.

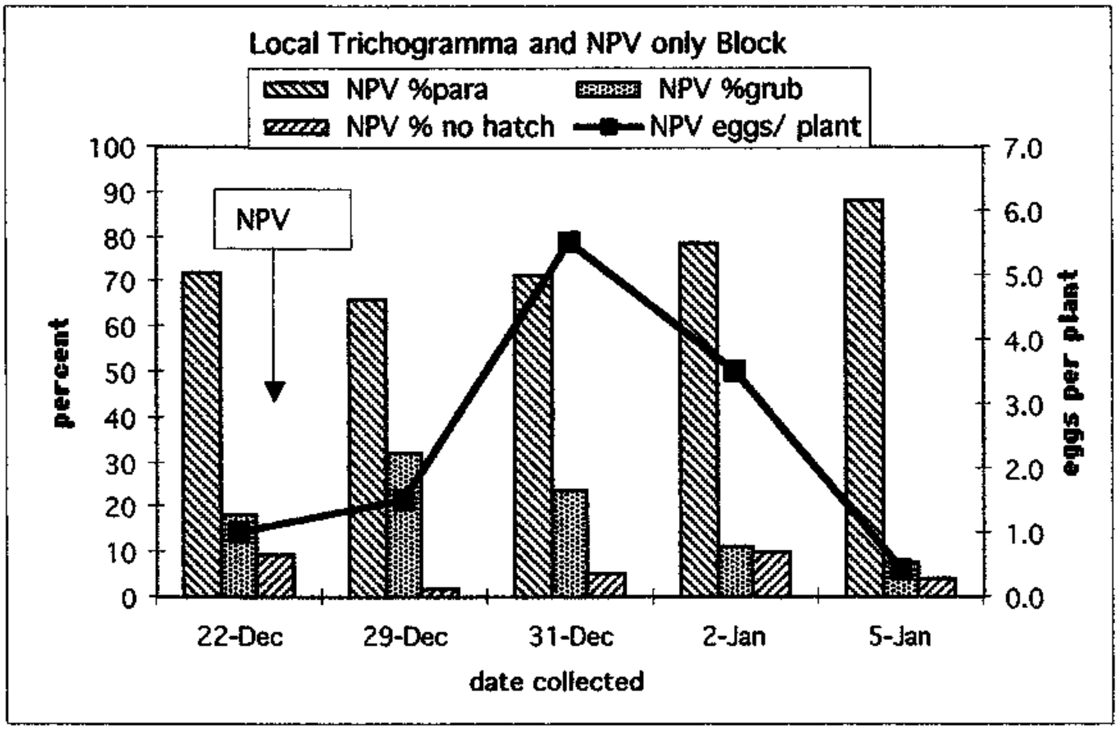
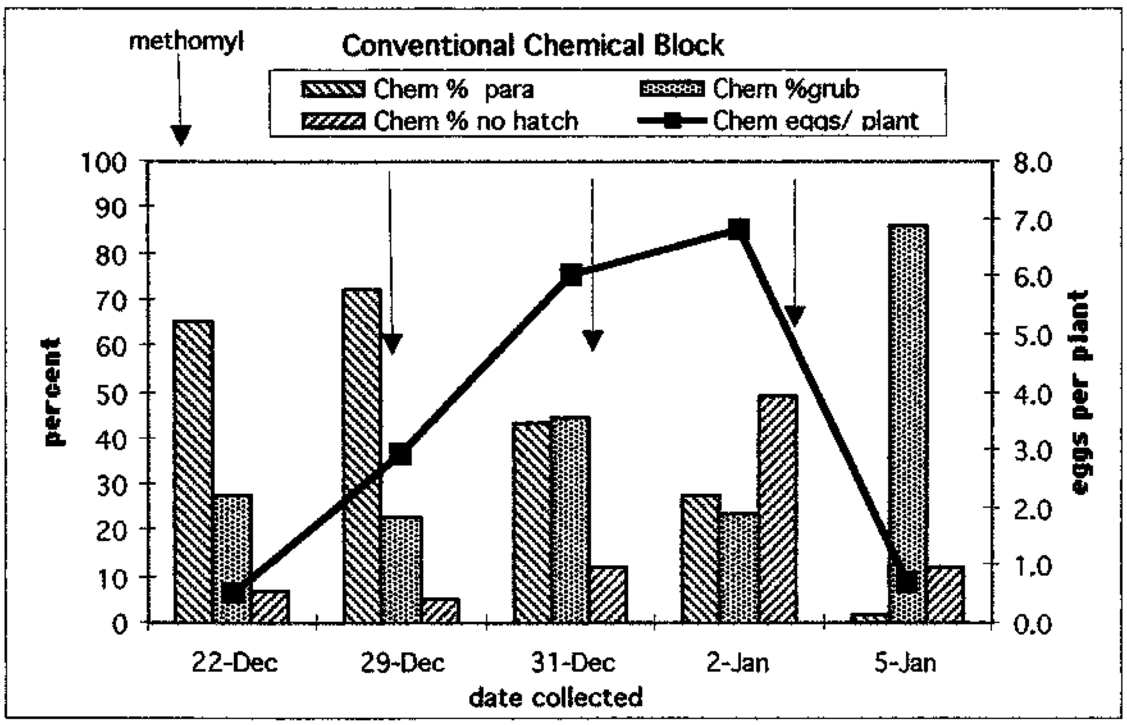


Figure 2. Trial 3, Percent Parasitism, Standard Chemical Block, Mulgowie, Dec 1997.



Trial 4. Processing sweet corn Lake Clarendon Rd Gatton Dec 1997
This trial, conducted in late December 1997, compared NPV and the local Trichogramma with a conventional insecticide treatment, (2 x methomyl + deltamethrin). The blocks were identical, 4 ha each and about 200 m apart.

The first egg collection was made two weeks before tasselling when plants were 600 mm high and yielded 92% parasitism with an egg pressure of 2 per plant. Egg pressure increased to 10+ eggs per plant at silking in both sites and parasitism increased to 95+% in both sites (chemicals not being applied in the chemical site until early silking). As expected parasitism levels dropped to less than 48% after the first insecticide application. In the NPV site, percent parasitism remained in the high 90's and all from one species of wasp.

One NPV was applied just as egg pressure increased but grubs were very hard to find (due to the high levels of parasitism) and no mortality test was performed so it is unknown just how much the NPV contributed. However, the egg parasitism data and the harvest assessment conclusively demonstrated the negative effects of chemical application in a situation of high egg pressure and very high egg parasitism:

Table 3. Trial 4. Harvest Assessment* Lake Clarendon Rd Site, Jan 1998.

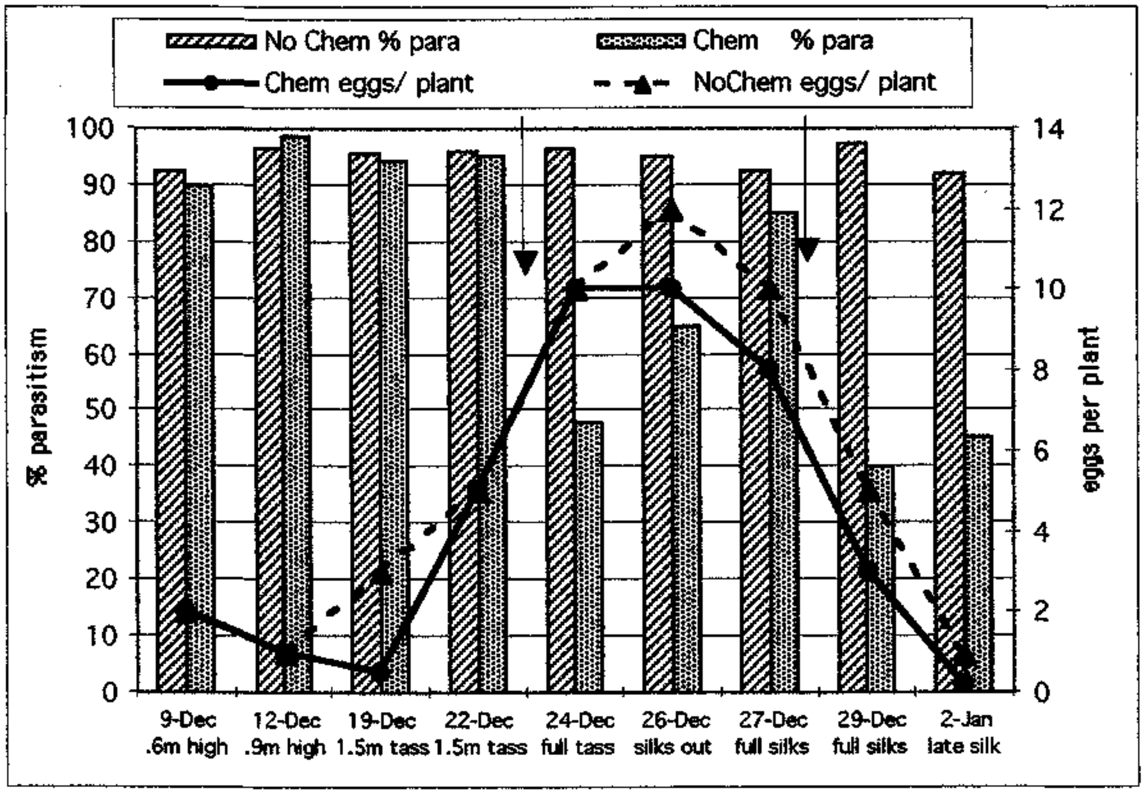
Treatment	% cobs with nil damage	% cobs silk damage only	% cobs with tip damage	% cobs with side damage	% cobs with grubs at harvest
NPV and local Trich	62	0	15	14	23
Standard Chemical	9	1	17	51	73

*100 cobs inspected in the field just before harvest per treatment.

Four days after the first chemical spray, parasitism had recovered to 85% probably a reflection of the high numbers of parasitoids emerging from eggs parasitised before the spray. After the second spray parasitism fell to 40%. Figure 3. below, illustrates the negative impact of the insecticide sprays on parasitism, allowing high numbers of larvae to get through which the insecticide was unable to check.

At this stage of the project and after discussions with Brad Scholz, QDPI Toowoomba, we realised that the species doing all the work was *T. pretiosum* which had become established in the district from several small releases in 1995. This species was imported from California in the 1970's and released in cotton in NW Western Australia where it has became established and in Queensland where it has not been recovered. Brad Scholz obtained a field sample from WA and reared a quantity in 1995 to conduct a series of small scale species comparison trials in sweet corn at the Gatton Research Station. The results showed that *T. pretiosum* was no better than other species tested and because *T. pretiosum* was not in commercial culture at the time, it was not tested any further (pers. comm. B. Scholz). *T. pretiosum* were then recorded in high numbers by Scholz at the Gatton Research Station in March/April 1997 (1998) and assumed to be the progeny of the those released in 1995.

Figure 3. Site 4. Percent parasitism and eggs per plant, NPV and local Trichogramma versus conventional chemical practice, Lake Clarendon Rd Site. Dec 97-Jan 98



The dramatic nature of the results at this site were instrumental in a shift in grower practices. This trial also provided an indication of the ability of *T. pretiosum* to keep up with a rapid increase in egg pressure (from 2 to 10 eggs per plant in 14 days). The number of parasitised eggs per plant (% parasitism x eggs per plant) was around 2, two weeks before full tassel.

The observations above were the first record of very high levels of parasitism in mid summer. Scholz had recorded high levels later in the previous season. This series of events and observations highlights the difficulty of assessing parasitoids for their suitability as mass reared biocontrol agents. It is often stressed in quality control and species selection procedures that laboratory performance may differ from field performance. (Hassan p 58). But the observations in the Lockyer Valley suggest that even field assessments may not necessarily indicate the most appropriate species. The ability of a biocontrol agent to survive and compete over a longer term within a district is of prime importance and very difficult to assess experimentally. Some emphasis has also been placed on the need to select local acclimatized species for mass release (Hassan p.59). But again this work has shown that *T. pretiosum* is performing better in sweet corn in the Lockyer Valley than the local *Trichogrammatoidea* species and overtakes the *Telenomus* species. This, however, may not be the case in other districts.

Gatton Feb 1998

At another site, 1 km west of Gatton, pre tassel sweet corn was sampled on 6 Feb and yielded only 20% parasitism. Egg pressure was low at this stage. Only B.t. was used from this time onward. Egg pressure jumped in early March. Checking recommenced in another crop nearby on 6 March at 1 egg per plant and yielded 100% parasitism. Egg pressure jumped to 16/plant while parasitism remained in high 90's. The crop had around 15% tip damage at harvest.

Mulgowie March 1998

Collections were made in early March in pre tassel and silking corn under very heavy pressure (15+/pl) and yielded close to 100% parasitism, all from *T. pretiosum*. At this stage the grower ceased chemical spraying but no harvest data is available. Yellow peach moth did emerge as an occasional problem with damage around 25% on one occasion. There was also a problem with thrips in some crops.

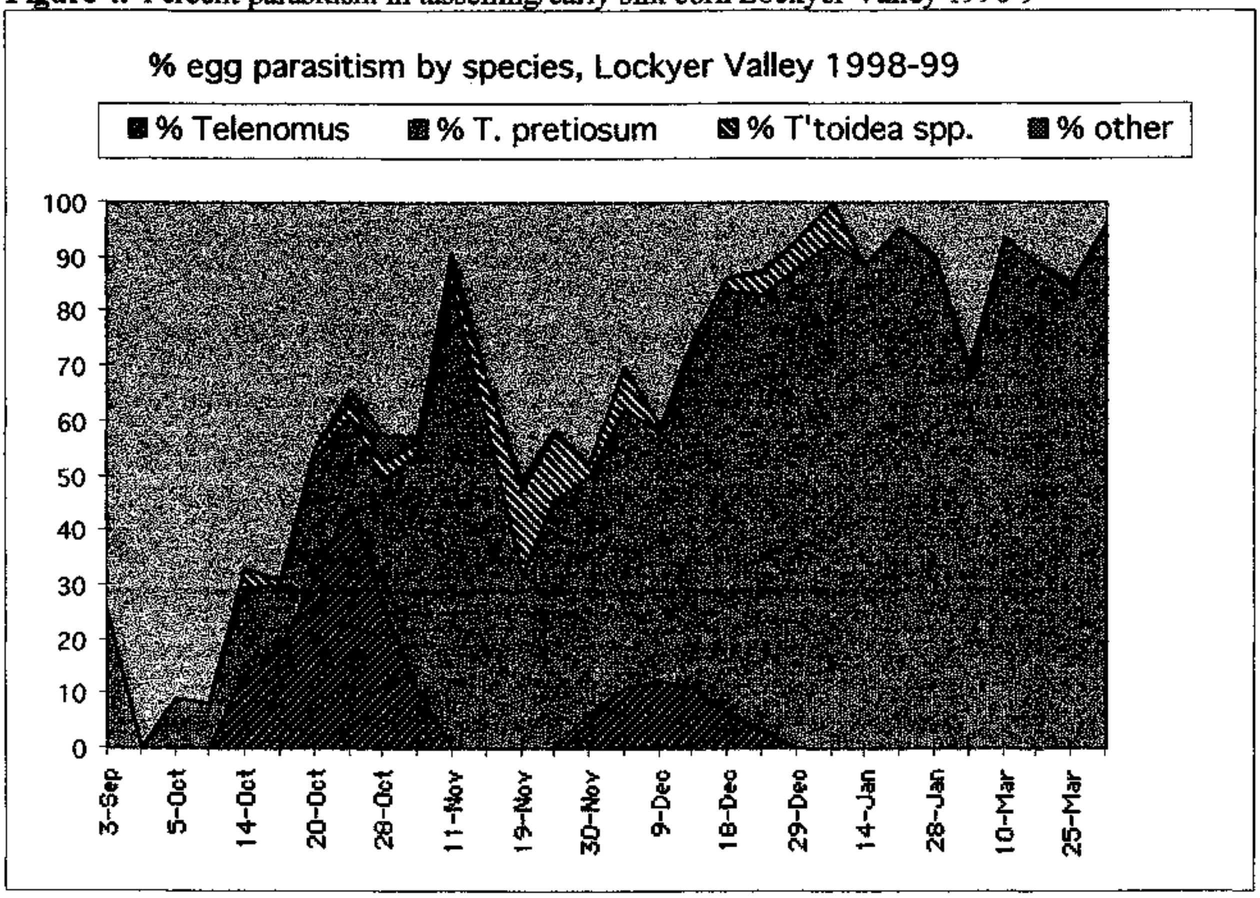
It was observed that only where *T. pretiosum* was producing the overwhelming majority of the parasitism (>90%) did we see very high levels of parasitism, between 90% and 100%.

Monitoring of egg parasitism in the Lockyer Valley, 1998-99

After the successful observations and trials in 1997-98, the question arose: would *T. pretiosum* reappear in spring and once again make a major contribution to heliothis control? Numerous crops and sites were sampled through the 1998-9 season and the graphs below summarise the data collected in crops where no Trichogramma releases were made. Some of the crops may have benefited from releases made earlier into nearby crops but this is impossible to quantify.

The graphs below average, week by week, both egg pressure and parasitism rates at the tasselling/early silk stage as well as the species present over the whole district (data in Table A2 in the appendix):

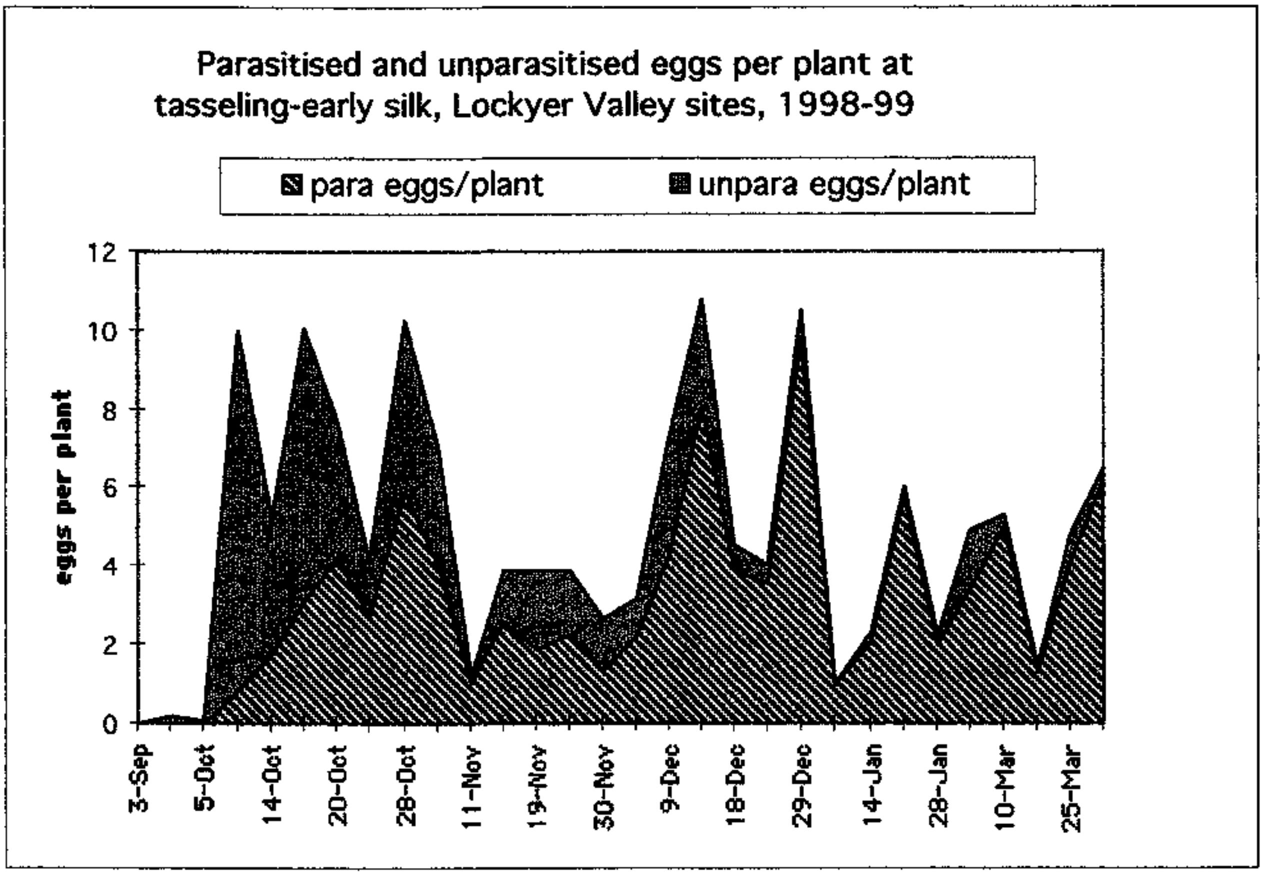
Figure 4. Percent parasitism in tasselling/early silk corn Lockyer Valley 1998-9



The data shows a relatively rapid increase in parasitism rates through October under high egg pressure. By early November rates at tasselling were around 65% under heavy pressure and by mid December were between 85% and 98%. *Telenomus* was important early but by late December *T. pretiosum* had gradually taken over and was causing close to 100% of the parasitism. By early December, growers had switched to a minimum chemical insecticide program, utilising B.t. products and Gemstar® as a backup to the parasites.

Figure 5 below shows the calculated absolute numbers of parasitised and unparasitised eggs in crops around tasselling. Egg pressure was low through September but jumped dramatically in October and remained high for that month. Through October egg parasitism increased, but with egg pressure high many larvae were getting through and chemical insecticides were applied in most crops.

