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Companion and interrow plantings as part of sustainable vegetable production

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Project Number: VX99039

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Purpose of Report : The purpose of this project was to develop new tools to be used in pest management in tomatoes and capsicums through the investigation of companion planting systems. The management of major pest species such as heliothis (*Helicoverpa* spp.) is almost totally reliant on chemical insecticides which have a negative effect on the biodiversity of the cropping system and if used incorrectly the nearby environment and people. The project investigated the use of companion plantings to modify the egg laying behaviour of heliothis to reduce the populations infesting cropping systems. The use of assassin bugs (*Pristhesancus plagipennis*) as predators of heliothis in capsicums was also investigated.

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Media Summary

Insect pest management in capsicum and tomato crops is heavily reliant on chemical insecticide applications. A reduction in the amount of chemical insecticides is both a desirable and achievable goal. This project aimed to increase the available tools to growers for the management of the key pest of capsicums and tomatoes, heliothis moth.

Aspects of companion planting were investigated along with the responses of heliothis to biologically diverse environments. Companion planting benefits have long been recognised in home garden situations. The same types of benefits of this increase in biodiversity may be seen in cropping situations.

The key findings of this project were:

- While sorghum companion plants acted as a trap crop in a small scale experiment, this effect was not seen in an experiment in a commercial capsicum crop. In fact, sorghum actually increased the numbers of heliothis eggs on near by capsicum plants.
- Marigolds proved to be highly attractive to heliothis moths in glasshouse experiments and may be a suitable trap crop for capsicums.
- Heliothis moths did not display any learning behaviour in relation to host selection in the field
- None of the reputedly pest repellent herbs tested (tansy, catnip, basil and coriander) were found to be repellent to heliothis moths. Tansy was found to increase the numbers of eggs on their tomato companions.
- Assassin bugs proved to be successful predators of heliothis larvae in capsicum crops. The optimal release rate was 3 bugs/m.

Further investigation of the suitability of marigolds as a trap crop for capsicums is necessary. The use of trap crops in general requires more work to determine if they actually result in a reduction in heliothis pressure within a crop. The use of assassin bugs as predators in capsicums looks promising but further research is required to determine their efficiency and to refine release rates. Assassin bugs should soon be commercially available.

Technical Summary

Conventional management of pests in tomato and capsicum crops has relied heavily on the use of chemical insecticides. While some integrated pest management (IPM) tools are used successfully, (such as crop monitoring and some biological insecticides) more tools are necessary to have an effective IPM system for these crops. The key pest species of both tomato and capsicum cropping systems is heliothis (*Helicoverpa* spp., particularly *H. armigera*). The control of *Helicoverpa* spp. drives the pest management choices of the systems as repeated applications of insecticides may result in increases in secondary pest populations. Development of a companion planting system was therefore targeted at this *Helicoverpa* spp..

In order to define how the introduction of companion plants may influence the management of *Helicoverpa* spp. in capsicum and tomato systems, it is necessary to understand the insects responses to more than one species of plant in a given area. Several experiments were conducted investigating trap cropping, host preferences, the influence of learning in host selection and pest repellent plants. The use of assassin bugs (*Pristhesancus plagipennis*) as a predator of *H. armigera* in capsicums was also investigated.

In a small scale field experiment investigating the use of sorghum (*Sorghum bicolor*) as a companion plant, it was discovered that flowering stage of sorghum was significantly more attractive to *H. armigera* larvae than tomatoes. In host preference experiments capsicums were shown to be significantly less attractive to ovipositing *H. armigera* than tomatoes. Experiments were then conducted in a commercial capsicum crop to determine if sorghum was a good trap crop for capsicums. However, sorghum did not reduce the numbers of *Helicoverpa* eggs found in the capsicum crop. On one sample date, plots with sorghum received significantly more *Helicoverpa* eggs than plots without sorghum companions.

In a glasshouse host preference experiment, marigolds (*Tagetes erecta*) were found to be significantly more attractive to ovipositing *H. armigera* moths than capsicums. The difference in egg numbers laid on these plants was very pronounced. Field based experiments were designed to determine if marigolds are successful as a trap crop under field conditions. Although two field experiments were conducted, *Helicoverpa* spp. pressure was insufficient in both experiments to be able to draw any conclusions.

Further investigation of the use of marigolds as a trap crop in capsicum cropping systems is recommended. Some results of this project indicate that trap crops may increase pest numbers in a crop by attracting more pests into the cropping area. This effect needs further investigation.

While learning behaviour in oviposition has been shown in the laboratory (Cunningham et al. 1998b), no conclusive evidence of this was found in the field.

Several species of herbs reported to be pest repellent in companion planting literature and scientific publications were investigated in glasshouse experiments for repellent activity against *H. armigera*. None of the herbs tested showed repellent activity. Tansy (*Tanacetum vulgare*) significantly increased the number of eggs laid on accompanying tomato plants in one experiment.

The potential of assassin bugs as a biological pest management agent of *H. armigera* in capsicums was assessed. Significantly lower larval numbers were found after one day of exposure the to predator. A release rate of three bugs per metre of crop row was found to be optimal. Further field experiments were planned under conditions of natural pest pressure, however, predator release was not warranted due to insufficient larval numbers. The use of assassin bugs requires further investigation as the number of commercially available *Helicoverpa* spp. biological control agents is small (assassin bugs should soon be commercially available).

1.0 Introduction

Companion planting is not a new concept and has gained popularity in home gardens. Many books for home gardeners have been written about companion planting (Riotte 1992, French 1997, Little 1997). Most companion planting recommendations have come about through gardeners observing that certain combinations of plants provide beneficial effects for one or both partners (Bigwood 1991). Often, plants that are said to 'like' each other simply prefer similar growing conditions (Kourik 1986). In trying to find 'hard data' to substantiate companion planting recommendations, Kourik (1986) found less than half of the studies he considered confirmed the recommendations being made. Many of the studies recommended that more research is needed to investigate companion planting interactions.

The same types of ecological interactions that are found in companion planting for home gardens are often considered in terms of polycultures (Alteri et al. 1990); vegetational diversity (Tahvanainen and Root 1972); multiple cropping (Listinger and Moody 1976); inter-cropping (Nafus and Schreiner 1986) and trap cropping (Pyke et al. 1987) in agricultural situations. Increasing biological diversity by introducing another plant species to a cropping system may confer the same types of benefits that companion planting does in home garden situations.

The mechanisms by which companion planting reduces pest insect pressure are complex. These mechanisms may be considered in terms of how having more than one plant species in an area may modify pest insect behaviour and ecological interactions between insects and plants.

The introduction of companion or inter-row plantings within a vegetable production system increases biodiversity within a crop. Increased biodiversity can have positive influences on the pest management of the system. However, biodiversity *per se* will not necessarily lead to better pest management (Murdoch 1975). A companion planting system needs to be developed so it introduces 'useful' biodiversity.

Companion planting may reduce the number of pests in a field by:
- acting as a trap crop (Hokkanen 1991),
- providing a physical barrier to entering the crop (Prasad and Chand 1989),
- confusing visual and chemical stimuli from the crop (Altieri 1994), (Tahvanainen and Root 1972) and
- encouraging beneficial insects within the crop area (Root 1973).

The vegetable production systems targeted by this project were tomatoes and capsicums. These two systems have a similar spectrum of pests and are grown in the same regions. For both crops the key pest is heliothis (*Helicoverpa* spp., particularly *H. armigera*).

Chemical management of heliothis causes frequent disruption to the cropping systems from early flowering until harvest. Often, the result of this disruption is an increase in secondary pest populations such as two-spotted mite (*Tetranychus urticae*) and tomato leafminer (*Phthorimaea operculella*). The chemicals applied for heliothis management often suppress other minor pests, such as green vegetable bug (*Nezara viridula*). Therefore, the management of heliothis is the dominant influence on pest management systems for tomatoes and capsicums.