Figure 5. Parasitised and unparasitised eggs per plant in tasselling/early silk corn Lockyer Valley 1998-9



In the Lockyer Valley there are three distinct periods in relation to parasitoids which will influence IPM programs. Each period has some key characteristics which define it and influence spray decisions:

1. Winter to Late October – natural enemies are low coming out of winter. Biological insecticides used in pretassel period will facilitate build up of parasitoids but high egg lays can occur suddenly and chemical insecticides maybe required at silking. (Work is ongoing to develop better tactics for this difficult period including mass releases of Trichogramma.)

2. Late October to Mid December - egg parasitism is typically 50-70% at tassel and other natural enemies are increasing. Chemical controls may be required during silking during periods of high pressure.

3. Mid December onward - *Trichogramma pretiosum* is typically at very high levels throughout the district and egg parasitism pretassel through silking is typically over 90% even under heavy egg pressure. H5 variety grown in this period is more resistant to heliothis. Crops from December onward may not require any controls for heliothis but the secondary pests yellow peach moth and green vegetable bug may require late applications of chemical insecticides.

Egg parasitism of heliothis in sweet corn in other Districts

Elimbah SE Qld 1998

As with sweet corn in the Lockyer Valley this site had typically high damage levels (60%-80%) through the season in spite of regular chemical applications. The last crop grown by this grower for the season was treated with NPV. Egg pressure remained very high (15+/pl) through tasselling and silking. NPV was applied from the ground at tasselling at 500 ml/ha and then every 3 days. The Trichogramma -NPV combination resulted in only 15% tip damage even under this heavy pressure.

Parasitism of heliothis eggs in sweet corn in NSW

Sydney Basin

Jan 1998

The first collection in this district was in unsprayed pre tassel sweet corn and collected 30 Jan 1998. Parasitism was 10% and all by *Telenomus* spp. (n = 72).

Egg parasitism in sweet corn, 1998

A relatively small release of 120,000 *T. pretiosum* (Strain TPLV0198) via capsules was then made in one sweet corn crop in mid Nov 1998. The numbers of eggs sampled was low but results indicated that *T. pretiosum* had established in the crop. Samples were taken again in successive crops in December and again in March 1999 under moderate to high egg pressure. By March, parasitism was over 90% with 96-100% of this caused by *T. pretiosum.*

This area, like the Lockyer Valley, has continuous plantings of sweet corn and other crops as well as lucerne and headland areas nearby, an ideal situation for the maintenance of Trichogramma.

Table 4 . Release of *T. pretiosum* in sweet corn, Sydney Basin, Nov 1998.

Date of sampling	% parasitism	% of total parasitism caused by *T. pretiosum*
pre release 13 Nov 1998	23	0
post release 20 Nov 1998	58	32
11 Dec 1998	82	44
10 Mar 1999 (3.4 egg/plant)	90	96

Sydney Basin 1999-2000:
No releases were made in this area in the 1999-00 season to see whether *T. pretiosum* would reappear. In early 2000, *T. pretiosum* was recovered in low numbers in unsprayed sweet corn near the previous years release site and at a site 2 km away. This was after a long period of wet weather. Samples were then taken on 4 March 2000 and showed parasitism had risen to 91% with 72% of this caused by *T. pretiosum.*

This work indicated that *T. pretiosum* has established to some degree in this area after a relatively small release. Parasitism is still low early in the season so that mass releases in the spring as soon as heliothis eggs appear are likely speed up the natural increase.

Central West NSW

Collections made 1998:
Some small samples were collected in processing sweet corn in early 1998. At Bathurst, eggs collected 29 Jan yielded 33% parasitism, all from *Telenomus* spp. (n= 48). A small release of *T. pretiosum* (Strain TPLV0198) was then made into one crop.

At Cowra eggs collected 6 Feb 1998 yielded nil parasitism (n = 50)

Collections made 1999
Bathurst site
Eggs were collected 26 Jan '99 at early silk, in processing sweet corn, where a small release of *T. pretiosum* was made in 1998 and followed by a flood in winter. Eggs yielded 89% parasitism, 95% of which was from *Telenomus* spp. and 5% from *T. pretiosum.* These high levels of parasitism were a surprise and help make sense of the in-parallel trials by NSW Agriculture where the nil treatments performed as well as the conventional chemical practice (Beckingham 1999).

Cowra, 26 Feb 1999 Survey and *T. pretiosum* release
This work was part of a NSW Agriculture trial which followed on from the work in Bathurst aiming to measure the levels of egg parasitism in the Cowra district and to make a release of *Trichogramma pretiosum* in an effort to establish this wasp in the district.

Materials and Methods
Immediately before the release of *T. pretiosum* field laid Heliothis eggs were collected into microtitre trays. The Trichogramma capsules were placed at 90 per hectare or every 11 meters down the row and in every 15th row (rows 750mm apart) aiming to release approximately 90,000 wasps per ha. The *T. pretiosum* released were Strain TPLV0998 and had been mass reared on *Sitotroga cerealella* for 15 generations.

Some wasps were emerging from the capsules at the time of release. Five capsules were set aside in individual vials to allow wasps to emerge to check emergence rate and percent females. An average of 1023 wasps emerged from each capsule with an average of 679 females per capsule. About 61,000 females were released per hectare.

Two days after placement of the capsules heliothis eggs were collected in the release area and in an area 200meters from the closest release point. Some live wasps were still on the capsules at this time.

Rain began to fall while collecting eggs so that only 50 eggs were able to be collected in the non release area.

Table 5. Summary of actions, Cowra, 26 Feb 1999

26/2/99	Collected field laid eggs prior to Trichogramma release. Placed Trichogramma capsules in grid approximately 11m x 11m.. Warm to hot, light variable winds
27/2/99	Sunny, Warm to hot. Light winds
28/2/99	Some wasps still on capsules. Collected field laid eggs 11.30 am to 3pm in release and non release areas. Cool, Overcast, light rain mid afternoon.

Results and Discussion

Table 6. Percent Parasitism, Cowra, Feb 1999

Date Col.	plot name	plant stage	eggs/ plant	total eggs	% para	% no hatch	para eggs/pl	unpara eggs/ plant
26/2	pre release	mid silk	3.6	97	53	14	1.6	1.4
28/2	post release	mid silk	2.4	93	45	8	1.0	1.2
28/2	nil release	mid silk	2.4	50	47	6	1.1	1.2

Table 7. Wasps Species Breakdown, Cowra, Feb 1999

Date Col.	plot name	% *Telenomus*	% *T.pretiosum*	% very pale	% very dark
26/2	pre release	93	0	5	2
28/2	post release	62	38	0	0
28/2	nil release	86	0	0	14

Prior to release, the levels of parasitism were moderate at 53% under a pressure of 3.6 eggs per plant resulting in a calculated 1.6 parasitised eggs per plant and 1.4 unparasitised eggs per plant. Very few predators were noted in the crop. The number of larvae getting through was therefore significant. Egg parasitism had not been checked in this area previously and there was some doubt that there would be any at all. 50% is a good base to build on. Provision of more overwintering sites and more district wide use of "soft" options may increase this activity.

Two days post release, parasitism was 45% with 38% of this caused by the released wasps *T. pretiosum*. Time and weather prevented further collections in the following days. This result supports recent work in the Lockyer Valley where increases in parasitism from a mass releases are not as great when background parasitism is moderate compared to when background is low, say below 20%. It does show that *T. pretiosum* was able to compete with relatively high levels of *Telenomus*.

Central West NSW Jan-Mar 2000

- Egg parasitism rates of heliothis were measured at various sites at Bathurst, Cowra and Dubbo.
- The wasps recovered were identified as fully as our expertise allowed.
- *Trichogramma pretiosum* were released at some sites.

Materials and Methods

As mentioned above, *T. pretiosum* were released in small quantities in 1998 and at a site in Bathurst and a site in Cowra in Feb 1999. In Feb 2000, heliothis eggs were sampled at these sites before releasing any more *T. pretiosum* to determine if the parasitoid was able to overwinter. Releases of *T. pretiosum* (Strain TPLV0199 a year in mass culture) were then made at three sites at Bathurst and two sites at Cowra. Eggs were collected after the release to observe the natural increase in parasitism as well as the impact of the mass release.

Egg samples were also taken at three sites in the Dubbo district, an area not previously sampled. *T. pretiosum* was then released at the three Dubbo sites.

Heliothis eggs were collected in a random fashion within the various treatment areas and placed directly into microtitre trays. The aim was to collect "brown ring stage" eggs but where egg pressures were very low, some eggs collected were on the "white" side and could have remained in the field and acceptable to egg parasitoids for another day.

Where releases of *T. pretiosum* were made, they were released from capsules and distributed in a grid fashion at 60 , 90 or 120 capsules per ha. The capsules were placed into the whorl of the plant. Wasps were beginning to emerge when they were placed. Heliothis eggs were collected immediately before the release and again several days after the release. The *T. pretiosum* (Strain TPLV0199) had been maintained in mass culture on *Sitotroga cerealella* for approximately 35 generations.

Results

Details of egg sampling are provided in Tables A3 and A4 in the Appendix. The notes below summarise the findings.

Bathurst:

Relatively small releases were made in 1999 at one site only. No *T. pretiosum* was recovered in the Bathurst area in 2000.

By late Jan 2000, parasitism ranged from 50% to 86% in pre tassel corn with *Telenomus* the overwhelmingly dominant species.

T. pretiosum was then released at three sites with very low egg pressure and was recovered at all sites in eggs sampled a few days after release. Ten to twelve days after the release *T. pretiosum* had become the dominant species at 2 of the 3 sites. This corresponds to the time the second generation of *T. pretiosum* would be emerging. This level of parasitism was surprising considering the low release rate of 60 capsules per ha and the very low egg pressure at the time of release, only 1 egg in 20 plants at Site 1 and 1 egg per 10 plants at site 2, providing few hosts for the wasps.

Site 1, 10 days after the release, egg pressure had increased to 1 egg per 2 plants and parasitism was now 83% with 76.5 % of this by *T. pretiosum.*

Sites 2 , egg pressure increased to 1.5 eggs per plant and parasitism to 91% with 53.5% of this from *T. pretiosum.* This is a rapid increase in the calculated numbers of eggs parasitised per ha over a 12 day period: from 2,895 to 56,580 parasitised eggs per ha. A 19 fold increase.

Site 3, parasitism was already 74% at the time of the release so the impact of the release was low. Parasitism increased to 84% ten days later at early silk with 14% of this caused by *T. pretiosum.* At this site product comparison trials were run by NSW Agriculture. And once again, the nil treatment had less tip damage than the conventional treatment, 63% and 73% respectively (Beckingham 2000).

Cowra:
Pre-release samples were taken at 'Warwick', the site where *T. pretiosum* were released in 1999 and at a new site, 'Mulyan' about 2 km away. No *T. pretiosum* were recovered at either site.

At 'Warwick' parasitism pre tassel was 29% and four days later increased to 57% with parasitism shared between *Telenomus* and a dark *Trichogrammanza* species. Egg pressure doubled in this time. *T. pretiosum* were released at a low rate in another section of the crop and recovered in good numbers four days later.

At 'Mulyan', pre release and pre tassel parasitism was 56% with the *Trichogrammanza* dominant. Four days after release, total parasitism was about 82% (only 8 % higher than the non release areas) with about 18% of this by *T. pretiosum.* This indicates, as in previous work, that if parasitism is already over 50% at the time of release the natural increase of the local species will compete well with the released wasps so that less benefit is achieved with a release.

Dubbo:
Parasitism had not been checked in this area previously and was found to be moderate to high (43%, 65% and 89% at three sites) with a species that looked like *T. pretiosum* present at all sites (also the opinion of Brad Scholz, however we were unable to verify this as the culture was lost). At the third site 64% of the parasitism was caused by the *T. pretiosum* look alike. We are not aware of any mass releases made in the area, so it is a mystery how they have reached such numbers. The balance of the parasitism was split between *Telenomus* spp. and a *Trichogrammatoidea* spp.

Most processing corn growers in Dubbo applied NPV when available rather than the conventional chemical insecticides and obtained as good as or better results (Beckingham 2000). The results of the sampling for parasitism suggests that the good results using NPV can be partly attributed to the high levels of parasitism in the area.

The area has cool and frosty winters which indicates that *T. pretiosum* can establish in inland areas. This needs further investigation and has implications for pest management in a variety of crops in other inland areas.

Discussion

These findings show that egg parasitoids were active at moderate to high levels at all the sites sampled. These results help make sense of field trials in processing corn where the nil treatment blocks have similar damage levels to those sprayed with broad spectrum insecticides which, if other factors were not operating, should have less damage. The data suggests that in this district, in processing corn, if parasitism is over 80% at tasselling there is no benefit applying chemical insecticides in the conventional manner (e.g. 2 or 3 methomyl + pyrethoid sprays).

Natural enemies are clearly having an overall greater impact on heliothis than the insecticide. One or two sprays with broad spectrum insecticides is not enough to reduce larvae numbers over the necessary period while the natural enemies are significantly reduced. Although other natural enemies are present, with between 40% and 95% of eggs parasitised this suggests that egg parasitoids are the main contributing natural enemy.

The data also shows that the number of parasitised eggs per hectare can increase many times in a week. This means that by silking a high proportion of the eggs present are likely to be parasitised but there may also be high numbers of grubs present that have hatched from eggs laid two weeks previous before parasitism had reached high levels.

In the NSW Agriculture replicated trials, the NPV only treatments yielded better results than the standard practice and the nil treatment. Can this be further improved? Commercial use of NPV is likely to become more common in processing crops and this will provide opportunities to further understand these interactions and to refine practices on a commercial scale.

Acknowledgments:

Thanks to Clarrie Beckingham and Adrian Lynch, NSW Agriculture for their assistance in the field and for arranging suitable trial sites. Thanks to the Growers: Bob Noble, G. Smith, John Willot, Jeff McSpedden, John and Peter O'Brien and Steve Muldoon (Simplot).

Egg parasitism and mass releases of *Trichogramma pretiosum* in the Bowen district June 1999- May 2000

- Egg parasitism of heliothis was investigated at various sites in the Bowen district.
- Mass releases of *Trichogramma pretiosum* were made at some sites.
- Parasitism rates were measured following the releases.

Results

Considerable data was collected on parasitism in this area. A better picture is now forming of the potential and problems involved in making better use of egg parasitoids in this environment.

Brief comments are provided about the findings at each site. Data collected is included in Tables A5, A6 and A7 in the Appendix.

Site 1 June 1999 Off Collinsville Road, Bowen.

Background parasitism was very low in the release area and the adjacent blocks but at the eastern (predominant wind) end of the property, "East B9", which borders the Don River parasitism was 27%. Three species were present.

In the release area (90 capsules/ha released) the crop was about 0.7m high at the start of the trial. The release of *T. pretiosum* increased parasitism from 3.4% to 66.7% in 4 days. Movement of the parasitoids down the rows from the release area into the adjacent "West 50" (50 meters in) was much slower than expected, in fact negligible after two weeks in spite of a steady east wind. See Table A5 for details.

Site 2 June 1999 Off Uri Ck Rd Bowen

The results at this site are complicated by the staggering of releases in the different sites. Only 2 of the 60 eggs collected pre release on 8 June at "Release 1" were parasitised and yielded wasps which appear to be *T. pretiosum*. This species was released at the site in mid 1998 but were not recovered at that time (pers. comm. Monsour). Samples taken two days post release on 10 June revealed 81.3% parasitism with 82.1% of this by *T. pretiosum* and the balance from a very pale *Trichogrammatoidea* species.

Subsequent sampling showed increasing levels of the local *T'toidea* species which must have been blowing into the crop from bushland. However, *T. pretiosum* remained dominant in the release area. There was a useful drift of *T. pretiosum* across the rows into the adjacent downwind crop, "West 50", which increased over time. The *Trichogrammatoidea* species also increased over time in the non release areas.

In "Release 1A" none of the 36 eggs collected pre release were parasitised. Two days after the release, parasitism had jumped to 98.3% (n =58). 40.5% of this was from a *T'toidea* species and 57.9% from *T. pretiosum*. Eight days later, parasitism was 48% (n=35) with 33% of this by *T. pretiosum*. A further seven days later, parasitism was 63% (n=12, small sample) with 28.6% from *T. pretiosum* and the balance from the pale *T'toidea* species. This data showed that *T. pretiosum* can establish within a crop in this area but also that parasitism from local wasps can increase many times in a few days. See Table A6 for details.

Site 3 Aug 1999 Delta, Bowen
This data was collected from the control area of field delivery method trial. Conditions were cool with nights down to 8°C. Egg pressure was very low so heliothis egg cards (196) were placed in a sweet corn crop that was about 1 m high. The cards were collected 2 days later. There was no parasitism on any card. 10% of the cards had no eggs at collection possibly due to predation.

Site 3a May 2000 Delta, Bowen
This site was bordered by a treed and grassy headland. A small sample of 24 eggs was taken on 2nd May in waist high corn. Egg pressure was very low at about 5 eggs per 100 plants but parasitism was 71% with 27% of this from a dark *Trichogramma* and 73% from a pale *Trichogrammatoidea*.

Site 4 May 2000 Collinsville Rd, Bowen
B1 at this site was bordered by a wide headland containing trees, long grass and weeds. B2 was further into the paddock. Egg pressure was relatively low (20 eggs per 100 plants) with parasitism in B1 and B2, 31% and 6% respectively. *T. pretiosum* were then released in B2 at 120 capsules per ha. Two days later, parasitism was 94% and 80% in B1 and B2 respectively with 0% in B1 and 40% in B2 caused by *T. pretiosum*. Once again a very rapid increase in parasitism from local wasps. See Table A7 for details.

Site 5 Off Mt Dangar Rd, Bowen May 2000
This site was bordered on the east by the Don River with trees, native scrub, grasses and weeds including pig weed. Parasitism was 45% at the time of the first sampling even though the crop had been sprayed with methomyl 8 days earlier. A pale *Trichogrammatoidea* and a dark *Trichogramma* were present.

T. pretiosum were released at 90,000/ha in P7 on 2nd May and again on 6th May using unprotected cards. On 4th May, parasitism in the release (P7) and non release (P6) areas was 76% with *T. pretiosum* forming 41% of the parasitism in the release area but nil in the non release area.

Heavy rain (about 25 mm) fell on the afternoon of 4th May. Parasitism rates on 6th were still high but then fell during the next few days. By 19th May, at tasselling, parasitism in P7 had increased to very high levels (97%) with 62.5% of this from *T. pretiosum*.

Table 8. Parasitism, Site 5 Bowen, May 2000.

DAP (P6) Date	23 2-May	26 4-May	28 6-May	30 8-May	32 10-May	40 19-May
Percent parasitism						
P6	-	76	83	51	45	-
P7	45	76	83	39	53	97
Percent of parasitism by *T. pretiosum*						
P6	-	0	5	0	0	-
P7	0	42	18	30	38	63

Site 6 Off Collinsville Rd, Bowen May 2000
This site was bordered by a dry forage sorghum crop on the south and large recently cultivated paddocks on the east. Parasitism pre release was very low. Ants were also prevalent with much evidence of them entering the release capsules. A release of 90 capsules per ha was made on 5th May, 24 days after planting, The crop was about 300-450 mm high. Four days after the release parasitism was 34.3%. Subsequent use of methomyl at this site (due to the unavailabilty of Gemstar®) led to an abandonment of the trial.

Table 9. Percent parasitism, Site 6 Bowen May 2000

Date collected	Nil release	Release area
4/5/00 pre release	3.6	3.6
7/5/00	14.0	20.0
9/5/00	1.4	34.3

Discussion
These observations indicate that egg parasitism levels are highly variable in the Bowen district, ranging from negligible to very high. The nature of the vegetation surrounding new plantings and their ability to harbour hosts suitable for egg parasitoids is clearly a major factor. Unlike the Lockyer Valley these hosts are limited and unreliable. Also, the way the growing season is split by winter with generally low heliothis pressure may make it difficult for parasitoids to remain at high enough levels to rapidly increase in late August when pressure typically rises. Nevertheless, the data shows that local parasitoids have the potential to make a significant contribution.

Early season crops in the Bowen district also get attacked by other pests which may require controls e.g. aphids and armyworm. Early chemical applications will set back the increase in parasitism levels while applications through silking will prevent carry over of wasps to adjacent plantings etc. The best crops for building up wasps in the Bowen area are probably unsprayed sweet corn but these are limited as most are sprayed from silking onward.

Releases of *T. pretiosum* were successful in rapidly increasing parasitism to very high levels by tasselling (e.g. Site 5, P7: 97%) and in some instances, parasitism from local species was high at tasselling. However, the crops being for the fresh market, the numbers of larvae present were deemed to be too high to withhold chemical applications through silking. Work by Monsour (2000) showed that a release of *T. pretiosum* significantly reduced the numbers of small and medium larvae present at tasseling but not the larger larvae as these had developed from eggs laid prior to the Trichogramma release. More work needs to be done on timing. It seems, the earlier the release is made, the better.

A number of questions arise (and these questions may apply to other districts). Some may have already been answered by other researchers:

- How can we encourage parasitism early and in turn reduce numbers of larvae at tasselling/silking?
- What control options exist for other pests which have minimal impact on wasps?
- Is it worth trying to conserve the parasitoids from tasselling onward ?
- If NPV has been applied, what proportion of larvae at tasselling are likely to be infected? Is there a practical, in-field way to assess the level of infection?

- What level of larvae at tasselling demands chemical insecticide treatment? How much damage do these larvae cause?
- What control options exist at silking that enable parasitoids to continue making a contribution?