To be successful in introducing companion planting to these vegetable production systems, it is necessary to first understand the behavior of *Helicoverpa* spp. their response to increased biodiversity.

Internationally, little research work has been undertaken on the effect of increased biodiversity on the management of *Helicoverpa* spp. in tomatoes or capsicums. Most work has centered on tomatoes, using various companions as trap crops attracting *Helicoverpa* spp. away from a tomato crop. Silking-stage corn and marigolds have been the preferred trap crops (Whitcomb 1960, Roltsch and Mayse 1984, Srinivadan et al. 1994).

This project aimed to develop an understanding of the use of companion planting in the management of *Helicoverpa* spp. in tomato and capsicum production systems. The response of *Helicoverpa* spp. moths to different host species and potentially pest repellent plants was assessed. An understanding of the role that experiential learning plays in host selection of moths and how this applies to pest management was investigated. An experiment on the use of assassin bugs (*Pristhesancus plagipennis*) as a biological pest management agent in capsicums was also conducted.

2.0 Materials and Methods

2.1 Sorghum as a companion for tomatoes

2.1.1 First Field Experiment

The experiment was conducted at the Horticultural Field Section at the University of Queensland Gatton, located in the Lockyer Valley, Queensland. The treatments were:

Treatment 1: 1 bed of tomatoes with tall sorghum (cv Chopper)
Treatment 2: 3 beds of tomatoes with tall sorghum
Treatment 3: 1 bed of tomatoes with short sorghum (cv DK35)
Treatment 4: 3 beds of tomatoes with short sorghum

The experimental design used was a radomised complete block with 3 replications. Originally, no control plots of tomatoes without sorghum were used. It was thought that the sorghum may effect the plant health of the tomatoes which could result in a differential attractiveness to *Helicoverpa* spp. moths to tomatoes with and without sorghum companions. The tomato cultivar used in the trial was Flora Dade, which is a common commercial 'round' variety used in the Queensland tomato industry.

The short cultivar of sorghum was removed on the 10/1/2000. At this stage very little *Helicoverpa* spp. activity had been recorded and the removal of the short sorghum aimed to maximise the differences between the treatments hopefully allowing for the easier detection of differences in *Helicoverpa* spp. counts. This meant the treatments altered to:

Treatment 1: 1 bed of tomatoes with tall sorghum (Chopper)
Treatment 2: 3 beds of tomatoes with tall sorghum
Treatment 3: 1 bed of tomatoes without sorghum
Treatment 4: 3 beds of tomatoes without sorghum

Data collection began on the 17/12/99. While the tomato plants were still small whole plant samples were examined. The plant was inspected for *Helicoverpa* spp. eggs and larvae as well as any other pests or beneficial insects that may be present. When the tomato plants reached approximately 50-60cm in height, six full leaves were sampled instead of sampling the whole plant. Up to and including this stage, all tomato plants in the experiment were being sampled. With increased plant size however, this was found to be time consuming. When plants began flowering 7 sites per plot were sampled. The sample consisted of three full upper leaves or equivalent, the youngest and second youngest hands of flowers (normally approximately 10 flowers), one hand of fruit from the middle of the plant and one hand of fruit from the bottom of the plant as well as one full lower leaf.

2.1.2 Second Field Experiment – Sorghum and Capsicums

This experiment involved the application of previous positive experimental results to a commercial cropping situation. The experiment was conducted on a capsicum farm in the Bundaberg district. The design consisted of two bays of eleven rows of capsicums, which was divided into eight blocks. With four of these blocks the middle row of the bay was planted with 30 m of sorghum (variety Chopper). The remaining four blocks consisted of crop plants only.

Egg numbers of *Helicoverpa* spp. were sampled in the capsicums on a transect basis. Samples were taken at 4 sites across the width of each experimental plot. This allowed the identification of any trends in egg numbers with proximity to the sorghum. The sample at each site consisted of counting the number of *Helicoverpa* spp. eggs found on the top third of the capsicum plants for one linear meter of row. Due to difficulties in finding *Helicoverpa* spp. eggs on sorghum heads in the field the sorghum was sampled destructively. At each sample date one linear meter row of sorghum heads were collected. These heads were then spun inside a plastic bucket to remove the eggs and then the eggs were counted. Sampling commenced when the sorghum started to flower on the 24/4/01. The experiment was sampled four times between 24/4/01 and the 4/5/01 after which time there was a sudden decline in the number of *Helicoverpa* spp. eggs found. At each sample date transects were conducted on the blocks consisting of capsicums.

2.2 Host Preference Experiments

2.2.1 First Host Preference experiment – Spring 2000

An experiment was conducted at the University of Queensland, Gatton investigating the preference of *Helicoverpa armigera* for different host species. The species used were: indeterminate and determinate tomatoes (*Lycopersicon esculentum*), chilli (*Capsicum annuum* var. *annuum*), pigeon pea (*Cajanus cajan*), chick pea (*Cicar arietunum*) and white clover (*Trifolium repens*). All plants were flowering, and with the exception of the white clover, had developing fruit.

The plants were arranged in 2 concentric circles with one plant of each species in each circle (Firempong and Zalucki 1990). The arrangement of species in each circle was random. Plants were kept in saucers full of water to stop ants from predating eggs laid on the plants. Jars with cotton wool wicks containing a 5% sugar solution were placed around the experimental area to act as feeding sites for the moths.

Twenty-three female and 23 male moths were released into the experimental area. On the first night of their release, the moths were observed from the start of ovipositional behaviour at 5.40 pm until 6.40 pm and observations were recorded. For 4 days the eggs were counted each morning and removed to prevent eggs being counted more than once. The arrangement of plants within each circle was randomly changed each day after eggs were counted to eliminate any positional effects (Firempong and Zalucki, 1990).

2.2.2 Second Host Preference Experiment – Spring 2001

In this experiment the hosts investigated were orange-flowering african marigolds (*Tagetes erecta*), yellow-flowering african marigolds (*Tagetes erecta*), indeterminate tomatoes (*Lycopersicon esculentum*) and capsicums (*Capsicum annum* var. *annum*).

Fifteen female and 18 male *H. armigera* moths were released on the 3/9/01. Data were recorded in the same way as described for the previous experiment. Observations of ovipositional behaviour were made on the first night of release of the moths.

2.3 Marigolds as a Trap Crop in Capsicum Crops

2.3.1 First Field Experiment

A field experiment was planted in the Lockyer Valley on the 21/11/01 to evaluate the potential of marigolds as a trap crop for *Helicoverpa* spp. in capsicums. The experimental design consisted of one large block of capsicums (34 rows) with 2 rows of marigolds planted in the middle of the block (Figure 1). Sampling was to consist of transect lines through crop and marigolds counting the number of *Helicoverpa* spp. eggs and larvae found per site. However, insufficient pest numbers were found to warrant transect sampling.