Some proposals and issues that could be investigated include:

- Planting of manure crops and/or perimeter strips which are suitable refuges for egg parasitoids and introduce *T. pretiosum* into these areas before the planting of sweet corn begins. The planting of refuges has to be compatible with district restrictions etc.
- Releases of *T. pretiosum* as soon as heliothis eggs appear in crops.
- Larger scale replicated trials through to harvest which enable various combinations of tactics to be compared.
- Larger scale "best bet" but unreplicated trials through to harvest. Comparison with standard practice still possible.

Table 10. Summary of most common egg parasitoids of heliothis found in sweet corn:

	Telenomus spp.	*Trichogramma* spp. other than *T. pretiosum*	*Trichogramma-nza* spp.	*Trichogramma pretiosum*	*T'toidea* spp.*
Lockyer V.	Sep-Nov			Oct-May	Oct-Nov
Bowen		Mar-			Mar-
West Syd	Nov-Mar			Nov-Apr	
Bathurst	Dec- Apr				
Cowra	Dec-Apr		Dec-		
Dubbo	Dec-		Dec-	Dec-	Dec-

**Trichogrammatoidea* species were found in low numbers in most districts.

This Table is based on results of sampling during this project. It provides an indication only of the distribution of species and there seasonal abundance and is clearly incomplete.

Egg parasitism in other vegetable crops

Egg parasitism of moth pests in brassicas - *Helicoverpa* spp. and *Plutella xylostella* (Diamondback Moth, DBM)

Some surveys and work was done in other crops including brassicas. These surveys revealed that the high levels of *T. pretiosum* in the district during the summer had carried over into the autumn planted brassicas. Parasitism of *Helicoverpa armigera* in cabbage through March-April was typically high (55% to 90%) under moderate to high pressure.

DBM was in low numbers and parasitism was difficult to measure. DBM sentinel cards were placed in broccoli mid March 1998 and yielded 89% parasitism but cards placed in mid April yielded only 19% parasitism. It was observed that egg parasitism fell during periods of rain.

Verifying the identity of *T. pretiosum* as a parasitoid of DBM in the Lockyer Valley

This work was conducted in conjunction with Liu, Shu-sheng (Department of Plant Protection, Zhejiang Agricultural University, Hangzhou, China) and Duff, J.D. (CRC for Tropical Pest Management, c/- QDPI Gatton Research Station). The work has been written up in detail by Lui Shu-sheng (1998). A summary follows:

Trichogramma were collected from DBM in brassicas in Oct 1997 (strain TPTH1097). *T. pretiosum* had not been recorded as a parasitoid of DBM in Queensland. This trial sought to verify our suspicions that the wasps were *T. pretiosum*, by conducting a cross with a known sample *of T. pretiosum* obtained from Brad Scholz, QDPI Toowoomba that had been verified by the taxonomist John Pinto USA.

Unmated Trichogramma produce only males. Controlled crosses between the males and females of the respective cultures and the inspection of any progeny will identify whether mating has been successful. *Sitotroga cerealella* were used as the host egg for the purposes of the trial.

Table 11. Details of cross treatments.

Cross treatments	Replicates	Remarks
Tent Hill female x Kun male	30	Inter-strain crosses
Kun female x Tent Hill male	30	Inter-strain crosses (different direction)
Tent Hill female x Tent Hill male	30	Intra-strain control for Tent Hill strain
Kun female x Kun male	30	Intra-strain control for Kun strain
Tent Hill virgin females	10	To check for deuterotoky in Tent Hill strain

Results

Table 12. Replicates conducted for the crosses.

Cross treatments	n	No. (%) of replicates with no progeny	No. (%) of replicates with no female progeny
Tent Hill female x Kun male	32	4 (12.5)	1 (3.1)
Kun female x Tent Hill male	33	2 (6.1)	3 (9.1)
Tent Hill female x Tent Hill male	28	2 (7.1)	0
Kun female x Kun male	30	0	2 (7.1)
Tent Hill virgin females	10	1 (10.0)	9 (90.0)
Kun virgin females	10		10 (100)

Results of the controlled crosses between strains show that female progeny resulted in a high percentage of the replicates. The study thus demonstrated that *T. pretiosum* parasitises the diamondback moth, *P. xylostella* in the field in Queensland, Australia.

A comparison of three strains of Trichogramma as biocontrol agents for Diamond back moth

Tests performed in the USA in 1997 identified *T. pretiosum* and *Trichogrammatoidea bactrae* as potential egg parasites for DBM. (Va´ squez *et al*, 1997) There can be considerable variation between strains of the same species. Laboratory and field tests were conducted to compare two Australian strains of *T'toidea bactrae* with the *T. pretiosum* strain recovered from DBM in the Lockyer Valley.

One preliminary laboratory trial was conducted by the author and repeated with fresher moth eggs in collaboration with Liu Shu-sheng (Department of Plant Protection, Zhejiang Agricultural University, Hangzhou, China) and John Duff (CRC for Tropical Pest Management, c/o QDPI Gatton Research Station, Qld). The second trial has been written up in detail by Lui Shu-sheng (1998). A summary of both trials follows:

Table 13. Backgrounds of *Trichogramma* strains

Code	Original locality		Species	Date of collection and culturing	Crop	Host	Original collector
Tent Hill	Tent Hill, Qld	S 27°30' E 152°30'	*Trichogramma pretiosum*	October 1997	Cabb-age	DBM	R. Llewellyn
LaTr	Victoria		*Trichogramma-toidea bactrae*			LBAM	
N2	Nandi, Qld	S 27°13' E 151°10'	*Trichogramma-toidea bactrae*	15 March 1995	Cotton	*Heli-coverpa* spp.	Brad Scholz

30 mated females of each strain were placed singly into glass vials containing DBM eggs with a drop of honey and water added and allowed to remain for 4 hours. The wasps are

then removed and moth eggs allowed to develop. The subsequent numbers parasitised eggs, wasps and the sex ratio recorded.

In the first trial, Tent Hill, LaTr, and N2 strains parasitised on average 6.4, 9.3, 12.5 DBM eggs per female wasp, and 44%, 41% and 11% of the wasps parasitised ≤2 DBM eggs each in the Tent Hill, LaTr, and N2 strains respectively and the rest of the wasps parasitised ≥6 DBM eggs each. The N2 strain looks like the more appropriate strain for DBM according to this lab test.

The second trial showed lower differences between strains which may have been the result of the more consistent and fresher DBM eggs. Nevertheless, the N2 strain had a higher level of successful parasitisation:

Table 14. Mean number of DBM eggs parasitised in a 4-h test by three strains of egg parasitoids.

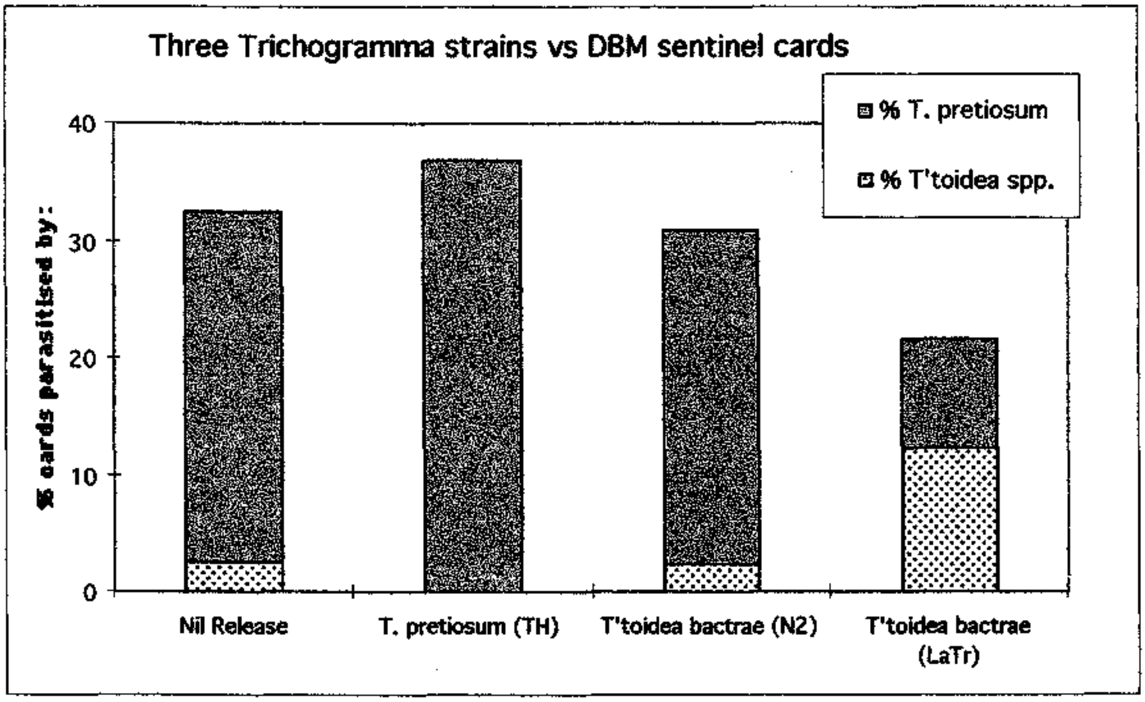
Species and Strain of parasitoid	All wasps tested			Wasps with successful parasitisation	
	n	Mean number (± S.D.) of DBM eggs parasitised		n (%)	Mean number (± S.D.) of DBM eggs parasitised
(T. p.) Tent Hill	30	16.0 ± 9.56		23 (77)	20.5 ± 4.48
(T't. b) LaTr	30	17.1 ± 8.25		26 (87)	19.7 ± 5.02
(T't. b) N2	30	20.5 ± 4.93		30 (100)	20.5 ± 4.93

An effort was then made to compare the strains in the field. A quantity of each was reared on *Sitotroga cerealella* for this purpose. The first field trial was conducted in April - May 1998 in broccoli with DBM egg cards as the indicator of parasitism. Trichogramma release cards (about 500 parasitised eggs per card) were placed midday 29th April in a grid approximately 10 meters apart down the bed and every third bed.

However, an overhead irrigation was applied the next morning. DBM egg sentinel cards were then placed midday 1st May every third plant along the edge of the bed (two rows of plants per bed) and in three adjacent beds in the central section of each release area (to provide overlap from release cards) 40 to 60 egg cards were placed per treatment. Rain started at 2 am 2nd May and continued for 16 hours with 50mm falling. The wet DBM cards were collected two days after placement at 11 a.m. 3rd May and dried out and examined in the usual method.

In spite of these very difficult conditions parasitism from *T. pretiosum* in the nil release area reached 33%. The trial was inconclusive in relation to a comparison of strains but did show that the background level of *T. pretiosum* makes a useful contribution in a chemical insecticide free program and that releases of anything other than *T. pretiosum* in the Lockyer Valley (even if perhaps a better parasitoid of DBM) is not likely to be of great benefit with such high background levels of *T. pretiosum*. Further, tests by Klemm & Schmutterer (1992) show that although some other species performed better than *T. pretiosum* in fecundity tests with DBM in glass vials, *T. pretiosum* performed the best in cage searching ability tests.

Figure 6. A comparison of three Trichogramma strains against DBM in broccoli



A point release trial was then conducted in May but again was inconclusive, encountering various difficulties in relation to the timing of wasp emergence. The sentinel cards were placed in the field too early and had to be collected before a significant number of wasps had emerged from the release cards. This resulted in poor performance from the two *T'toidea* strains. The trial did again show the background parasitism from *T. pretiosum* to be around 30%. No further field trials were conducted specifically against DBM.

Egg parasitism in other vegetable crops

In view of the high activity of *T. pretiosum* in sweet corn in the Lockyer Valley, numerous other crops were monitored for egg parasitism of heliothis through March and April 1998. Sampling revealed very high levels of parasitism in a range of crops that were sprayed only with B.t., at times close to 100%. As a result of this monitoring, some crops of French beans, capsicum and lettuce were grown without using chemical insecticides and yielded good results, comparable if not better than conventional practices (pers. comm. Shane Gishford) although no harvest data is available.

The high level of wasp activity clearly has implications for the management of Helicoverpa in a wide range of crops. Lettuce is under particular pressure in the Lockyer Valley with many crops in the 1998 season suffering very high losses of up to 80%.

Parasitism through winter and host range of *Trichogramma pretiosum*.

Egg parasitism was monitored in the Lockyer Valley using Heliothis egg sentinel cards at a number of sites through the winter of 1998.

At 10 June, 13.2% of egg cards had some parasitism. By 25 June this dropped to 0.3% and on 10 July and 10 August no cards were parasitised.

Some Trichogrammatid species can enter a diapause state where development ceases for periods of 3 to 6 months. This state is triggered by reductions in light and temperature. Development recommences in spring when temperature and light conditions increase. In earlier work by the author with *T. nr brassicae* and *T. carverae* only a very low proportion of samples (2-3%) were able to be put into a state that resembled diapause with up to 122 days in cold storage (Butz and Llewellyn, 1997). This work did however show that eggs parasitised by Australian species could be cold stored for over 60 days with up to 70% yielding wasps. In this case, quiescence rather than diapause was operating.

The *T. pretiosum* that is found in the Lockyer Valley is believed to be of North American origin. In the USA, attempts have been made to trigger diapause in *T. pretiosum* but have been unsuccessful (pers. com. Richard Morrison). The development threshold for *T. pretiosum* is around 9°C.

It is possible that some Australian species do diapause more readily but as yet these have not been identified. This means that the common species we find most likely need to overwinter as slowly developing larvae within moth eggs or as adults.

Access to suitable hosts and food sources leading into and coming out of winter are therefore likely to be important for their survival in numbers which will enable a rapid build up in spring when temperatures and pest pressures increase.

In the course of the work, numerous samples were taken of other potential host eggs in a range of crops in the Lockyer Valley. These revealed variable levels of parasitism in a wide host range covering numerous crops:

Table 15. Hosts for *T. pretiosum* in Lockyer Valley crops.

Common name	**Scientific name**	**Plant hosts in Lockyer Valley**
Heliothis Corn earworm Tomato grub	*Helicoverpa armigera*	Sorghum, sweet corn, maize, brassicas, lettuce, potatoes, beans, mung beans, tomatoes, capsicum, cotton, sow thistle, weeds
Native budworm	*Helicoverpa punctigera*	Sorghum, brassicas, french beans, mungbeans, tomatoes, capsicum, cotton
Yellow peach moth	*Conogethes punctiferalis*	Sweet corn, (maize likely)
Sorghum head caterpillar	*Cryptoblades adoceta*	Sorghum, sweet corn, (maize likely)
Diamondback moth	*Plutella xylostella*	Brassicas, weeds
Beet webworm	*Spoladea recurvalis*	Pigweed, beetroot, spinach, Amaranth
Lucerne leaf roller	*Merophyas divulsana*	Lucerne, lettuce
Vegetable looper	*Chrysodeixis argentifera*	Lettuce, soybean
Soybean lopper	*Thysanoplusia orichalcae*	Soybeans
Cabbage centre grub*	*Helulla hydralis*	Brassicas
Cabbage cluster caterpillar	*Crocidolomia pavonana*	Brassicas
Potato tuber moth**	*Phthorimaea operculella*	Potatoes, tomatoes

Notes:

* Collections made by Larry Hooper, DPI Redlands Research Station.

***T. pretiosum* is a know parasitoid of potato tuber moth (Kfir) although no work has been done in the field in Australia.

Cluster caterpillar (*Spodoptera litura*) is not readily parasitised by *Trichogramma* spp., probably due to the barrier that is formed by the moth scale covering the egg raft.

Nor is cabbage white butterfly, *Pieris rapae*, which has a relatively large egg with a hard shell. There are reports of other Australian species parasitising this egg (McLaren).

There are no doubt numerous other hosts for Trichogrammatids that are of low or no economic significance which may serve to maintain the wasps at useful levels during periods of low pest egg pressure. Various weeds including sow thistle are important hosts for heliothis (Gu & Walter). Food sources for the wasps during this period like nectar and honey dew will extend the life span of the wasps and therefore improve their chances of finding more egg hosts (Gurr *et al*, 2000 and Berti *et al* 1993).

Although the list above is incomplete, there are clearly numerous hosts for *T. pretiosum* and other egg parasitoids which enable a carry over from one crop to the next and from one season to the next. Using some of these crops as in-field insectories in the early spring period to facilitate a rapid build up of parasitoids coming out of winter is an area that needs further attention. Likely candidates for this approach are minimum sprayed beetroot, lucerne, field peas, lettuce, potatoes and brassicas. Table 16 below provides a seasonal overview of crops which harbour hosts for *T. pretiosum* in particular but other parasitoids as well:

Table 16. Crops which provide hosts for *T. pretiosum* in the Lockyer Valley

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lucerne	■	■	■	■	■	■	■	■	■	■	■	■
Field peas						■	■	■	■			
Brassicas		■	■	■	■	■	■	■	■	■	■	
Beetroot		■	■	■	■	■	■	■	■	■		
Lettuce		■	■	■	■	■	■	■	■	■		
Potatoes		■	■	■	■	■	■	■	■	■		
Corn, maize	■	■	■	■	■				■	■	■	■
Soybeans	■	■	■	■	■					■	■	■
French beans	■	■	■	■					■	■	■	■
Toms, caps.	■	■	■	■					■	■	■	■
Sorghum	■	■	■	■						■	■	■

The Lockyer Valley has a greater diversity of crops than many districts. But the Sydney Basin and Lindenow districts and along the river near Dubbo have some similar features and may provide the best opportunity for the establishment of economically useful numbers of *T. pretiosum*. Indications are that *T. pretiosum* has established in these areas but more work is required to verify its extent. The table below lists some plants that harbour hosts for Trichogrammatids by district:

Table 17. Some crops and plants which harbour some of the above moths.

District	Host plants for moth pests with low chemical insecticide inputs (other than sweet corn)
Sydney Basin	Lucerne, sweet corn, vegetables, brassicas, weeds
Bathurst	Lucerne, brassicas, sweet corn, maize, weeds
Cowra	Lucerne, sweet corn, maize, field peas.
Dubbo	Lucerne, sweet corn, maize, soybeans, canola, brassicas, weeds
Narromine	Lucerne, canola
Murray Bridge	Lucerne, brassicas, weeds, lucerne, peas
Lindenow	Lucerne, maize, sweet corn, a range of vegetables, brassicas, weeds
Bowen	Pigweed, french beans, green manure crops e.g. Dolocos,

The above plants include: native vegetation, pasture and non crop lands, agricultural crops and horticultural crops. Some districts have a combination of these (e.g. Lockyer, Sydney Basin, central west NSW) while in others districts (e.g. Bowen) there are limited refuge sites for Trichogrammatids and the main potential breeding sites, the vegetables, are repeatedly sprayed with insecticides. This makes re-establishment difficult. In the former districts, the prospects for a wider and better utilisation of Trichogrammatids are promising while in the Bowen and similar districts, the development and availability of more "soft" options is a prerequisite for better utilisation of Trichogrammatids.

Work on suitable plantings for overwintering or in-field insectories/refuges is in its early stages and recommendations are limited as interactions can be complex. For instance, chick pea trap crops for heliothis are being planted in cotton growing areas on the Darling Downs but it would also be desirable if these areas could serve as in-field insectories for Trichogramma. However chick peas are reportedly toxic to Trichogramma (pers. comm. B. Scholz and D. Murray) although some reports from overseas suggest otherwise

(Balasubramanian *et al*, 1989). Also, the size requirements of trap crops are being investigated (Cunningham *et al*, 1999).

It may be difficult to determine the net benefit of refuge crops. For instance, lucerne appears to be a good refuge for egg parasitoids as it is attractive to a number of moth species but on the other hand, in some districts, lucerne may harbour virus infected aphids which can migrate into vegetable crops. Aphids, however, are not all bad, they produce honey dew, a food source for parasitoids. They also attract a whole complex of other natural enemies like lady bettles, lacewings and hoverflies. Despite these contrary factors, observations in sweet corn over the last three years indicate that where parasitism levels are high, there is often lucerne adjacent to or nearby the sampled crop.

Issues relating to the mass release of *Trichogramma pretiosum*

A number of issues related to mass releases were investigated at various times during the life of the project. Release rates were compared under differing conditions early in the project, followed by a comparison of field delivery systems and some observations of the effects of chemical insecticides on parasitism in the field.

Application rates for mass released *Trichogramma pretiosum*

Trial 1. Mulgowie 24 Sept-8 October 1998

This trial sought to compare release rates of 120, 240 and 360 capsules per ha (approx. 1,000 wasps per capsule). Field laid eggs were very difficult to find so parasitism was measured as the presence of parasitism on Heliothis egg sentinel cards. All Trichogramma release plots (strain TPLV0198) exhibited extremely high levels of parasitism: 98%, 99%, 98% in the 120, 240 and 360 capsules per ha plots respectively. In the nil release area, 100 meters from the nearest release plot, 23 % of cards were parasitised (and this was probably drift from the release area). All the parasitism was caused *by T. pretiosum*. Approximately 100 sentinel cards were placed per plot. Eggs parasitised in this trial were used to start a new colony used to rejuvenate the mass reared culture at Bugs for Bugs.

Trail 2. Release rate trial in sweet corn at Lower Tent Hill, 9-14 Oct 1998

Background

This trial sought to establish if rates of 30, 60 and 120 capsules per hectare would increase parasitism when background parasitism is low. This was also an unreplicated trial but release plots were of good size, approximately 60m x 60m to allow for the overlapping dispersal of wasps from the capsules.