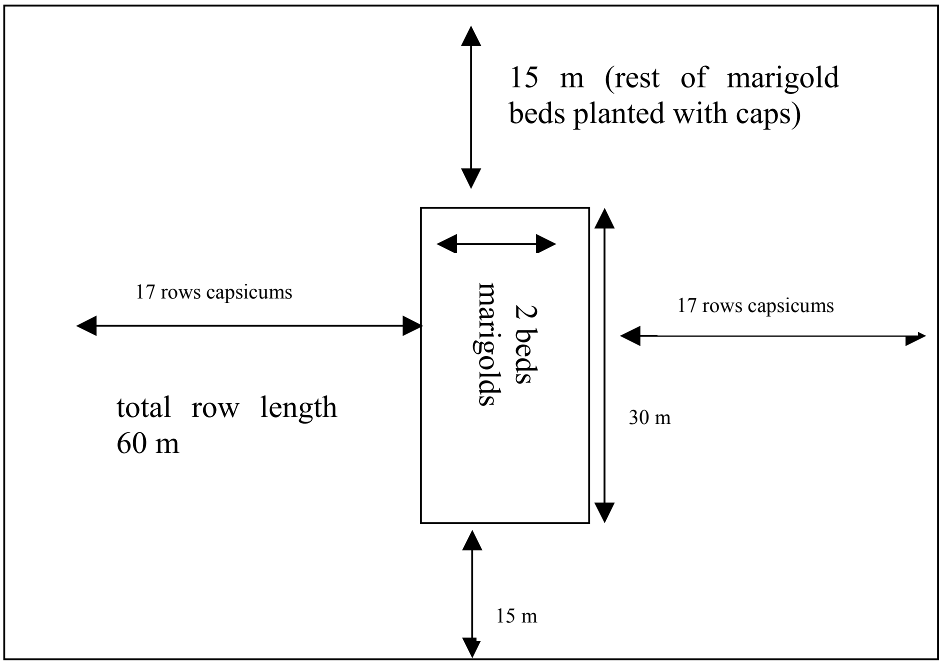

Figure 1: Experimental design for first marigold field experiment.

2.3.2 Second Field Experiment

A second field experiment was carried out at Biloela, central Queensland. This location was selected as there is usually heavier *Helicoverpa* spp. pressure o crops than found in the Lockyer Valley. The experimental design was similar to the previous field experiment but consisted of two identical blocks in the one cropping area. Each block was 30 meters long by 15 rows wide and had a 15m by 2 row block of marigolds in the middle. Sampling procedures were to be similar to those for the previous marigold trap crop experiment in the Lockyer Valley.

2.4 Investigation of the Influence of Learning on host selection behaviour

This experiment was conducted at a property on the Forrest Hill Rd, Gatton. The experimental area consisted of two blocks both ¼ ha in size (100m x 25m). The blocks were located approximately 200m apart to minimise any interactions between them. Each block consisted of a large crop area, either of pigeon pea (*Cajanus cajan*) or tomato (*Lycopersicon esculentum*) with strips and patches of the alternative crop (Figure 2) Rows in both blocks ran north-south, perpendicular to the prevailing easterly winds. As *Helicoverpa* spp. moths fly into the wind, they came into the blocks from the short sides and therefore had the opportunity to first experience the main crop planted in the block.

This gave moths the opportunity to learn in relation to oviposition before encountering the strips of the alternative crop in the middle third of each block.

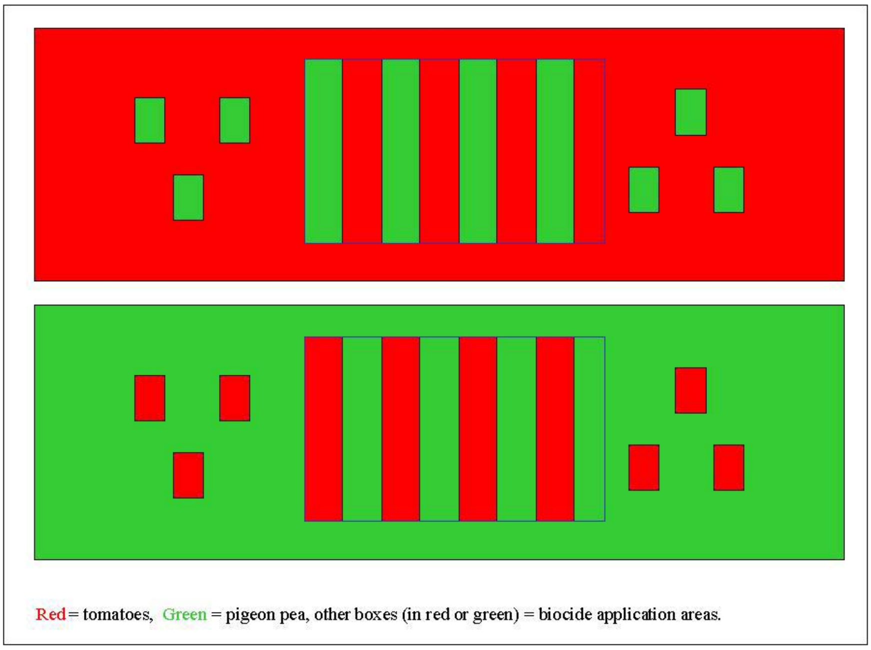

Figure 2: Experimental design used in learning experiment.

The predominately pigeon pea block was planted on the 3/10/00. However, due to a hail storm on 3/11/00 and moderate weed pressure, the block was replanted on 24/11/00 with the tomatoes planted on 27/11/00.

Background data sampling was started in the predominately tomato block on the 8/12/00. Sampling in the tomatoes consisted of checking three terminals to the first fully expanded leaf, five flowers and three fruit per plant per sample. Initially, 12 sample sites were checked in the tomatoes, four sites in each third of the block. Sampling in the pigeon pea consisted of checking all flowers, leaves and pods in the top third of one plant per site. In the patches of pigeon pea, six sites were checked per patch, while in the strips 12 sites were checked per strip. The block was sampled each morning before a night time observation. From 3/01/01, the middle section of the block containing the pigeon pea strips was checked as separate strips of tomato as opposed to a bulk area. Each strip of tomatoes between the pigeon pea strips was checked separately with 3 sites being checked in each strip. Sampling concluded on 6/01/01 as there was little *Helicoverpa* spp. pressure and the tomato crop was aging and no longer attractive.

In the predominately tomato block, night time observations of moth behaviour began on 2/1/01. For the collection of observational data only the middle of the block was considered. The experimental area consisted of the alternate strips of pigeon pea and tomatoes in the middle of the block including the 2 rows of tomato on the western side of the last pigeon pea strip (represented by the blue lines in Figure 2). *Helicoverpa* spp. moths were observed as they entered the experimental area at around dusk. Observations were recorded using a hand held tape recorder. Once a moth was located it was followed and data collection began after the moth had laid its first egg. This ensured that data was only collected for ovipositing females. The amount of time a moth spent in each crop was also recorded as was any other behaviors observed, such as feeding.

Data collection began on the predominately pigeon pea block on 19/2/01. Counts of *Helicoverpa* spp. eggs were made on a per meter row basis in both the pigeon pea and tomatoes to allow for an easier comparison. A site consisted of 1m row of crop generally two pigeon pea plants and one tomato plant. Pigeon pea plants were initially divided into top middle and bottom thirds and egg data recorded for each third. However, when no eggs were found on the middle or the bottom thirds only the top third of plants were considered. In the tomato patches and strips a site consisted of a 1 m of row sample where the whole plant was sampled.

The pigeon pea block was divided into three sections consisting of the bulk areas of the crop at either end and the experimental area containing the tomato strips in the middle. The number of *Helicoverpa* spp. eggs counted in one metre row sections of crop along transect lines was recorded. In the bulk pigeon pea areas at either end of the block, transect lines, consisting of 6 sites, were conducted running from west to east (from the edges of the block to the middle section) and from north to south (from edge to edge). This allowed for the identification of any trends in egg data with increasing distance away from the tomato strips and also for any trends in the data across the width of the block. In the middle section of the trial, the experimental area, three sites per strip of tomatoes or pigeon pea were sampled. There were three sites sampled in each patch of tomatoes occurring in the bulk areas of pigeon pea crop either side of the middle experimental area.

2.5 Assassin Bugs for the management of *Helicoverpa* spp. in Capsicums

The potential of the assassin bug (*Pristhesancus plagipennis*) as a biological pest management agent of *H. armigera* in capsicums was assessed in an opportunistic experiment in the Lockyer Valley. The experimental area had been planted for an experiment investigating the use of marigolds as a trap crop for capsicums. Unfortunately, over the period of the marigold/capsicum experiment no *Helicoverpa* spp. were found in the crop. Since the capsicum crop was not being used for the originally planned experiment, the area was available for an investigation of the potential of *P. plagipennis* as a biological pest management agent in capsicums.