Materials and Methods

The *Trichogramma pretiosum*, strain TPLV0198, had been approximately 26 generations on *Sitotroga cerealella* at the time of release. The wasps were released from capsules, each capsule yielding approximately 1,000 wasps. The capsules were placed at three different densities in plots about 60 m by 60 m:

- 120 capsules per hectare, capsules placed in a grid 9 m by 9 m
- 60 capsules per hectare, capsules placed in a grid 13 m by 13 m
- 30 capsules per hectare, capsules placed in a grid 18 m by 18 m

Such placement enables the overlap that is likely to occur in a commercial release. The capsules were stapled to a leaf. The wasps were starting to emerge at the time of placement. The following day heliothis egg cards were placed in a central area of each plot and also in two non release areas 100 meters and 200 meters away. Each sentinel card had a minimum of 3 eggs at the time of placement. A card was stapled to an upper leaf every 1.2 meters for 12 meters down the row and in 12 adjacent rows thus covering an area of approximately 12 m by 10 m with a total of 120 sentinel cards per treatment.

Field laid eggs were present (approx. 6 eggs per plant) and were collected before and after release in all treatment areas.

The afternoon 13th Oct a storm was approaching and more field laid eggs were collected. Very high winds and 12 mm of rain damaged many sentinel cards and around 20% had no eggs at collection. Field laid eggs were collected into 96 cell microtitre trays. Actions performed and a brief description of conditions:

Table 18. Actions by day, Trial 2, Lower Tent Hill Oct 1998.

9 Oct	Collected field laid eggs.
11 Oct	Collected field laid eggs prior to placing Trichogramma release capsules between 10 am and 11am. Wasps starting to emerge. 23 deg C. Wind 5-7 km/hr gusts to 15 km/hr
12 Oct	Placed heliothis sentinel cards 11 am to 1 pm. Sunny, Warm to hot. Light winds
13 Oct	Collected field laid eggs 11.30 am to 1.30 pm. Sunny max. 32 deg. C. Wind 12-15 km/hr and steady with gusts to 25 km/hr. Storm hit around 4 pm. High winds and 12 mm rain. Some damage to crop.
14 Oct	Collected field laid eggs and sentinel cards in all treatment areas, 1 pm to 6pm. Light winds. Sunny. Max 28 deg C.

Results and Discussion.

The levels of parasitism achieved in this trial were well below those achieved in the previous trial. The severe wind and rain conditions mid-trial would have had some impact. Parasitism of field laid eggs in the Trichogramma treatment areas were similar to that found on sentinel cards but parasitism on 14 Oct in the control was much higher on field laid eggs than on sentinel cards, 33.3% compared with 5.4%.

No *Telenomus* were recovered from heliothis eggs on sentinel cards and this may partly account for the very low level of parasitism measured in the sentinel card control. *Telenomus* accounted for up to 56% of the parasitism of field laid eggs prior to the release.

Table 19. Parasitism on heliothis sentinel cards, Trial 2, Lower Tent Hill Oct 1998.

Plot Name	n	% cards with parasitism	% cards with no eggs
30k/ha	108	28.6	28.7
60k/ha	114	31.4	24.6
120k/ha	114	65.5	26.3
control 100 meters	49	7.5	18.4
control 200 meters	47	2.9	27.7
control combined	96	5.4	22.9
All parasitism on sentinel cards was caused by *T. pretiosum*.			

Figure 7. Parasitism on heliothis sentinel cards, Trial 2, Lower Tent Hill Oct 1998.

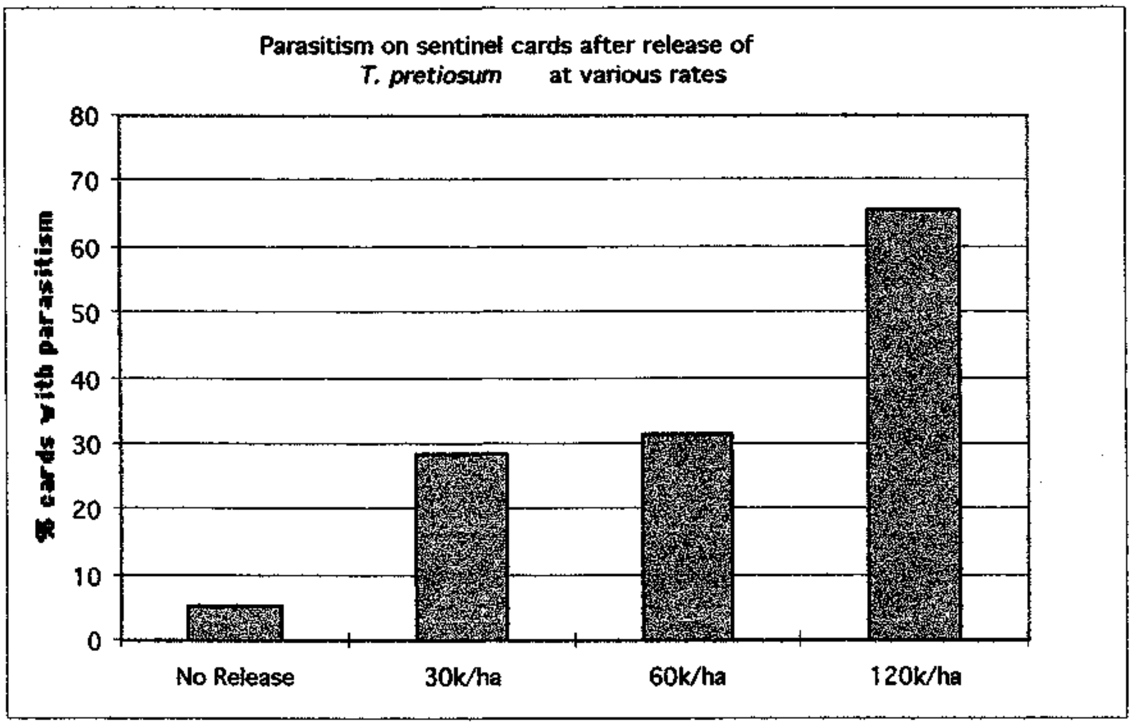
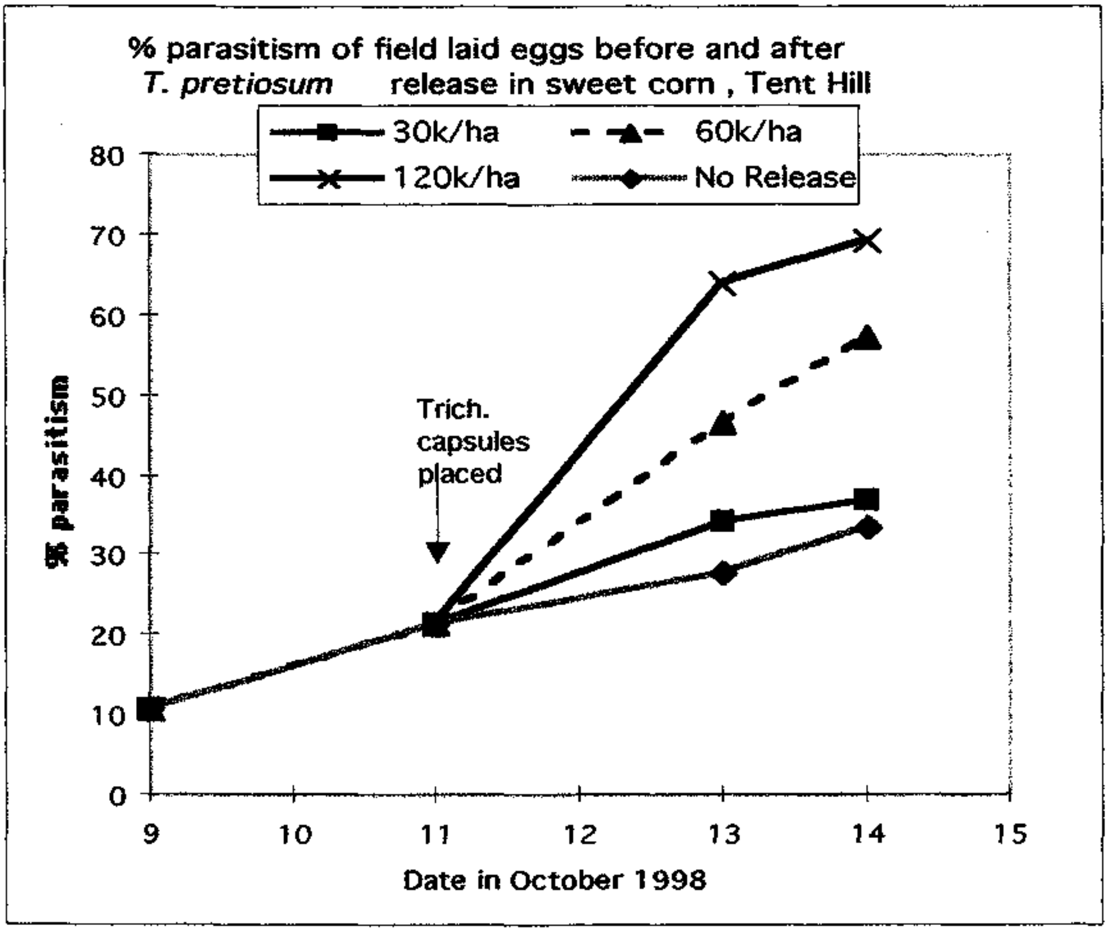


Table 8. Parasitism of field laid eggs and breakdown of wasps species*. Trial 2, Lower Tent Hill Oct 1998.

Date Collected	Days from planting	Treatment	n	% para	% no hatch	% Tele	% T.p.	% T't..
9-Oct	51	control	39	10.8	5.1	33	67	0
11-Oct	53	control	133	21.4	5.3	30	70	0
13-Oct	55	control 100 m away	59	27.8	8.5	20	73	7
"	"	30k/ha	46	34.1	4.3	7	87	7
"	"	60k/ha	47	46.5	8.5	15	85	0
"	"	120k/ha	47	63.8	0.0	10	87	3
14-Oct	56	control	59	33.3	13.6	41	47	12
"	"	30k/ha	48	37.0	4.2	18	82	0
"	"	60k/ha	39	57.1	10.3	20	70	10
"	"	120k/ha	40	69.2	2.5	11	89	0

* Tele = *Telenomus* spp. T.p. = *T. pretiosum* T't.. = *Trichogrammatoidea* spp.

Figure 8. Parasitism of field laid eggs. Trial 2, Lower Tent Hill Oct 1998.



This trial was considered a simulation of an inoculative release and was conducted pre tassel. Inundative releases at silking present too many difficulties for large scale application. Inoculative releases pre tasselling are more practical and this data (and that collected in the previous trial) show that a release of 60k to 120k per hectare will result in a useful increase in parasitism over background parasitism when the latter is relatively low, say below 20% and enables the introduction *T. pretiosum*, a very aggressive parasite, into the crop. Two releases a week apart would provide a continuous presence of wasps until the progeny from the first release begin to emerge. Moderate levels of eggs laid in the crop during the vegetative stages can be seen as an asset in these circumstances and importantly (whether a wasp release has been made or not) are a prerequisite before egg parasitism can be a significant contributor to grub control at tasselling and silking.

Trial 3. *T. pretiosum* release in sweet corn, Lower Tent Hill, SE Qld, 17 Oct 1998

Aim of this trial

Previous trials indicated that a release rate of 120 capsules per hectare (1,000 wasps per capsule) will significantly increase egg parasitism rates above background rates when background rate is less than 30%. This trial, under commercial conditions sought to refine Trichogramma release rates and timing.

Materials and Methods
120 capsules per hectare were placed over approximately 1.5 ha in the NE corner of a crop about 8 ha. The release capsules were placed at approximately 9 m x 9 m grid on 17 October. The capsules were stapled to a leaf. The wasps began to emerge the day after placement of capsules in the crop.

Field laid eggs were present in high numbers (6+ eggs per plant) and were collected before and after release.

Results
Table 21. Trial 3. *T. pretiosum* release Lower Tent Hill, Oct 1998.

Date Col	Treatment	plant stage	eggs/ plant	total eggs	% para	% no hatch	para eggs/pl	unpara eggs/ plant
9-Oct	Pre Release	tassel	10	36	8	0	0.8	9.2
16-Oct	Pre Release	earl silk	15	95	16	9	2.2	11.4
20-Oct	No Release	full silk	8	98	57	16	3.8	2.9
21-Oct	No Release	full silk	6	98	57	14	2.9	2.2
27-Oct	No Release	late silk	2	36	56	11	1.0	0.8
20-Oct	Trich 120k	full silk	8	94	48	18	3.1	3.4
21-Oct	Trich 120k	full silk	6	96	74	10	4.0	1.4
27-Oct	Trich 120k	late silk	2	35	61	6	1.1	0.7

Figure 9. Trial 3. *T. pretiosum* release Lower Tent Hill, Oct 1998.

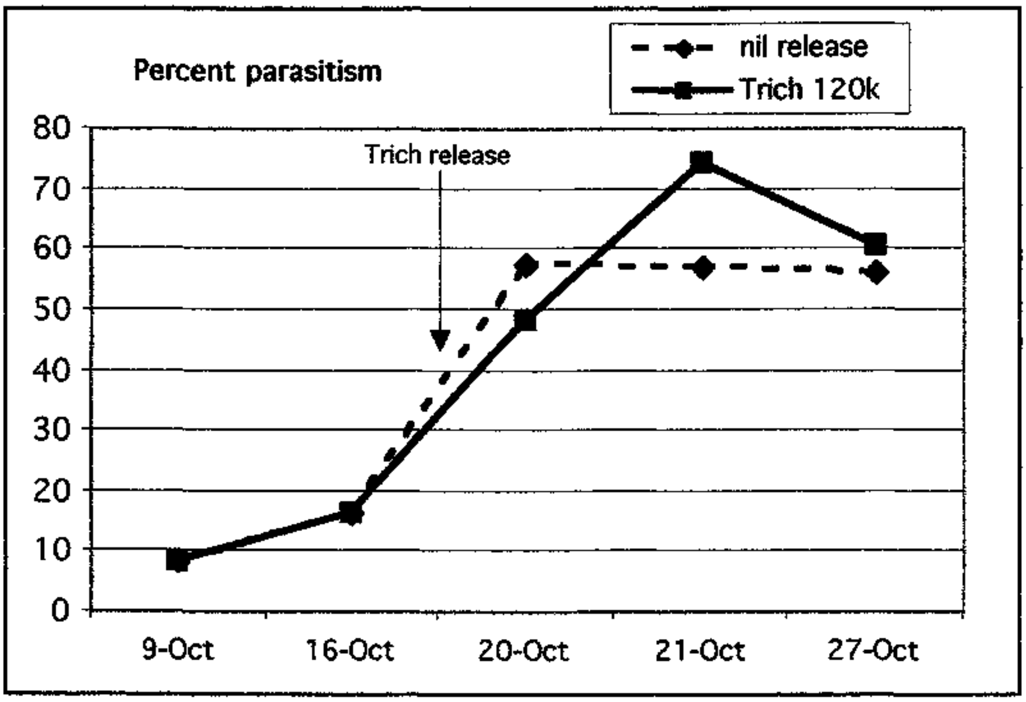
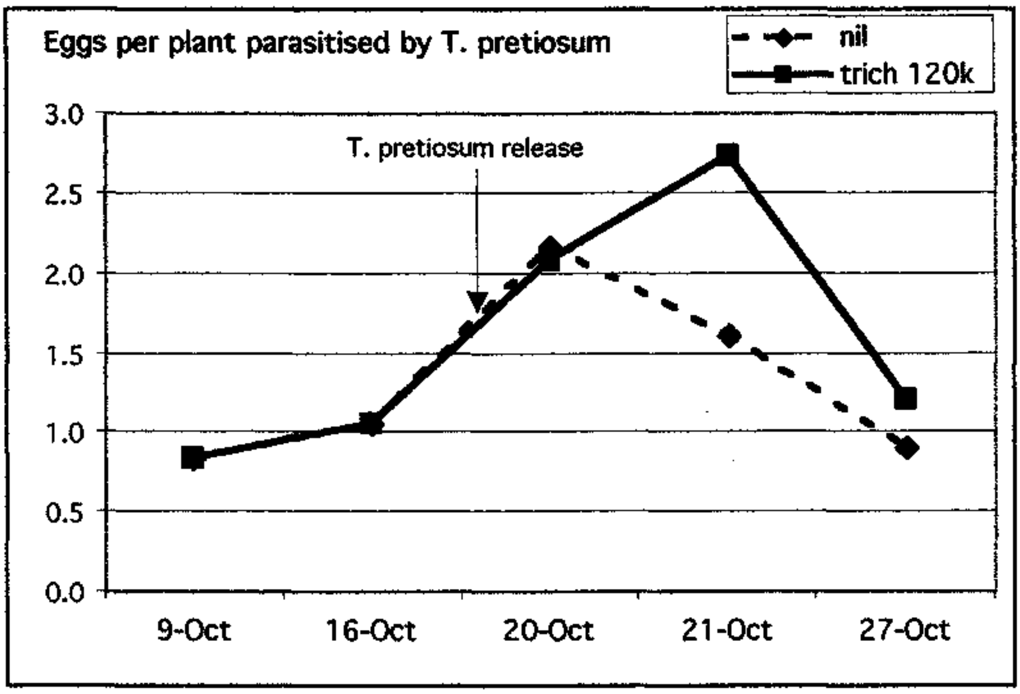


Table 22. Wasp species, Trial 3. *T. pretiosum* release Lower Tent Hill, Oct 1998.

Date Col	Treatment	% para	% *Telenomus*	% *T. pretiosum*	% *T'toidea* spp	% other.
9-Oct	Pre Release	8	0	100	0	0
16-Oct	Pre Release	16	50	43	7	0
20-Oct	No Release	57	53	47	0	0
21-Oct	No Release	57	60	35	2	2
27-Oct	No Release	56	13	80	7	0
20-Oct	Trich 120k	48	46	54	0	0
21-Oct	Trich 120k	74	33	61	3	3
27-Oct	Trich 120k	61	0	100	0	0

Figure 10. Trial 3. *T. pretiosum* release Lower Tent Hill, Oct 1998.



Comments

Background parasitism increased from 16% four days before the release to around 50% at the time of release. This level of parasitism was unexpected relatively early in the season and once again shows how quickly parasitism can increase. The impact of the Trichogramma release on overall parasitism levels was therefore less pronounced compared with Trial 2. It does show an acceleration of the displacement of *Telenomus* spp.

Egg pressure was high at this site for several weeks and the crop was subsequently sprayed with insecticides due to high numbers of larvae. This site would however serve as a good, early season, in-field insectory if options to broad spectrum chemicals were available: 50% parasitism of 8 heliothis eggs per plant would potentially yield over 400,000 wasp per hectare (50,000 plants/ha x 8 eggs/plant x 50%parasitism x 2 wasps per egg).

A general discussion of releases rates is provided below on page 62.

A comparison of three methods for field delivery of Trichogramma

Background

Trichogramma wasps are mass reared on *Sitotroga cerealella* eggs. Once parasitised, the eggs can be supplied to growers in the loose form for distribution by various means or loaded into "capsules". The capsules used, (described earlier in Material and Methods) were supplied by Bugs for Bugs, Mundubbera. The capsule provides some protection from heat and rain and protection from some predators. They are best placed by hand but have been scattered in some crops. The capsules have been a successful means of distributing Trichogramma in trial and commercial releases.

The capsules are more expensive per 1,000 wasps than the loose eggs. For larger areas, alternative systems which enable mechanical distribution may be an option if efficacy is maintained or improved and/or if costs are reduced. Loose parasitised eggs can be immersed in water, with a thickener added to keep the eggs in suspension, for two hours with minimal effect on emergence rates (Butz and Llewellyn 1997). Various means can then be used to dose the liquid onto the crop. Work in the USA by Gardner & Giles (1997) and Morrison (1995) also indicates that these methods are worth pursuing.

The trials also provide an opportunity to observe the degree of establishment of mass reared wasps under differing conditions – rain, wind and chemical applications.

Methods and Materials

Three methods of distributing Trichogramma wasps were compared:

- **Capsule system:** (1,000 wasps per capsule) In field trials, one capsule was placed every 9 meters in every 12th row. Approximately 120 capsules per ha.

- **Soap pump:** 4 gm (50,000 parasitised eggs per gm) of loose eggs were mixed in 2 litres of water plus a polyacrylate thickener (2 gm/l) and dosed via a hand operated soap type pump that uses a gravity action ball bearing valve. In field trials, (unless stated), a 4 ml dose was applied to foliage every 4.5 meters in every 6th row. Approximately 500 doses per hectare with a total of 2 litres of liquid applied per ha.

- **Peristaltic pump:** 4 gm of loose eggs were mixed in 4 litres of water plus a polyacrylate thickener (2 gm/l) and dosed via a peristaltic pump (MasterFlex® L/S Standard with Tygon® tubing, size 17, 6.4 mm internal diameter), hand driven at 1 rev per second. In the field trials, a continuous trickle of the mixture was applied over every 6th row. 4 litres total was applied per ha. The peristaltic pump works by squashing and rolling a flexible plastic tube. Liquid is drawn into the tube by creating a vacuum then it is pushed along to the outlet. These pumps are easily automated with slow speed electric motors and could be easily mounted on spray booms.

The first step was to establish the degree of damage to the parasitised eggs from the various mechanisms. Two laboratory trials were performed with eggs at different stages of development: three days from emergence and just about to emerge. To keep the eggs in suspension, the water was thickened with a polyacrylate powder, Aquakeep® 10SH at 2 gm per litre. The liquid was dosed onto paper and hung up to dry. Wasps were allowed to emerge. Parasitised eggs were then examined for emergence holes. Those without holes were deemed to be damaged. The three delivery devices are illustrated below:

Figure 11. The capsules are supplied in A4 size sheets of 60 capsules that are separated into single units by the grower. Minute escape holes enable the wasps to emerge.