The experiment consisted of 4 treatments; 0, 1, 3 and 5 *P. plagipennis* nymphs released per meter row of crop. These treatments were replicated 6 times. Each plot was 6m long and 1 row wide. At either end of each plot two capsicum plants were removed to limit the movement of *P. plagipennis* nymphs out of the plot area.

Third and fourth instar *P. plagipennis* nymphs were released on 18/2/02. As there was a complete absence of *Helicoverpa* spp. eggs or larvae in the capsicum crop, it was necessary to release *Helicoverpa* larvae into the crop. To increase the survival rates of larvae released, third instar *H. armigera* larvae (rather than smaller larvae) were released on the 19/2/02. The larvae were released on the day following the release of the *P. plagipennis* nymphs to simulate a flight of moths laying eggs in a crop in which where *P. plagipennis* nymphs were already established by inundative release.

The experimental plots were sampled by visually examining three 1m sections of row per plot. The numbers of *H. armigera* larvae and *P. plagipennis* were observed and recorded 1 and 2 days after release of the larvae. After 2 days few *H. armigera* larvae were found because most surviving larvae had burrowed inside the capsicum fruits. Plots were sampled for *P. plagipennis* only 6 and 9 days after the larval release. Observations of *P. plagipennis* were also made 14 days after *H. armigera* larval release.

A damage assessment was done 14 days after the release of the larvae. Three samples of ten fruit each were taken from each plot and examined for evidence of *H. armigera* larval damage.

2.6 Pest Repellant Plants

2.6.1 Glasshouse Experiments

Several herbs listed as being pest repellent were investigated for their ability to repel *H. armigera* away from tomato plants. They were: Catnip (*Nepta cataria*), Tansy (*Tanacetum vulgare*), Basil (*Ocium basilicum*) and Coriander (*Coriander sativum*).

Potted tomato plants and herbs were used in all experiments. Treatments consisted of a single tomato plant or a tomato plant with a pot of the herb to be tested on either side of it. The experimental design used was similar to that used in the host preference experiments. Moths were offered 3 tomato plants with companion herbs and 3 without companions, set around the perimeter of a small glasshouse bay. Moth behaviour was observed on the first night of each experiment. Egg numbers per tomato plant were counted each day for 3 days. The experiment was repeated twice for each herb.

2.6.2 Olfactometer Experiments

Purpose built olfactometers were used to investigate the response of gravid *H. armigera* female moths to the odours of the same repellent plants used in the glasshouse experiments. The olfactometers were designed to test for true repellence rather than a lack of attractiveness in plants. After 12 months of experimentation, no meaningful results were obtained from the system.

3.0 Results

3.1 Sorghum as a companion for tomatoes

3.1.1 First Field Experiment

Throughout the period of the experiment, numbers of *Helicoverpa* spp. larvae and eggs were low. The highest average number of eggs found on any sample date was only 1.71 (Table 1). Average numbers of larvae were also consistently low. There were no significant differences detected in the numbers of eggs or larvae between any of the treatments on any sample date (ANOVA).

Table 1 : Average numbers of *Helicoverpa* spp eggs and larvae found on each sample date in sorghum as a companion for tomatoes experiment.

Date	Treatment	average number of eggs	average number of larvae
17/12/99	1	1.04	0.14
	2	0.90	0.14
	3	1.23	0.24
	4	1.71	0.70
23/12/99	1	0.48	0.15
	2	0.51	0.11
	3	0.25	0.19
	4	0.48	0.15
30/12/99	1	0	0.95
	2	0.06	0.02
	3	0.14	0.05
	4	0.13	0.02
6/1/00	1	0.05	0.14
	2	0.14	0.60
	3	0	0
	4	0.14	0.05
13/1/00	1	0.14	0
	2	0.33	14
	3	0.14	0
	4	0.33	0
20/1/00	1	0	0.19
	2	0	0.05
	3	0.4	0.10
	4	0	0
27/1/00	1	0.05	0.10
	2	0.19	0.10
	3	0.19	0.48
	4	0.14	0
10/2/00	1	0	0
	2	0.48	0.10
	3	0.48	0.10
	4	0.14	0.05