Figure 12. In corn, the capsules are placed in the whorl.

Figure 13. The soap pump was attached to a 2 litre plastic bottle or to a 5 litre back pack. A 4 ml dose was applied to foliage at regular intervals.

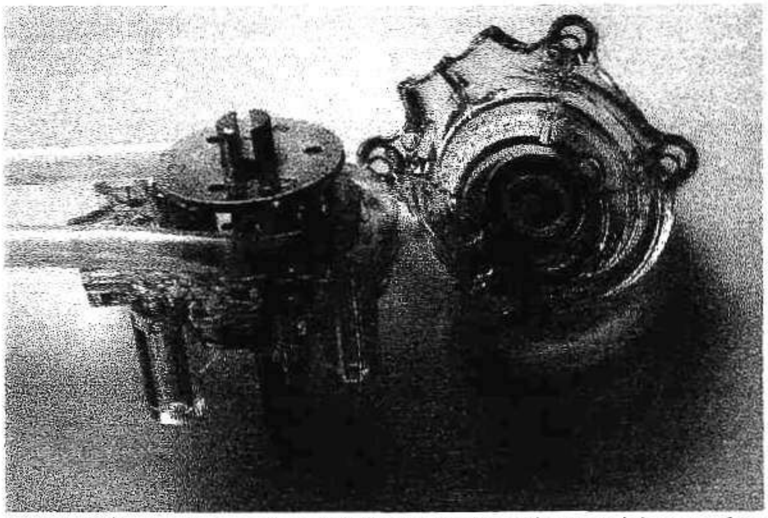


Figure 14. The peristaltic pump used and dismantled to show tubing and rollers. The pump was set up with a manual drive handle and a 5 litre backpack supply.

Laboratory Trial Results

Table 23. Laboratory Trial 1

The parasitised eggs were emersed in the solution for 5-10 minutes before being dosed. The wasps emerged 3 days later.				
Method of application	% emergence	n	% of the emergence rate of dry eggs on a card	% of the emergence rate of aqueous solution, no pressure
dry eggs on a card	93.8	386	-	-
In aqueous solution, nil pressure	85.9	715	91.6	-
In aqueous solution dispensed via Peristaltic Pump at 1 Rev Per Sec.	71.4	688	76.1	82.1

Table 24. Laboratory Trial 2.

A second lab trial compared the peristaltic pump at two speeds with the soap pump:

The parasitised eggs were emersed in the solution for 30 minutes before being dosed. A few wasps were emerging at the time of test.				
Method of application	% wasp emergence	n	% of the emergence rate of dry eggs on a card	% of the emergence rate of egg in aqueous solution, no pressure
dry eggs on a card	93.1	814	-	-
In aqueous solution, nil pressure	88.8	855	95.4	-
soap pump, normal	88.4	846	94.9	99.6
soap pump, harder	85.1	656	91.4	95.8
Peri 0.5 Rev Per Second	73.5	339	78.9	82.8
Peri 1 Rev Per Second	79.4	734	85.3	89.5

The above results for the peristaltic pump are slightly better (higher emergence) than the previous trial but also show very low damage (about 5%) from the soap pump. The wasps were about to emerge when the test was performed while in the previous trial, wasps still had three days before emergence. The level of damage observed in these trials was slightly higher than that measured by Gardner and Giles (1997) but comparable with that by Morrison (1995).

The next step was to test the delivery methods in the field.

Field trials

Field Trial 1 Bowen.
This trial was inconclusive due to extremely low egg pressure in Bowen at the time of the trial. Heliothis egg sentinel cards were used as the means of assessment but were not placed in the crop at the optimum time and had to be collected before the wasps had sufficient time to emerge and disperse. About 196 sentinel cards per treatment (4 reps of 96 cards) were placed in the field for two days. In the reps, a sentinel card was placed every 1.5 meters in every second row.

Table 25. Comparison of release methods, Field Trial 1.

Treatment	Total no. of sentinel cards	% of cards with eggs at collection with parasitism	Parasitism, stdev between reps	% of cards with no eggs at collection
Nil release	194	0.0	0.00	10.3
Soap pump	194	7.9	7.34	14.9
Peristaltic pump	196	8.4	7.26	9.2
Capsules	199	12.9	2.95	14.6

The capsules performed better and had lower variation between plots but considering the problem of timing of sentinel cards and the overall low levels of parasitism no clear conclusions can be drawn from this trial.

10-15% of cards had no eggs at collection most likely due to predation. Ladybirds and ants and the occasional big eyed bug were observed in the field but no predators were found on cards at collection. This level of predation is significant as larvae would take about 5-6 days to emerge at Bowen winter temperatures and egg cards were in the field for only two days.

Field Trial 2 Lockyer Valley
An egg sample was taken just before any Trichogramma were released on 24 Sep. An area of approximately one hectare was treated with each method. A few wasps were emerging at the time of application but the majority emerged the next day. The day after that egg samples were taken from each treatment area plus the non release area. Eggs were collected into microtitre trays and placed at 26°C. A second egg collection was made three days after the first post release sample. Egg pressure then dropped to very low levels. The crop was sprayed with methomyl on 8 Oct. Egg pressure increased and further field samples were taken from the nil release area and the capsule release area. The crop was sprayed again on the 21 Oct with methomyl and more samples were taken on 25 Oct. In spite of these problems, good data was obtained on the relative effectiveness of the release systems as well as sampling showing a high level of establishment of *T. pretiosum*.

At the trial site, a sample was dosed from the liquid dosing devices onto a piece of paper to verify the emergence rate.

Table 26. Field Trial 2 - Percent eggs yielding wasps from dose sample on site.

Treatment	Emerged	Not emerged	n	% emerged
Peristaltic pump	399	171	570	70.0
Soap pump	256	105	361	70.9

The emergence rate for the peristaltic pump is near that obtained in the earlier laboratory tests. The emergence rate for the soap pump, while equal to the peri pump, is 84% of that achieved in laboratory trial 2.

Table 27. Field Trial 2 - Percent of viable eggs parasitised.

Date	**24 Sept**	**26 Sept**	**29 Sep**	**18 Oct**	**25 Oct**
Days after release	**0**	**2**	**5**	**24**	**31**
Treatment					
Nil release	9.1	2.1	2.1	59	38
Peristaltic pump	0	31.9	42.6	-	-
Soap pump	0	4.3	33.3	-	-
Capsules	0	37.5	59.6	93	9

This crop was sprayed with methomyl on 8 Oct and 21 Oct. Samples taken on 18 Oct (24 days after the release) reveal a high level of parasitism (93%) in spite of the low egg pressure and the methomyl spray in the intervening period. In the capsule release area, 24 days after release, 95% of the parasitism was from *T. pretiosum* indicating that the second generation was active. However, after the 2nd methomyl, parasitism fell to 9%.

Table 28. Field Trial 2 - Percent of parasitism caused by *T. pretiosum.*

	Date eggs collected				
Treatment	**24-Sep**	**26-Sep**	**29-Sep**	**18-Oct**	**25-Oct**
Nil release	50.0	0.0	0.0	42*	0.0
Soap pump	-	100.0	93.3	-	-
Peristaltic pump	-	86.7	90.0	-	-
Capsules	-	94.4	100.0	95	100.0

**T. pretiosum* this sample was most likely result of drift from the release area so that parasitism from local species was probably around 25%.

A test was conducted to determine if wasps emerging from eggs distributed via the liquid methods were able to mate as readily as those distributed via the capsules – parasitism may be comparable but if there is a low percentage of females then there will be a slower increase in parasitism in the next generation. Unmated female Trichogramma lay eggs but these produce males only. Heliothis eggs usually yield 2 or 3 wasps with most yielding males and females or females only with a low percent having males only. The sex ratio of Trichogrammatids is usually in favour of females.

To test this, *T. pretiosum* wasps that emerged from eggs collected on 29th Sept (5 days after the release) were examined and scored either "males only" <u>or</u> "females present". The percentage of eggs yielding "males only" was:

Soap pump	14.3% (n=14)
Peristaltic pump	0% (n=18)
Capsules	10.7% (n=28)

The results show that of those released wasps that found heliothis eggs in the crop, a high level of mating had occurred for all the release methods. The very low numbers of *T. pretiosum* recovered in the nil treatment give us confidence that close to all the *T. pretiosum* collected for this test were the mass released wasps.

Field Trial 3 Lockyer Valley

This site had a very even plant growth of about 1 meter when an egg sample was taken prior to release. Shortly after sampling a violent storm came through washing most eggs off the plants and laying the crop over. Two days later, on 4th Oct, the release was made and the day after that sentinel cards were placed in 4 replicates of 24 cards per treatment and collected two days later.

A second set of sentinel cards was then placed and collected on 11 Oct. A second wasp release was also made on 11 Oct. Egg pressure remained very low until 16th Oct when it jumped to 5.6 eggs per plant so samples of field laid eggs were taken to observe the level of establishment of the *T. pretiosum* in the various treatment areas.

Initially, the capsules performed the best while the soap pump performed better than the peristaltic pump. A week after the second release and with the second generation from the first release coming through, the total parasitism and percent by *T. pretiosum* were very similar in the three treatment areas.

Table 29. Field Trial 3 – Comparison of release methods

T. pretiosum released at 120,000/hectare on 5/10 and 11/10.								
	% para of field laid eggs		% Cards with parasitism*		% parasitism of field laid eggs			
Date	26-Sep	4-Oct	8-Oct	11-Oct	18-Oct	21-Oct	25-Oct	28-Oct
Days before/after 1st wasp release	-9	-1	3	6	13	16	20	23
eggs/100 plants	20	20	<5	<5	560	700	300	200
Treatment								
Nil release	-	-	3.9	6.7	13.3	25.0	75.6	52.1
Peristaltic pump	9	18	32.8	62.2	16.7	51.1	71.7	68.8
Soap pump	9	18	64.6	89.6	50.0	57.4	75.6	76.6
Capsules	9	18	84.9	95.2	51.1	54.2	72.3	72.3

*Excludes cards with no eggs at collection.

Figure 15. Parasitism on sentinel cards, field trial 3.

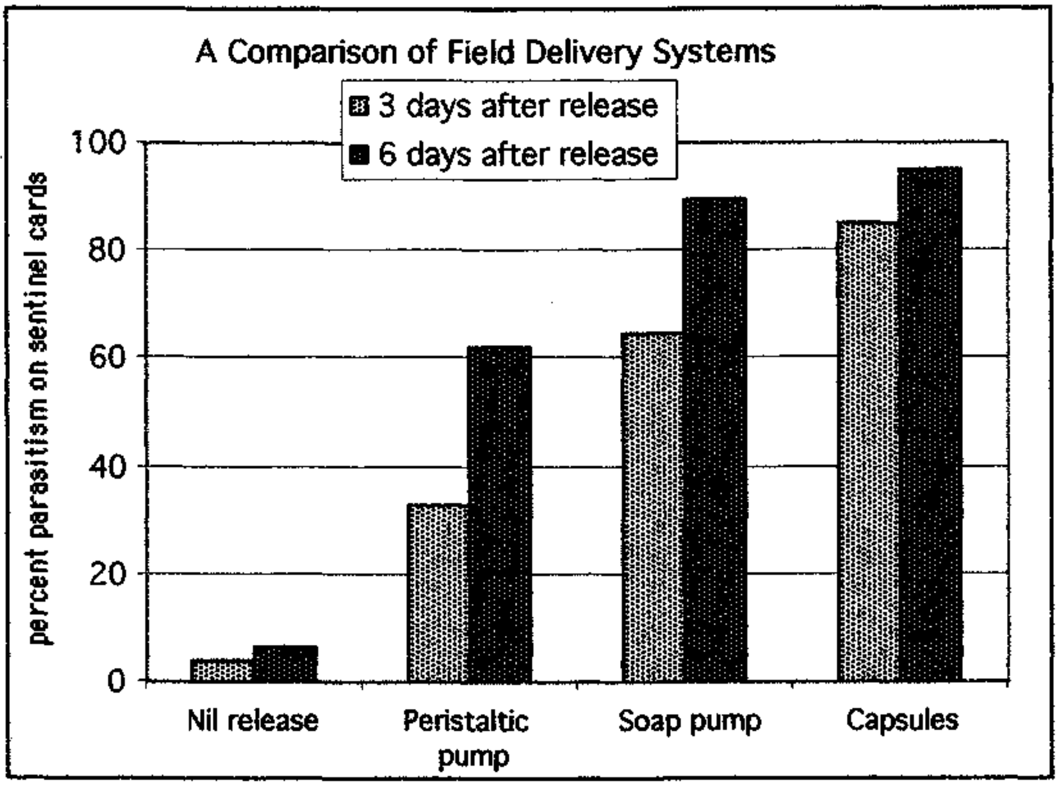
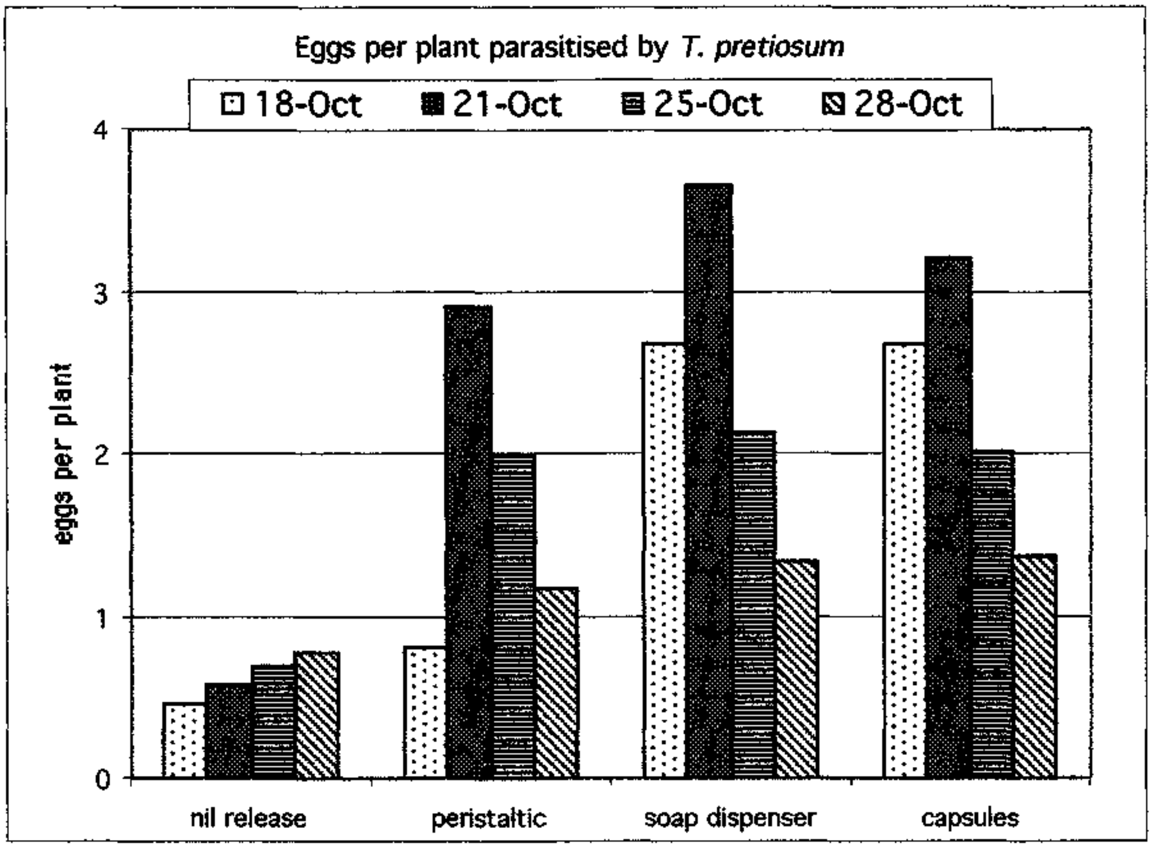


Table 30. Field Trial 3 -Percent of parasitism by *T. pretiosum*

	Field laid eggs		Sentinel cards		Field laid eggs			
	26-Sep	4-Oct	8-Oct	11-Oct	18-Oct	21-Oct	25-Oct	28-Oct
nil release	-	-	0.0	80.0	66.7	36.4	35.5	76.0
peristaltic	0	0	95.5	97.8	87.5	83.3	97.0	84.8
soap pump	0	0	94.1	100.0	95.8	92.6	100.0	91.7
capsules	0	0	96.8	98.3	95.8	84.6	97.1	97.1

*Eggs on sentinel cards are rarely parasitised by *Telenomus*.

Figure 16. Estimated eggs parasitised per plant by *T. pretiosum*.



Field Trial 4 Lockyer Valley

This trial compared the capsule and soap pump methods only. The capsules were placed as in the other trials. With the soap pump a dose was applied every 3 meters in every 12th row (rather than every 6 meters in every 6th row as in trials 1, 2 and 3).

At this site the parasitism was monitored for several weeks after release in order to observe the impact of one only release of *T. pretiosum* and the drift to adjacent plantings.
Nil release areas were also sampled: a site 60 rows south west in the same planting and in the next planting 120 rows west of the boundary of the release area.

Table 31. Percent parasitism of viable eggs, field trial 4.

Date	21-Oct	24-Oct	26-Oct	4-Nov	8-Nov	11-Nov
Days after wasp release	0	3	5	14	18	21
Treatment						
Nil trich 120 rows W	-	-	-	15.2	33.3	66.7
Nil trich 60 rows SW	-	52.5	55.8	55.8	56.8	66.7
Trich - Capsules	73.2	78.3	62.8	50.0	88.6	90.2
Trich - Soap pump	48.7	81.0	84.8	70.0	86.4	82.9

Parasitism on 21 Oct just before the release was moderate to high (73.2% and 48.7% in capsule and dispenser sites respectively) and mostly from *Telenomus*. The release of *T. pretiosum* did not initially increase this already high level but *T. pretiosum* now accounted for 72% of the parasitism in the capsule release area compared with zero in the nil release area 60 rows to the west. The proportion of parasitism caused by *T. pretiosum* declined as the wasps died in the field and increased again 14 days later upon the emergence of the second generation. This indicates that even under heavy competition from *Telenomus*, *T. pretiosum* is able to establish from one release (given a steady supply of host eggs). In this trial, the capsules performed slightly better than the soap pump although the different starting points of the background parasitism prevent direct comparison.

Table 32. Percent of the parasitism by *T. pretiosum*, field trial 4.

Treatment	**21-Oct**	**24-Oct**	**26-Oct**	**4-Nov**	**8-Nov**	**11-Nov**
Days before/after wasp release	0	3	5	14	18	21
Treatment						
Nil Trich 120 rows W	-	-	-	0	23	9
Nil Trich 60 rows SW	-	0	4	21	19	11
Capsules	3	72	48	23	56	68
Soap pump	21	41	69	4	71	88

Discussion of delivery systems

The capsules achieved the most consistent results with the liquid application methods being less reliable. It takes about 10-15 minutes on foot to apply capsules to 1 hectare depending on layout pattern. Capsules remain the best option for smaller areas while the liquid techniques are suitable for larger areas where an inoculative release rather than an inundative release is the goal.

The soap dispenser is a readily available device for easy application and can be applied quickly on foot or from a bike or four wheeler. For larger areas, the mechanisation of the drive for the peristaltic pump and mounting on a spray boom is relatively easy and needs to be tested. Trichogramma could be applied at the same time as an NPV spray.

In the Bowen district, where heliothis start laying on very young plants, releases are desirable as early as possible if eggs are being laid. This may be only 2 weeks after planting. The loose egg systems in this situation are not suitable as there is next to no foliage to target and mortality on the ground is likely to be high. In this case, the capsules can be placed on the ground as close as practical to the time of wasp emergence. Predation from ants can be significant in crops where little cultivation is done prior to planting or where dripper systems leave patches of dry soil that enable ants to survive. Although the capsules protect the eggs to some degree, some ants are able to widen the escape holes and enter the capsules.

These trials also showed the ability of *T. pretiosum* to compete with local species and to establish in the subsequent generations if there is a good supply of eggs in the field.

Chemical insecticides and Trichogramma

Effects of methomyl applications on parasitism
In the Lockyer Valley, during October-November 1998, heliothis egg pressure was very high pre tassel and growers needed to apply chemical insecticides at tasselling even though parasitism rates were on the increase. Although unreplicated and without controls, this situation provided an opportunity to make some observations of the impact of chemicals on parasitism under commercial conditions.

Five of these crops were sampled before and after the chemical insecticide applications. All crops were sprayed from the air with methomyl. Parasitism before the spray ranged from 46% to 67% with all sites having a calculated near 6 parasitised eggs per plant (% parasitism x eggs per plant) - a very high rate - before the insecticide spray. One spray reduced parasitism to 44%, 54%, 56%, 65% and 72% of the parasitism before the spray in the respective sites. Two sprays in four days reduced parasitism below 30% of pre spray levels.

Black eggs were also collected post spray and emergence of healthy looking wasps ranged from 40% to 80% while unsprayed black eggs were typically over 90% emergence. The large variation in emergence mostly likely reflects the difficulty in obtaining complete spray coverage from the air.

Likewise, mortality of brown eggs collected post insecticide varied greatly, ranging from a low of 19% to a maximum 65%. It is easy to see how problems can arise and "spray failures" occur - if spray penetration is poor and mortality of eggs is low but penetration is sufficient to kill adult parasitoids then parasitism will fall and a large number of larvae can get through and into silks before the next application - the poor coverage of the insecticide compounding the problem.

Tables A8 and A9 in the Appendix include the data while the graphs below represent the fate of eggs collected on a per plant basis and illustrate how parasitism was on the increase and accounting for high numbers of eggs before the chemical application:

Figure 17. Site 1, fate of eggs laid per plant.

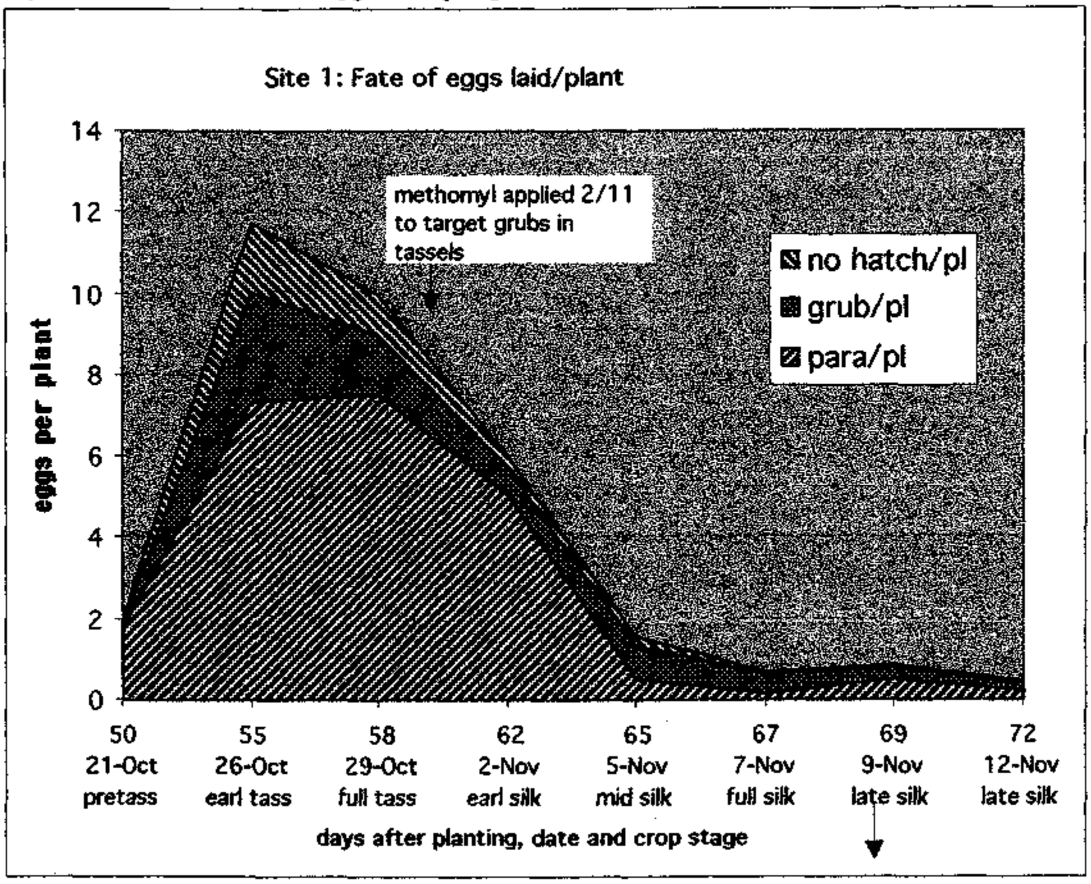


Figure 18. Site 2, fate of eggs laid per plant.

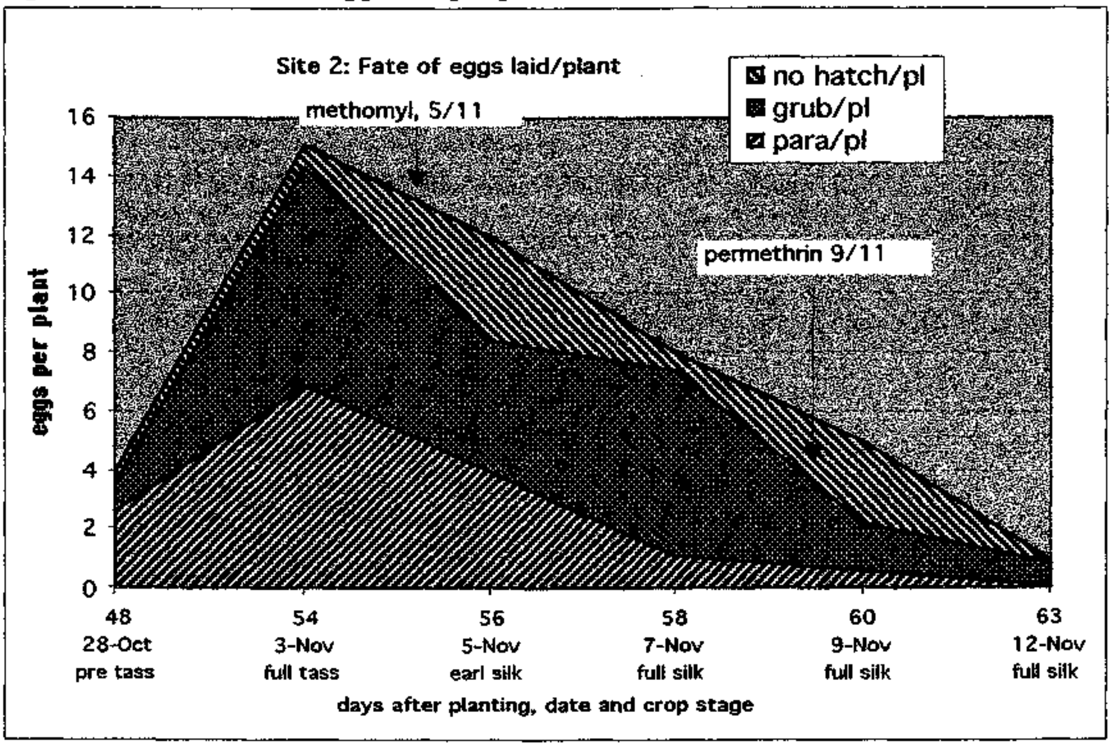


Figure 19. Site 3, fate of eggs laid per plant.

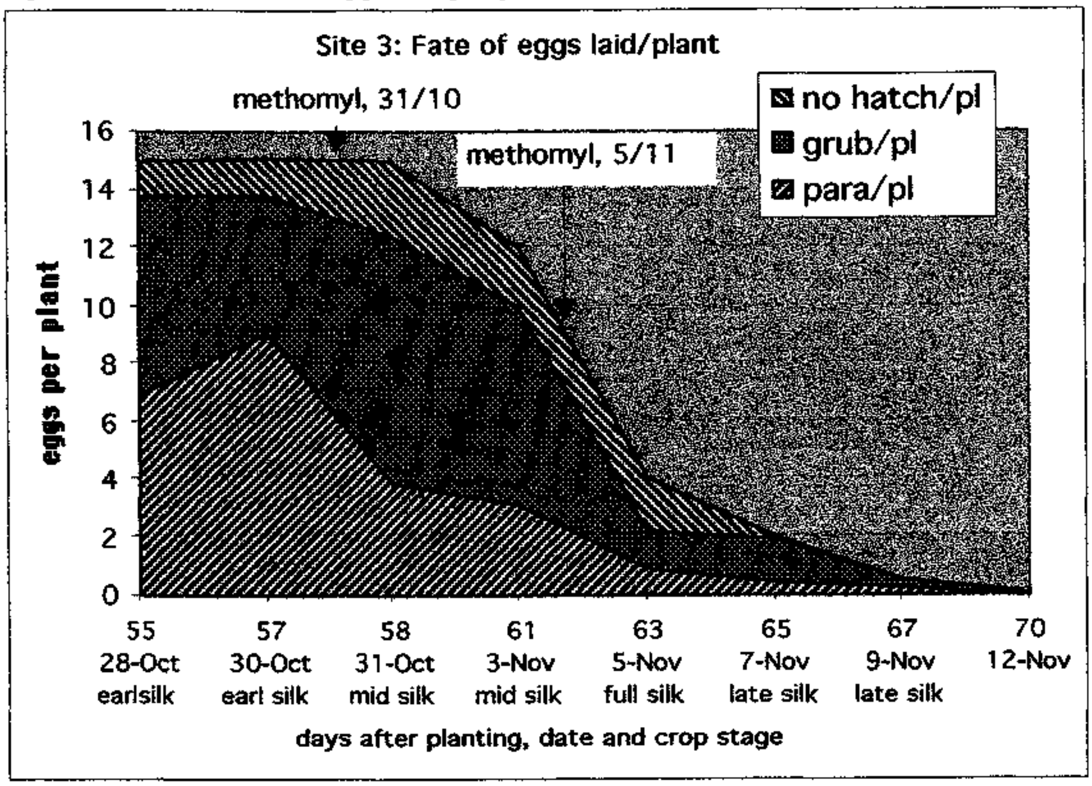


Figure 20. Site 4, fate of eggs laid per plant.

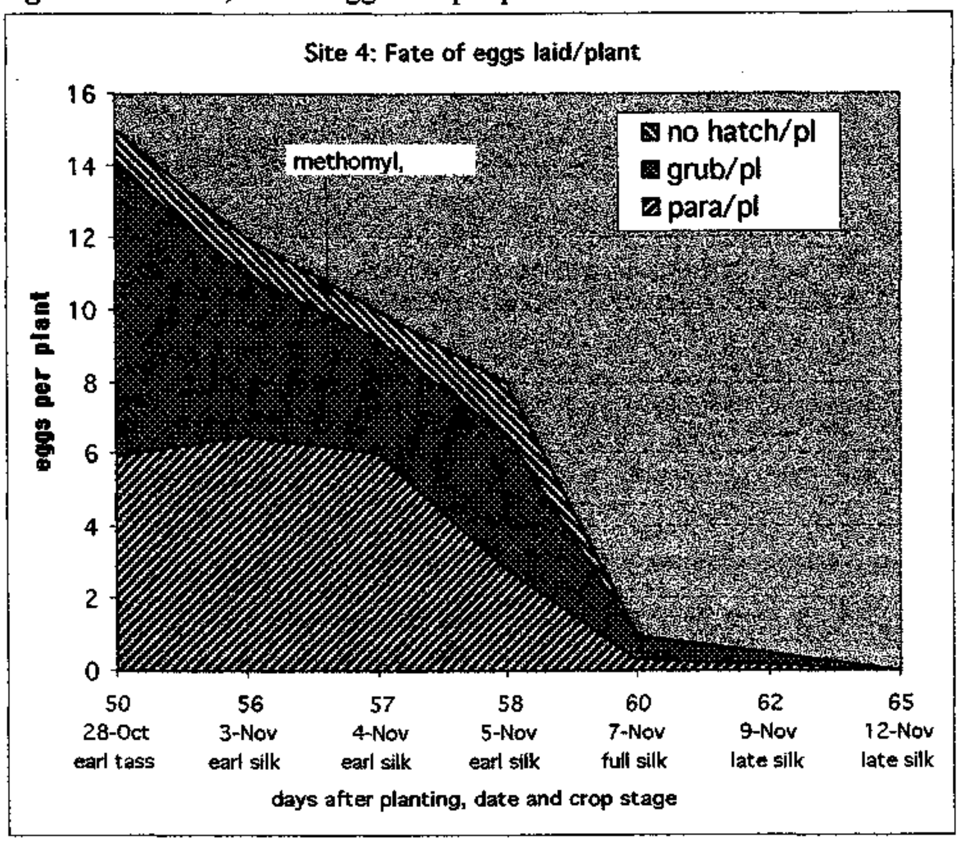
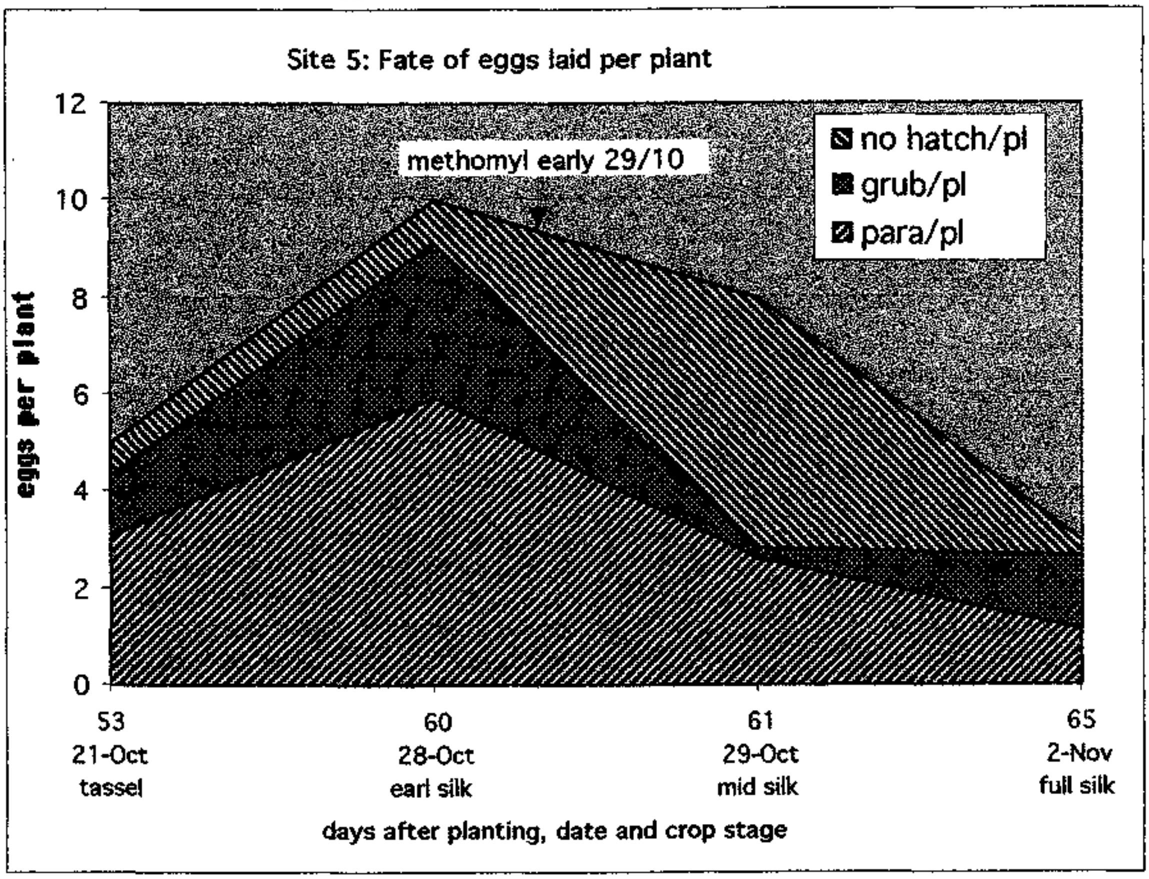


Figure 21. Site 5, fate of eggs laid per plant.



The observations are instructive in a number of ways:
Parasitism was on the rise at all sites, so that around six of the brown eggs present per plant were parasitised at the time of spraying. This is a relatively high number, representing around 300,000 parasitised eggs per hectare. And this does not allow for the eggs at other stages - the just black stage through to close to emergence.

It is worthwhile noting the level of eggs laid per plant over a week. At the above sites, over 30 eggs may be laid per plant per week. This level of pressure is going to be difficult for any product or combination of products and natural enemies to control.

All crops witnessed a rapid fall in egg pressure soon after the silks were out and all had a peak in egg pressure around full tassel/early silk.

With such a high level of parasitised eggs in the field, recovery from one methomyl spray had begun before the second spray reduced levels to around 30% of the pre spray percentage levels. In an unsprayed situation these percentages would have likely risen to close to 100% in the following week.

This work once again suggests that products safe to parasitoids are highly desirable. After this period of very high pressure growers moved to using Gemstar®.

Effect of spinosad on Trichogramma wasps

Background

Some preliminary observations were made in the field of the effects of spinosad applications on egg parasitism and the fitness of wasps emerging from eggs sprayed in the field. Moth egg parasitoids make a significant contribution to Heliothis control in sweet corn in the Lockyer Valley and in some other districts. The new chemical spinosad is to be registered for sweet corn. The impact of this chemical on Trichogramma needs to be better understood. This work, conducted on short notice, observed the effect on parasitised eggs in the field and the impact on parasitism levels in the days after the application which is an indirect indicator of the toxicity of the product to adult wasps. This work aims to assist growers to make pest management decisions especially in areas where parasitism is very high from pre tassel through to harvest.

Method

Field laid eggs were collected before and after the application of spinosad. The eggs were grown out in microtitre trays in an incubator so that any chemical breakdown effects from UV, dew, rain or irrigation were absent.

"Unfit" wasps were noted. "Fit" wasps moved freely around the microtitre cell and did not appear deformed. "Unfit" wasps were unable to chew their way out of the eggs or they were deformed in some way and did not move freely. The ability of "fit" wasps to search and parasitise in the field is not established.

Results

Trial 1 Lowood

At the first site, there was no unsprayed control. The crop, at early tassel was sprayed with spinosad at 600 ml per ha using a boom with droppers attached on the early morning of 4th Nov. Heliothis eggs were collected on the late morning (post spray) of the 4th Nov. Three areas within the 4 ha crop were sampled. Approximately 48 eggs were collected per replicate per collection.

Table 3. Trial 1: Percentage parasitism

Date collected:	4 Nov	10 Nov	14 Nov
Time after spray:	6 hours	6 days	10 days
Rep A	65.1	45.2	79.5
Rep B	69.8	44.4	82.2
Rep C	64.3	45.9	67.7
All Reps	**66.4**	**45.2**	**77.5**

Eggs collected at the brown ring stage on 4th Nov, about 6 hours after the spinosad application yielded 66.4% parasitism. Most of this parasitism would have occurred before the spray application. 32% of those eggs parasitised produced "unfit" wasps (it is usually close to nil in unsprayed crops) while the unviable unparasitised egg rate (10%) was comparable with that usually encountered in crops. Parasitism dropped to 45.2% six days after the spray and was back up to 77.5% ten days after the spray. Unfortunately, an unsprayed control was not available but from previous experience, parasitism in an unsprayed crop is likely to have increased markedly between 4th and 10th November rather than fallen.

Table 34. Trial 1. Percent parasitised eggs yielding "unfit" wasps

Replicate	4-Nov	10-Nov	14-Nov
A	32.1	0.0	2.9
B	40.0	5.0	2.7
C	22.2	11.8	9.5
All plots	**31.8**	**5.4**	**4.3**

Table 35. Trial 1 Eggs per plant during trial period

Replicate	4-Nov	10-Nov	14-Nov
A	1.3	0.9	1.6
B	1.4	0.4	0.8
C	1.3	0.4	0.7

Trial 2 Gatton

At the second site an unsprayed control was available. Two applications were applied 4 days apart during the silking period via an air assisted boom on the 22/11 and 26/11. This site had 2 to 3 eggs per plant during the trial period so there were plenty of newly emerging wasps and the impact of the spinosad was not as marked. There is a lag until more fit wasps emerge from parasitised eggs. The higher the number of parasitised eggs per plant before the spray the more chance of quick recovery.

Table 36. Trail 2 Percent parasitism.

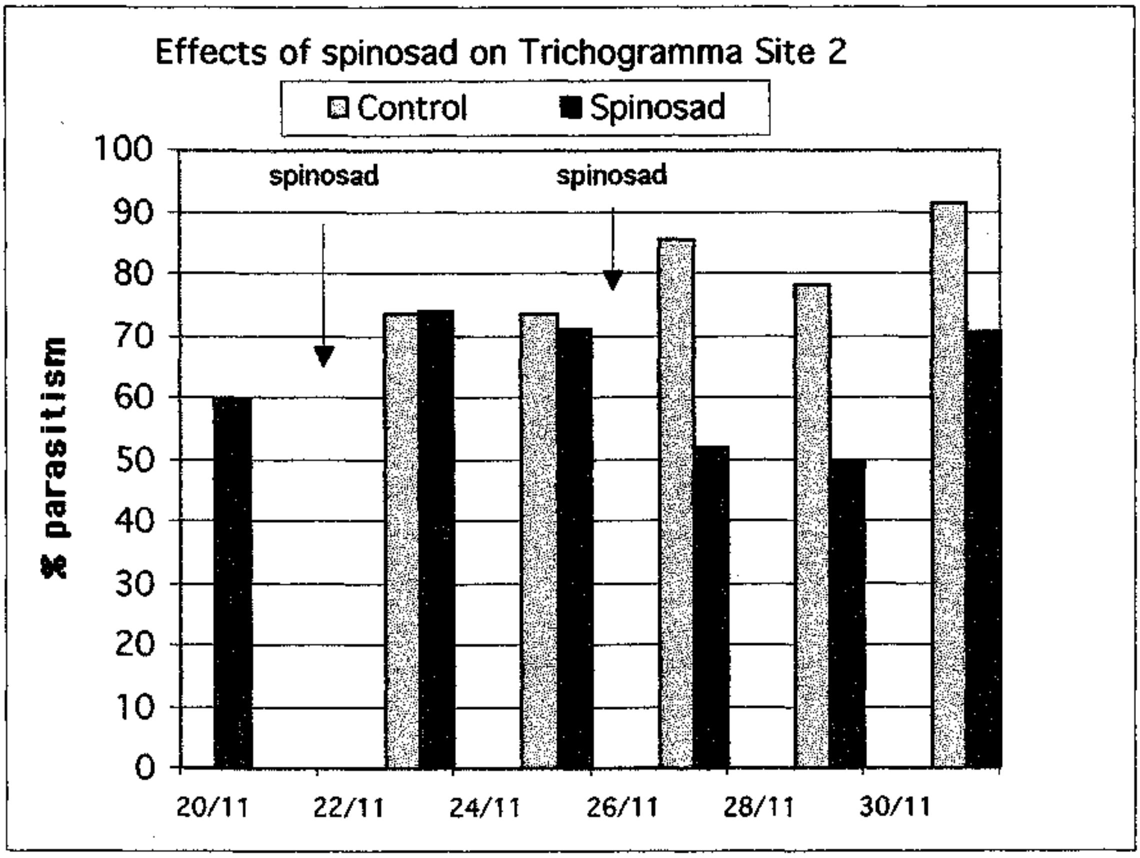
	20-Nov	23-Nov	25-Nov	27-Nov	29-Nov	1-Dec
Control	-	73.7	73.8	85.4	78.3	91.5
Spinosad	60	73.9	70.9	51.9	50.0	70.8
Spinosad applied on 22/11 and 26/11						

Mortality and deformities in wasps emerging from parasitised eggs was lower at this site even after two sprays:

Table 37. Trail 2 Percent parasitised eggs yielding "unfit" wasps.

	20-Nov	23-Nov	25-Nov	27-Nov	29-Nov	1-Dec
Control	-	0	0	0	0.0	0.0
Spinosad	0.0	2.9	2.6	10.7	5.6	0.0
Spinosad applied on 22/11 and 26/11						

Figure 22. Effects of spinosad on egg parasitism



Trial 3 Bowen

At this site a release of *Trichogramma pretiosum* at 120 capsules per hectare was made in Block B on the 1st May and a second release on 5th May. Block A was closer to a weedy headland and registered higher pre release parasitism. Egg pressure was low at both sites. Spinosad was applied to both blocks in the afternoon of 4th May. A high proportion of eggs collected on the 5th May that were parasitised were most likely parasitised before the spray hence the high parasitism rate for the 5th May

Table 38. Percent parasitism of field laid eggs.

	1-May	3-May	5-May	7-May	9-May
Block A	31	94	79	22	6
Block B Trich	6	80	72	16	14

Table 39. Heliothis eggs per plant.

	1-May	3-May	5-May	7-May	9-May
Block A	0.20	0.60	0.37	0.25	0.25
Block B Trich	0.10	0.25	0.32	0.25	0.25

Figure 23. Trial 3. Bowen. Percent parasitism after application of spinosad

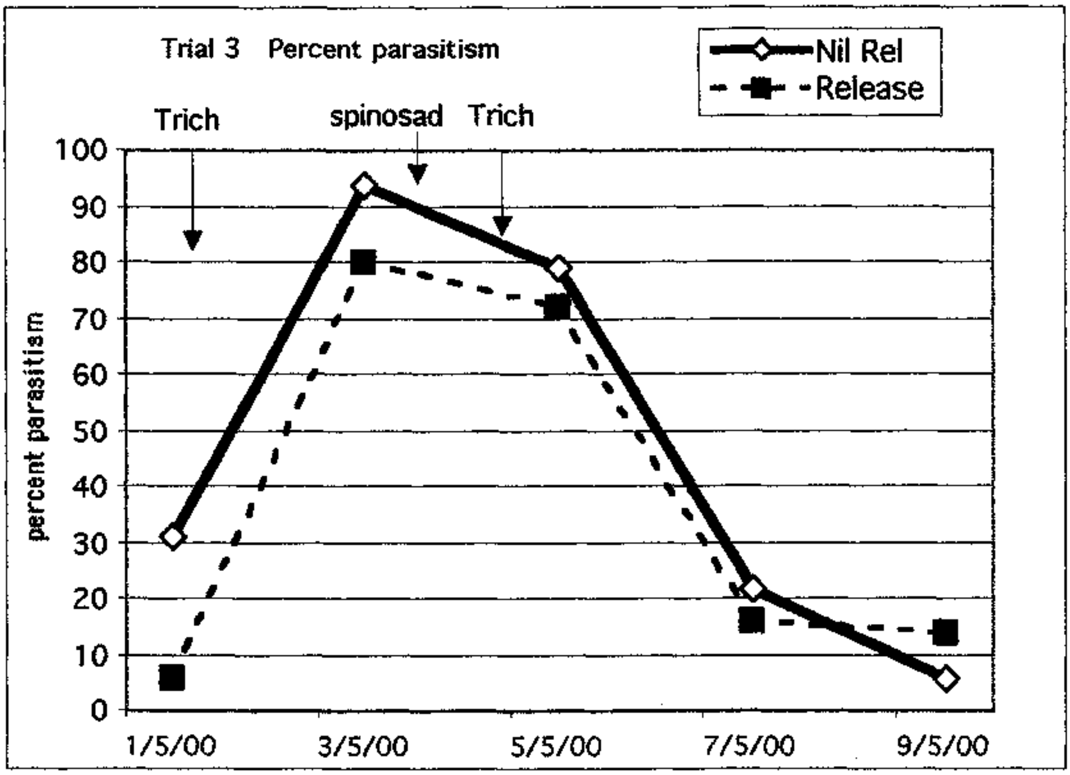


Table 40. Percent of parasitism by *T. pretiosum.*

	1-May	3-May	5-May	7-May	9-May
Block 1	0	2	0	0	0
Block B Trich	0	44	26	17	40

The percentage of unfit wasps emerging from parasitised eggs was very low at this site. Percent unviable unparasitised eggs increased from 3% to around 10% post spinosad.

Discussion

These chemical trials were of a preliminary nature and conducted at short notice. More work needs to be done in this area. The trials did show that the impact of spinosad varies considerably under differing conditions. The greatest impact was in Trial 3 where egg pressure was very low and parasitism was also likely to have been low in the previous week. In this case, parasitism was reduced below useful levels.

Trichogramma development inside the moth eggs takes from 7 to 12 days so one spray only may see a quick recovery of parasitism levels. But if few parasitised eggs are in the field at the time of spraying (say only 1 per 10 plants) then recovery will be slow.

In Trials 1 and 2 where pre spray parasitism and egg pressure were moderate, the impact was not so great although in the control in Trial 2, parasitism increased to 91% 11 days after the spray compared to 71% in the sprayed area. Spinosad is active in the field against larvae for about 3 days. If parasitism rates take longer than this to recover then larvae hatch will increase again requiring repeated treatments. This dynamic needs further study.

"Sweet corn pests and their natural enemies" an IPM field guide.

Soon after commencing the field work in sweet corn, it was evident that secondary pests may arise in crops not sprayed with broad spectrum insecticides but also that other natural enemies were increasing. There was little information about these topics readily available.

In the course of the Trichogramma field work, information and photos of secondary pests and other natural enemies were collected and put on a web page for access by growers, consultants and researchers. The information was subsequently brought together and expanded into an IPM field guide.

The booklet was printed in June 2000 and is being distributed by the QDPI Bookstore. It is printed in full colour on waterproof "paper" and contains 72 pages and over 100 images covering 15 pests and 26 natural enemies. It includes details on measuring egg parasitism.

The booklet will increase awareness of natural enemies and facilitate the wider adoption of IPM. Although the focus of the guide is sweet corn, it will be a useful tool for anyone interested in IPM and the biological control of insect pests.

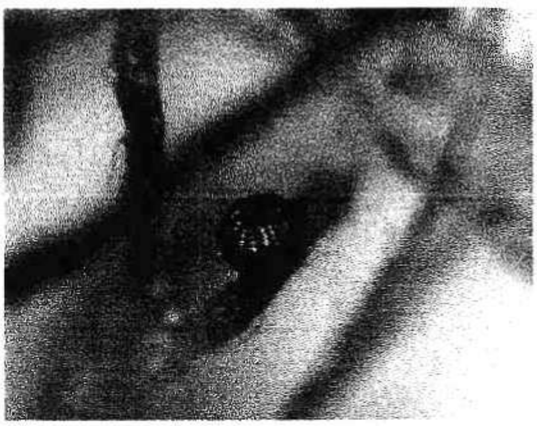


Figure 24. Parasitised heliothis egg in corn silks

General Discussion and Recommendations

Local and introduced parasitoids

Egg parasitoids were present, to various degrees, in all districts sampled. Parasitism ranged from very low levels to close to 100% in some instances. The Lockyer Valley appears to be a particularly suitable site with a wide variety of moth egg hosts due to the wide range of plant hosts. *T. pretiosum*, a species originally from California, has established well and becomes the dominant egg parasitoid by December. A relatively mild winter also contributes to a fairly rapid build up in the spring. The Sydney Basin has similar characteristics but the build up of *T. pretiosum* appears to be slower and this may be the result of incomplete establishment and a colder winter. The Lindenow district also looks promising in this regard but it is too early to say whether *T. pretiosum* will establish and make a significant contribution there. Sampling this year at Dubbo, also showed that *T. pretiosum* is present in high numbers. This area has sub zero temperatures during winter thus indicating possibilities for inland areas.

Telenomus spp. make a significant contribution in SE Qld, NSW and Victoria. In the Lockyer Valley, *Telenomus* appears early spring and can cause 70+% parasitism before *T. pretiosum* moves in. In central west NSW parasitism from *Telenomus* by mid summer is commonly over 50% and sometimes over 80%. At Cowra, parasitism was split between *Telenomus* and a *Trichogrammanza* species while at Dubbo, four species were active including one that is most likely *T. pretiosum*. The mix of species seems to vary from year to year in inland NSW.

The Bowen district has the potential to harbour high levels of parasitoids in some seasons when non crop areas are lush from late summer rains but (in the absence of soft chemicals) high pest pressures, other pests and a season split by cooler winter months may make it difficult to benefit from their activity.

Monitoring

The research has brought home the value of monitoring for egg parasitism. The results from sampling suggests that many crops are being sprayed based on egg pressure alone, in spite of the fact that close to 100% of these eggs can be parasitised. Spray thresholds based on the number of eggs per plant and aiming to spray on egg hatch have been used to varying degrees in the sweet corn industry. In the processing corn industry in NSW spraying has generally been targeted at 10% silk and again at full silk. (pers com. Beckingham).

By allowing for parasitism and not assuming that all eggs are viable, the spray threshold may not be reached or reached later in the life of the crop thus reducing the number of spray applications and giving more time for natural enemies to build up. If a spray threshold for a chemical insecticide is 10 *viable* eggs per 100 plants and a crop has 50 eggs per 100 plants with parasitism at 90% then there are 5 *viable* eggs per 100 plants and the threshold has not yet been reached.

It is likely that parasitism is significant at various times during the season in most districts. Crop consultants need to be aware of these periods and to recognise the signs of parasitism in a crop (presence of black eggs, lower larvae than expected) and the environments which

Mass releases and release rates
Once parasitism checks are performed and the level of local parasitoids determined a number of options are available including mass releases. The research has shown that releases can be used in a number of ways:

- To establish an aggressive species like *T. pretiosum* in an area.
- To quickly increase the level of parasitism within a crop.
- To speed up the level of parasitism within an area early in the season.
- To reintroduce parasitoids after a period of heavy chemical use or a long period of wet weather.

The work has also shown that mass releases at low to moderate rates (60-120k/ha) are not of significant short term benefit if parasitism is already over 50% (or over 1 parasitised egg per plant in corn) that is, unless the purpose of the release is to establish *T. pretiosum* on a property or district. In the latter case, the research shows that *T. pretiosum* typically increases its proportion of the parasitism in the weeks after release even when local parasitoids are causing over 50% parasitism. Relatively small mass releases of *T. pretiosum* have enabled the establishment of this species in the Lockyer Valley.

The greatest short to medium term benefit from mass releases will be had where successive plantings are made in an area. If spraying is required at silking in the first crop, by this time progeny from the first release will have drifted into the adjacent plantings. The earlier the wasps move into the new crops the better.

Release rates will vary depending on the purpose of the release as mentioned above. Releases of 60k per ha have enabled establishment but may not have a fast enough impact to reduce harvest damage in their own right. Two release a week apart of 90k-120k per ha typically increase parasitism to 60-70% in a few days. The progeny from the release are more evenly dispersed through the crop and parasitism typically increases to 90% by tasselling.

Higher rates will produce more rapid increases and higher levels of parasitism. It is likely that in the future that some growers will adopt the inundative release approach. Availability of parasitoids is a limiting factor at present as demand exceeds supply. Organic growers in particular will consider this option.

The conservation, encouragement and/or mass release of Trichogrammatids may not only increase the level of this group (and other natural enemies) and increase parasitism within a crop but reduce the numbers of pupating larvae within the season as well as the numbers overwintering. Pest pressure in subsequent seasons may be reduced. This hypothesis is yet to be proved in Australia but trends such as this have been observed overseas (Li-Ying Li, 1994 and Dietrich, 1998).

IPM programs, chemicals and resistance management
IPM programs need to be developed for local conditions. The role of parasitism in these programs will vary from one district to the next. Utilising parasitism in some instances is relatively easy – for example in processing sweet corn where broad spectrum insecticides can be replaced with NPV and tip damage is tolerable. In fresh market corn there are more factors to consider including the type and severity of damage, secondary pests etc. Nevertheless, in most fresh market areas gains have also been made simply by using NPV, aimed at egg hatch, up to tasselling. This gives more time for parasitism to increase and

make a contribution. Further, once a commitment is made to using "soft" options new ways are then developed for improving their activity. For example, a better understanding and more experience with NPV has led to experiments with application via sprinklers and post spray irrigation while some growers have already planted lucerne strips along roadways to encourage parasitoids.

Chemical insecticides are however still an important part of production systems especially for fresh market growers. More work is required to better understand the impact of various insecticides and whether or not there are benefits in spraying under various conditions. The work has shown that a single methomyl application reduces parasitism significantly but that recovery occurs within a week if the number of parasitised eggs per hectare is relatively high. Where it is low or a second application is made within a week, recovery is much slower and is likely to reduce parasitism below useful levels. Spinosad is less hazardous, but more work is required to observe the impact of repeated applications under various egg pressures and parasitism levels. Neem extract and insect growth regulator type products appear relatively safe to Trichogrammatids and are likely to be important tools in the future.

Importantly, the findings reinforce to industry and chemical manufacturers the need to develop products that are soft on non-target organisms and that such products are more likely to have a long useful life when there are good numbers of natural enemies present. An IPM program which utilises biological insecticides, selective chemical insecticides and natural enemies is likely to be more sustainable than the present broad spectrum focused programs - parasitised eggs produce no larvae to potentially develop resistance while predators clean up potentially resistant larva that survive a chemical application. This approach has important implications for resistance management and the sustainability of pest management programs.

Overwintering sites

Parasitoid overwintering sites need to be identified in each district. Once identified measures can be taken to promote their conservation and enhancement. Deliberate plantings of suitable refuge crops may be appropriate in some areas. Some growers in the Bathurst area have already planted lucerne along roadways to provide refuges for parasitoids. But, as discussed earlier, knowledge of this area is patchy and needs more study.

Other crops

The success of *T. pretiosum* in sweet corn in the Lockyer Valley and the monitoring of high levels of parasitism in beans, tomatoes, capsicum and lettuce, suggests that this resource of natural enemies could be better utilised in these crops if "soft" options were used and when more "soft" options become available in future.

Just before the end of the project, it came to our attention that beetroot growers in the Lockyer Valley were having trouble, particular in late summer-autumn with beet webworm and were spraying their crops up to ten times with broad spectrum chemical insecticides. This pest is believed to migrate from pigweed into the beetroot. The crops also had some problems with aphids and jassids. Beet webworm has been identified as an alternative host of *T. pretiosum* and at this time of year *T. pretiosum* is at its peak. An IPM program combining B.t. sprays with local and mass reared Trichogramma may be an alternative to current practices and needs investigation.

On the other hand, some non-horticultural crops like lucerne in the Hunter Valley which are regularly attacked by Lepidopteran pests including heliothis and lucerne leaf roller (Bishop, 1984) may benefit from the establishment of *T. pretiosum* in that district and this may have carry over benefits for vegetable growers in those areas.

Likewise, the finding of high levels of parasitism in the inland district of Dubbo has implications for other inland areas and crops like sorghum, azuki beans (Forbes), soybeans and cotton. Unsprayed maize in the MIA is believed to be a source of heliothis which migrate into soybean and cotton (pers. com. S. Duffield, CSIRO) and may be quelled by the establishment of effective egg parasitoids in the district. Efforts are currently in progress for the 2000-2001 season to establish *T. pretiosum* on a large property in the MIA growing a range of crops including sweet corn, tomatoes, canola, maize, soybeans and cotton.

Organic vegetable production

Organic production is slowly increasing in Australia and if trends over seas are an indicator may increase more rapidly in the coming years. The difficulty of controlling Lepidopteran pests, most notably heliothis, cabbage moth and potato moth is a factor inhibiting the growth of the organic industry. This work identifies some strategies and tools for organic growers as well as conventional growers. Crop monitoring, biological insecticides, local natural enemies and mass releases of beneficial organisms are perhaps under-utilised by the organic industry. Greater awareness and implementation of these strategies is likely to make the organic option more appealing and realisable.

Technology Transfer

This project has used a number of means to disseminate information arising from the research:

Discussions with growers and consultants

The numerous field trials and observations in a number of districts provided an opportunity to speak with growers, crop consultants and processing company representatives about the work and to show them how moth eggs are collected and assessed for parasitism. Showing growers a plate of eggs with a high percentage of parasitism was very instructive. On the other hand, much was learnt from crop consultants and growers in the process and this made for a constructive relationship with practical outcomes.

Collaboration with other researchers

A number of trials were run in collaboration with other researchers, in particular those associated with the National Sweet Corn Project. This project provided specific expertise in the area of measuring parasitism, releasing Trichogramma and the identification of parasitoids. This provided numerous opportunities to discuss findings with other researchers.

Workshops

A number of industry workshops were attended including Brassica Improvement Group meetings in the Lockyer Valley, Gatton Expo Field day, full participation (paper and presentation) at all the National Sweet Corn Project workshops and participation in the QFVG Growing for Profit Day at Gympie.

IPM Field guide for sweet corn

The compilation of the "Sweet corn pests and their natural enemies" pocket book has been a concrete technical transfer output of the project and will facilitate the wider use of IPM and increase awareness of role of natural enemies and parasitism in particular.

Acknowledgments

Thank you to the following people and organisations for their support and assistance in conducting this work:
Brad Scholz and David Murray, QDPI Toowoomba.
Clarrie Beckingham, NSW Agriculture Bathurst.
Chris Monsour, Bowen Crop Monitoring.
Peter Deuter, John Duff, Brendan Nolan and Bronwyn Walsh, QDPI Gatton.
Warren Ford, Vecon Australia P/L.
Dan Hood and Richard Teis from Rugby Farm.
Rodney Emerick, Andrew Johansen, Paul Villis from Mulgowie Farming.
Dan Papacek, Bugs for Bugs, Mundubbera for the supply of Trichogramma for field trials.

Bibliography of cited references

and references used in compiling the "Sweet Corn Pests and Their Natural Enemies" IPM field guide.

Balasubramanian, S; Arora, R.S and Pawar, A.D. (1989). Biological control of *Heliothis armigera* using *Trichogramma pretiosum* Riley and nuclear polyhedrosis virus in Srigangangar district of Rajasthan. Plant Protection Bulletin Faridabad. 41:3-4, 1-3.

Beckingham, C. (1999) Developing and IPM system for improved control of Heliothis in processing sweet corn -Bathurst and Cowra 1998-99 Season. 130-151 in Proceedings of 2nd National Workshop on Insect Pest Management in Sweet Corn, Bathurst May 1999.

Beckingham, C. and Llewellyn, R. (2000) Developing and IPM system for improved control of Heliothis in processing sweet corn -Bathurst, Cowra and Dubbo 1999-2000 Season. 33-48. in Proceedings of 3rd National Workshop on Insect Pest Management in Sweet Corn, Bowen May 2000.

Berti, J and Marcano, R. (1993) Effect of different food substances on the life span of the female *Trichogramma pretiosum* Riley. Boletin de Entomologia Venezolana. 8:2, 105-110.

Butz, H. and Llewellyn, R.R. (1997) Quality Assurance procedures for Trichogramma spp. and maintenance of large colonies for field evaluation. HRDC Final Report HG 403.

Bishop A.L. (1984). *Heliothis* spp. and *Merophyas divulsana* (Walker) in the seasonal damage of lucerne in the Hunter Valley, New South Wales. General and Applied Entomology. 16: 36-44.

Brough, E., Elder, R., (1994). Managing Insects and Mites in horticultural crops. QDPI.

Cunningham, J.P., Zalucki, M.P. and West, S.A. (1999). Learning in *Helicoverpa armigera* (Lepidoptera: Noctuidae): a new look at the behavior and control of a polyphagous pest. Bulletin-of-Entomological-Research, 89: 3, 201-207.

Dietrick, Jan. (1998). Biological Control in Turkmenistan – 1998. Report to the World Bank.

Gardner, J. and Giles, K. (1997). Mechanical Distribution of *Chrysoperla rufilabris* and *Trichogramma pretiosum*: Survival and Uniformity of Discharge after Spray Dispersal in an Aqueous Suspension. Biological Control 8, 138–142.

Greatti, M. & Zandigiacano, P. (1995) Post release dispersal of T. brassicae Bezdenko in corn field. Journal of Applied Entomology, 119: 671-675.

Gu, H. and Walter, G.H. (1999). Is the common sowthistle (Sonchus oleraceus) a primary host plant of the cotton bollworm, *Helicoverpa armigera* (Lep., Noctuidae)? Oviposition and larval performance. Journal-of-Applied-Entomology, 123: 2, 99-105.

Gurr, M.G. and Nicol, H.I., (2000). Effect of food on longevity of adults of *Trichogramma carverae* and *Trichogramma nr brassicae,* Australian Journal of Entomology. 39, 185 – 187.

Hassan, S.A. (1994). 'Selection of Trichogramma species' in Wajnberg, E. & Hassan, S.A. eds. Biological Control with Egg Parasitoids. CAB International. 55-71.

Hely, P.C., Pasfield, G. and Gallatley, J.G., (1982). Insect Pests of Fruit and Vegetables in NSW, Inkata Press.

Hoffmann, M. P., and Frodsham, A., (1993). Natural Enemies of Vegetable Insect Pests, Cornell Cooperative Extension.

Hoffmann, M.P; Wilson, L.T; Zalom, F.G. and Hilton. R. J. (1990) Parasitism of *Heliothis zea* eggs: effect on pest management decision rules for processing tomatoes in the Sacramento Valley of California. Environmental Entomology, 19:3, 753-763.

Keaster, A., (1998) Corn Insect Pests, A diagnostic Guide, University of Missouri.

Kfir, R. (1983) Functional response to host density by the egg parasite *Trichogramma pretiosum.* Entomophaga. , 28: 4, 345-353.

Klemm, U. and Schumutterer, H. (1992) Selection of effective egg parasitoids of the genera Trichogramma and Trichogrammatoidea and diamond back moth control in Taiwan. Mitteilungen der Deutschen Gesellschaft fur Allgemeine und Angewandte Entomologie. 8:1-3, 82-86.

Knutson, Allen., (1998). The Trichogramma Manual, Texas Agricultural Extension Service.

Knutson, A. and Ruberson. J., Recognising the Good Bugs in Cotton. Texas Agricultural Extension Filed Guide.

Llewellyn, R.R. (1997) Development of mass production and field delivery systems for Trichogramma wasps. HRDC Final Report HG504.

Li-Ying Li, (1994). Worldwide use of Trichogramma for biological control on different crops: A survey, in Wajnberg, E. & Hassan, S.A. eds. Biological Control with Egg Parasitoids. CAB International. 37-53.

Liu, Shu-sheng, Llewellyn, R., Duff, J.D., (1998) Acceptance of Diamondback Moth Eggs for Parasitization by *Trichogramma* in the Laboratory. Unpublished report.

Liu, Shu-sheng, Llewellyn, R., Duff, J.D., (1998) Identification of a *Trichogramma* Species Collected from the Diamondback Moth, *Plutella xylostella,* in the Locker Valley, Queensland, Australia. Unpublished report.

McLaren, I.W. and Rye, W.J. (1981). Occurrence of *Trichogramma ivelae* and its use to control Heliothis punctiger on tomatoes. J. Australian Entomological Soc. 20:110

Monsour, C. (2000) Assessment of *Trichogramma pretiosum* Releases as Best Management Option for Control of *H. armigera* in Sweet Corn in North Queensland in Proceedings of 3rd National Workshop on Insect Pest Management in Sweet Corn, Bowen May 2000.

Morrison, R. K; Rose, M. and Penn, S. (1995) The effect of extended immersion in agitated liquid carriers on the viability of two entomogphagus insects. Southwestern Entomologist, 23:2, 131-135.

Nordlund, D. A., Wu. Z. X. and Greenberg, S. M. (1997). In Vitro Rearing *of Trichogramma minutum* Riley (Hymenoptera: Trichogrammatidae) for Ten Generations, with Quality Assessment, Comparisons of in Vitro and in Vivo Reared Adults. Biological Control 9, 201–207.

Papacek, D., Llewellyn. R., Altmann, J., Ryland, A. and Seymour, J. (1995). The Good Bug Book, QDPI and RIRDC.

Pyke, B. A. and Brown, E. H., (1996) The Cotton Pest and Beneficial Guide. CRDC & CPTM.

Smith, M; Ridland, P and Bentley, J. (1994) Integrated Pest Management – It works! And other articles in Australian processing Tomato Grower, Vols 15 & 16.

Va´squez, L. A., Shelton, A. M, Hoffmann, M. P. and Roush, R. T. (1997). Laboratory Evaluation of Commercial Trichogrammatid Products for Potential Use against *Plutella xylostella*. Biological Control 9, 143–148.

Scholz, B. C. G., (1994). An evaluation of parasitoids for the management of heliothis, HRDC Final Report V106.

Scholz, B.C.G., Monsour, C.J. and Zalucki, M.P. (1998). An evaluation of selective *Helicoverpa armigera* control options in sweet corn. Australian Journal of Experimental Agriculture 38: 601-607.

Smith, S. A., Methods and Timing of Releases of Trichogramma to Control Lepidopterous Pests, (1994). In: Biological control with egg parasitoids, ed. E. Wajnberg & S.A. Hassan, CAB International.

Smith, D., Beattie, A., and Broadley, R. Eds. (1997) Citrus pests and their natural enemies. QDPI and HRDC.

Steffey, K.L., (1999). Handbook of Corn Insects, Entomology Society of America.

****

Appendicies

Appendix 1 Identification of parasitoids
The following simplified key is based on information provided by John Pinto at the Trichogramma Taxonomy Workshop held in Brisbane in 1996. The characteristics described below are a guide only. For complete verification of species, slides need to be taken which clearly display male genital capsules which are then examined by a specialist Trichogramma taxonomist.

For the purposes of field trials, where a large number of samples are inspected, wing fringes and male antennae are the features initially used to group wasps. The long wing fringes of the *Trichogrammatoidea* group are clearly seen with 30x magnification.

Male antennae are made of 3 parts: the scape, the pedicule & the club or flagellum which is the part at the end of the antennae. A magnification of 60x is preferred.

Table A1. Identifying features of Trichogrammatids used where many samples need to be classified.

Trichogramma: male has a single lobed flagellum, short to medium setae on wings	
T. nr brassicae	Dark wasp
T. pretiosum	Two toned – dark abdomen and pale, honey coloured thorax
T. australicum	Darker than *T. pretiosum*, difficult to separate
Trichogrammanza: male has 3 lobed flagellum, short to medium setae on wings	
T.carverae	Pale brown wasp
T. funiculatum	Dark wasp
Trichogrammatoidea: male has 5 lobed flagellum, long setae on wings	
T'toidea bactrae	Variable colour but commonly dark
T'toidea robusta	Very pale yellow wasp with red eyes

Table A2. Summary of parasitism of heliothis eggs in tasselling and silking sweet corn at various sites throughout the Lockyer Valley 1998-9.

Date Col.	eggs/ plant	total eggs	% parasitism	% *Telenomus* spp.	% *T. pretiosum*	% *T'toidea* spp.	% other species
5-Oct	0.05	24	9	0	100	0	0
9-Oct	10	36	8	0	100	0	0
14-Oct	6	59	33	41	47	12	0
16-Oct	11.3	309	31	60	38	2	0
20-Oct	9.3	269	55	57	39	3	0
21-Oct	5.7	183	59	62	29	4	4
26-Oct	12	144	62	70	25	4	1
28-Oct	11.2	215	56	29	46	9	15
2-Nov	1	24	87	0	100	0	0
3-Nov	7	108	57	25	70	2	4
11-Nov	1.5	41	91	0	93	3	3
19-Nov	4.05	121	59	0	78	21	1
30-Nov	2.8	48	52	13	83	4	0
3-Dec	4.3	36	78	0	79	21	0
4-Dec	2.5	71	66	26	69	5	0
8-Dec	9.3	170	56	13	85	1	0
9-Dec	3.9	58	72	44	51	5	0
10-Dec	6.6	36	62	24	76	0	0
11-Dec	13.5	223	72	2	98	0	0
12-Dec	5.6	55	69	24	68	9	0
13-Dec	1.7	35	97	61	39	0	0
14-Dec	9.3	54	89	10	83	7	0
16-Dec	5.2	115	87	2	95	3	0
18-Dec	4.0	27	82	39	61	0	0
21-Dec	2.1	84	96	4	92	3	1
23-Dec	4	35	91	3	77	19	0
29-Dec	10.7	120	93	0	95	5	0
6-Jan	1.0	29	100	0	93	7	0
14-Jan	2.3	60	88	0	100	0	0
18-Jan	7.4	60	95	0	100	0	0
22-Jan	6.8	108	97	0	100	0	0
25-Jan	3.6	47	100	0	100	0	0
28-Jan	1.3	23	71	0	100	0	0
23-Feb	5.0	51	70	0	97	3	0
10-Mar	8.0	72	99	0	100	0	0
10-Mar	3.0	60	88	0	100	0	0
15-Mar	2.0	49	92	0	100	0	0
22-Mar	2.0	36	100	0	100	0	0
22-Mar	2.0	48	81	0	100	0	0
22-Mar	0.5	12	90	0	100	0	0
25-Mar	8.0	47	94	0	98	2	0
25-Mar	2.0	24	67	0	100	0	0
14-Apr	6.6	48	96	0	100	0	0

Table A3. Parasitism in sweet corn, Bathurst and Cowra, Jan-Feb 2000.

Date Collected	plot name	DAP	eggs/ plant	total eggs col.	% para of viable eggs	% *Tele-nomus*	% *T. pret-iosum*	% Dark *Trich'nza*	% *T'' toidea* spp.
Bathurst Sites									
Site 1: 60 caps of T. pretiosum per ha applied after egg collection on 20/1									
20/1/00	PreRelease	51	0.05	60	52	85.2	0.0	11.1	3.7
24/1/00	Post Rel	55	0.08	72	57	41.7	47.2	8.3	2.8
1/2/00	Post Rel	63	0.50	43	83	20.6	76.5	2.9	0.0
Site 2: 60 caps of T. pretiosum per ha applied after egg collection on 20/1									
20/1/00	PreRelease	47	0.10	76	65	88.6	0.0	6.8	2.3
24/1/00	Post Rel	51	0.30	95	86	48.6	40.5	10.8	0.0
24/1/00	Nil Rel	51	0.30	71	86	98.2	0.0	0.0	1.8
31/1/00	Post Rel	58	1.50	57	91	41.9	53.5	2.3	2.3
Site 3: 60 caps of T. pretiosum per ha applied after egg collection on 20/1									
20/1/00	PreRelease	50	0.20	74	74	100.0	0.0	0.0	0.0
24/1/00	PostRel	54	0.30	95	73	87.9	10.3	1.7	0.0
31/1/00	PostRel	61	3.00	58	84	80.5	14.6	0.0	4.9
14/2/00	buffer	75	1.00	48	81	80.0	14.3	5.7	0.0
Insecticide sprayed crop near Site 3									
14-Feb	insecticide	75	1.00	41	80	85.0	0.0	15.0	0.0
Note: 87% of the "unviable" eggs were parasitised but did not yield wasps.									
Cowra Sites									
"Warwick": 60 caps of T. pretiosum per ha applied after egg collection on 21/1									
21/1/00	PreRelease	57	0.50	96	29	73.1	0.0	23.1	0.0
25/1/00	Post Rel	61	2.00	95	55	18.4	30.6	49.0	2.0
25/1/00	Nil Rel	61	2.00	84	57	56.5	0.0	43.5	0.0
"Mulyan": 120 caps of T. pretiosum per ha applied after egg collection on 21/1									
21/1/00	PreRelease	49	1.50	81	56	20.5	0.0	75.0	2.3
23/1/00	Post Rel	51	1.50	91	77	37.7	10.1	49.3	2.9
25/1/00	Post Rel	53	4.30	96	82	28.0	18.7	48.0	5.3
"Mulyan" nil release area:									
23/1/00	100m west	51	2.00	85	65	32.1	0.0	67.9	0.0
25/1/00	100m west	53	3.40	95	74	14.7	0.0	83.8	1.5

Notes

1. Wasp collected at Dubbo appears to be *T. pretiosum* but this has not been confirmed.
2. *T. pretiosum* released at 90 capsules/ha on 24 Feb.
3. Rained steadily for 24 h prior to egg collection at the 2 sites collected on 6th March.

Table A4. Parasitism in sweet corn, Dubbo district, Feb-Mar 2000.

Summary of collections at Dubbo, 2000						Species breakdown			
Date Col.	Plant stage	Eggs/ plant	Total eggs col.	% para of viable eggs	% not viable	% *Telenomus*	% *T. pretiosum*?	% Dark *T'nza*	% *T''toidea*
Site 1, 10 km south of Dubbo									
21-Feb	tassel in boot	2	53	89	11	14.3	64.3	4.8	16.7
3-Mar	full silk	1	21	78	14	14.3	50.0	7.1	28.6
Site 2, 10 kms south of Dubbo, over the river from Site 1.									
6-Mar	pre tassel	1.5	96	43	13	47.2	22.2	2.8	27.8
Site 3, 20 kms west of Dubbo									
6-Mar	Tassel emerge	1	96	65	8	47.4	14.0	0.0	38.6
Rained steadily for 24 hours prior to egg collection at the 2 sites collected on 6th March.									

Table A5. Parasitism, Site 1, Bowen June 1999

Date Col.	plot name	eggs per plant	total eggs col.	% para of viable eggs	% eggs not viable	% para by *T. pretiosum*	% para by *T'toidea* spp	% para by other species
7-Jun	Release	0.6	60	3.4	1.7	0.0	100.0	0.0
8-Jun	Release	0.6	60	16.1	6.7	100.0	0.0	0.0
9-Jun	Release	1.2	59	49.1	3.4	100.0	0.0	0.0
11-Jun	Release	1.0	59	66.7	3.4	94.7	5.3	0.0
13-Jun	Release	2.1	93	50.5	2.2	95.7	4.3	0.0
15-Jun	Release	0.8	60	52.5	1.7	96.8	0.0	3.2
17-Jun	Release	1.9	81	28.2	3.7	95.5	4.5	0.0
9-Jun	EastB9	3.0	60	19.0	3.3	18.2	36.4	45.5
11-Jun	EastB9	4.2	45	27.3	2.2	25.0	50.0	25.0
13-Jun	EastB9	3.8	48	0.0	6.3	0.0	0.0	0.0
15-Jun	EastB9	1.0	33	0.0	84.8*	0.0	0.0	0.0
9-Jun	Nth50	1.0	60	3.5	5.0	0.0	100.0	0.0
11-Jun	Nth50	1.0	36	0.0	0.0	0.0	0.0	0.0
9-Jun	West50	1.2	58	0.0	1.7	0.0	0.0	0.0
11-Jun	West50	1.0	36	0.0	5.6	0.0	0.0	0.0
13-Jun	West50	1.0	47	2.2	4.3	100.0	0.0	0.0
15-Jun	West50	1.0	36	8.3	0.0	66.7	33.3	0.0
17-Jun	West50	1.0	35	0.0	8.6	0.0	0.0	0.0
9-Jun	Sth30	1.2	60	5.6	10.0	0.0	100.0	0.0
11-Jun	Sth30	1.0	43	2.3	0.0	0.0	100.0	0.0
17-Jun	Sth30	1.9	35	21.2	5.7	14.3	57.1	28.6

*Methomyl sprayed in EastB9 on 14 June hence high "no hatch" rate.

Table A6. Parasitism, Site 2, Bowen, June 1999

Date Col.	plot name	eggs per plant	total eggs col.	% para of viable eggs	% eggs not viable	% para by *T. pretiosum*	% para by *T'toidea* spp	% para by other species
8-Jun	Release 1	0.5	48	4.2	0.0	100.0	0.0	0.0
10-Jun	Release 1	0.5	48	81.3	0.0	82.1	10.3	7.7
8-Jun	Release 1A	1.3	36	0.0	0.0	0.0	0.0	0.0
10-Jun	Release 1A	2.0	58	98.3	0.0	57.9	40.4	1.8
18-Jun	Release 1A	0.5	35	48.0	28.6	33.3	66.7	0.0
25-Jun	Release 1A	0.5	12	63.6	8.3	28.6	71.4	0.0
10-Jun	Release 2	0.5	49	37.5	2.0	100.0	0.0	0.0
12-Jun	Release 2	1.2	96	16.0	2.1	100.0	0.0	0.0
14-Jun	Release 2	0.6	97	59.1	4.1	85.5	10.9	3.6
16-Jun	Release 2	1.3	97	83.2	2.1	94.9	3.8	1.3
18-Jun	Release 2	0.7	60	79.3	3.3	89.1	10.9	0.0
25-Jun	Release 2	0.5	29	88.9	6.9	72.7	27.3	0.0
12-Jun	West 50m	1.2	48	16.7	0.0	100.0	0.0	0.0
14-Jun	West 50m	0.6	61	23.3	1.6	100.0	0.0	0.0
16-Jun	West 50m	1.3	60	44.8	3.3	42.3	53.8	3.8
18-Jun	West 50m	0.7	36	52.8	0.0	47.1	47.1	5.9
25-Jun	West 50m	0.5	25	68.0	0.0	47.1	52.9	0.0
18-Jun	West 100m	0.7	47	9.1	6.4	100.0	0.0	0.0
18-Jun	South 150m	0.4	48	63.0	4.2	20.7	79.3	0.0

Table A7 Parasitism, Site 4 , Bowen 2000.

Date Col.	Site	Planted	DAP	eggs per 100 plants	total eggs col.	% para of viable eggs	% grubs from viable	% not viable	calc. para egg/ ha*	% dark Trich	% pale T' Toid	% T. pretio sum
1/5/00	B1	7/4/00	24	20	51	31	69	0	3,137	38	63	0
3/5/00	B1	7/4/00	26	60	49	94	6	2	27,551	27	71	0
Trichogramma Release Block												
1/5/00	B2	10/4/00	21	10	50	6	94	2	300	100	0	0
3/5/00	B2	10/4/00	23	25	51	80	20	4	9,559	10	46	44

*eggs per plant times plants per hectare times percent parasitism.

Table A8. Effects of methomyl sprays on egg parasitism. Lockyer Valley 1998.

Site 1								Species breakdown			
Date Col.	plant stage	eggs/ plant	total eggs	% para	% grubs	% no hatch	Notes	% Tele	% T.p.	% T't..	% oth.
21-Oct	pretass	2	35	91	3	6		84	13	3	0
26-Oct	earl tass	12	72	61	23	14		64	32	2	2
5-Nov	mid silk	2	48	27	41	10	methomyl on 2/11	46	38	15	0
7-Nov	full silk	1	35	20	44	9	Gemstar on p.m. 7/11	0	71	29	0
9-Nov	late silk	1	36	50	33	3					
12-Nov	late silk	0.5	10	50	27	20	Ambush on ??				
Site 2											
Date Col.	plant stage	eggs/ plant	total eggs	% para	% grubs	% no hatch	Notes	% Tele	% T.p.	% T't..	% oth.
28-Oct	pre tass	4	36	67	22	11		21	54	8	17
3-Nov	full tass	15	70	46	50	4		20	71	9	0
5-Nov	earl silk	12	73	33	37	30	methomyl am 4/11	21	50	8	21
7-Nov	full silk	8	59	14	80	7		25	75	0	0
9-Nov	full silk	5	39	13	31	56		0	80	20	0
12-Nov	full silk	1	25	16	72	12	Ambush 9/11/1998				
Site 3											
Date Col.	plant stage	eggs/ plant	total eggs	% para	% grubs	% no hatch	Notes	% Tele	% T.p.	% T't..	% oth.
28-Oct	earl silk	15	48	46	46	8		32	45	9	14
3-Nov	silk	12	74	26	57	18	methomyl 31/10 8.30 am	32	42	21	5
5-Nov	silk	4	72	26	57	17		21	58	5	16
7-Nov	full silk	2	33	21	33	45	methomyl 5/11 5.30 pm				
9-Nov	late silk	0.5	24	21	71	8					
Site 4											
Date Col.	plant stage	eggs/ plant	total eggs	% para	% grubs	% no hatch	Notes	% Tele	% T.p.	% T't..	% oth.
28-Oct	earl tass	15	48	40	54	6		37	16	11	37
3-Nov	earl silk	12	72	54	38	8		31	67	3	0
5-Nov	earl silk	8	74	35	46	19	methomyl am 4/11	23	54	12	12
7-Nov	full silk	1	36	33	58	8		58	25	0	17
9-Nov	late silk	0.5	36	39	58	3		7	71	7	14
Site 5											
Date Col.	plant stage	eggs/ plant	total eggs	% para	% grubs	% no hatch	Notes				
21-Oct	tassel	5	36	61	25	14					
28-Oct	earl silk	10+	47	60	32	9					
29-Oct	mid silk	8	71	32	3	65	methomyl early 29/10				
2-Nov	full silk	3	34	38	50	12					

Table A9. Emergence of wasps from eggs collected at the "black" stage after applications of methomyl from the air. Lockyer Valley 1998.

Date Col.	**Site**	**Total eggs**	**% emerge**	**% not emerge**	**Notes**
5-Nov	Site 1	23	57	43	methomyl on 31/10 8.30 am
7-Nov		14	43	57	methomyl on 5/10 5.30 pm
9-Nov		37	57	43	
12-Nov		24	21	79	Ambush on 10/11
5-Nov	Site 2	12	83	17	methomyl 4 /11
7-Nov		25	68	32	
9-Nov		27	11	89	methomyl 9/11
12-Nov		25	64	36	
5-Nov	Site 3	12	75	25	methomyl 5/11
7-Nov		33	82	18	
9-Nov		37	78	22	
29-Oct	Site 5	59	32	68	sprayed early am 29/10
					eggs collected 11 am