Treatment 1 = 1 bed of tomatoes and tall sorghum; Treatment 2 = 3 beds of tomatoes and tall sorghum; Treatment 3 = 1 bed of tomatoes and short sorghum; Treatment 4 = 3 beds of tomatoes and short sorghum. From sample on the 13/12/99 short sorghum was removed leaving only tomatoes.

Table 2: Average numbers of *Helicoverpa* spp. larvae found in tomatoes and sorghum on the 10/2/00

Treatment	average number larvae in tomatoes/site	average number larvae in sorghum/head	average number larvae in tomatoes/m	average number of larvae in sorghum/m
1	0	0.7	0	0.84
2	0.5	0.97	0.6	11.64
3	0		0	
4	0		0	

Significant numbers of *Helicoverpa* spp. larvae were noted in the sorghum heads on the 10/2/00. Table 2 shows significantly higher numbers of larvae were detected in the sorghum than in the tomatoes on this sample date (p = 0.001, paired t-test). Numbers are presented as both a per site/head value to a per linear metre of row value to allow for easier comparison between tomatoes and sorghum.

3.1.2 Second Field Experiment – Sorghum and Capsicums

Sorghum was not a suitable companion plant for capsicums in a commercial situation. Only relatively low levels of *Helicoverpa* spp. eggs were found during the period of the experiment. However on the 4/5/01 significantly more eggs were found on capsicums with sorghum companions than capsicums alone (Table 3).

Table 3: Average numbers of *Helicoverpa* spp. eggs found in one metre of capsicum plants with and without sorghum trap crops.

Date	Treatment	Average number of egg/m	Standard deviation	Level of Significance
27/4/01	capsicums + sorghum	2.50a	1.00	ns
	capsicums	1.75a	2.47	
4/5/01	capsicums + sorghum	0.69a	0.25	0.002
	capsicums	0.06b	0.70	

Egg counts for each sample date followed by the same letter are not significantly different (ANOVA). ns = not significantly different

Up to 32 *H. armigera* larvae /m were found in sorghum heads on the 27/4/01, with an average of 9.25 eggs/m. On the same date, an average of 0.33 eggs/m were found in the sorghum. On the 4/5/01, an average of 1.78 larvae/m were found in the sorghum and an average of only 0.13 eggs/m.

3.2 Host Preference Experiments

3.2.1 First Host Preference Experiment – Spring 2000

There were significant differences ($p=0.002$) between the numbers of eggs laid on different host species. Significant differences ($p < 0.001$) also occurred in the numbers of eggs laid on hosts over the four days of the experiment was run.

Both tomato varieties were more preferred than any of the other host species in this experiment (Table 4). No significant differences were found in ovipositional preference between clover, pigeonpea and chilli, with these species being ranked second. Chickpea was the least preferred species.

Table 4 : Mean total number of eggs laid on different hosts in first host preference experiment

Host species	Mean total number of eggs laid (log 10 transformed)
Chickpea	1.263 a
Clover	1.975 b
Pigeonpea	2.032 b
Chili	2.250 b
Indeterminate Tomatoes	2.631 c
Determinate Tomatoes	2.733 c

Means followed by different letters are significantly different: $p = 0.0001$, Tukey's critical value = 5.63

While moths were being observed on the first night after their release it was noted that there was quite a lot of activity around the chickpea plants. However, this activity did not equate to higher numbers of eggs laid on these plants.

The untransformed cumulative number of eggs laid on each species is shown in Figure 3. It can be seen that round tomatoes had the highest cumulative number of eggs with a total of 542 eggs. Chickpea clearly had the lowest number of cumulative eggs with only 19 eggs being laid on this host over the 4 days of the experiment.

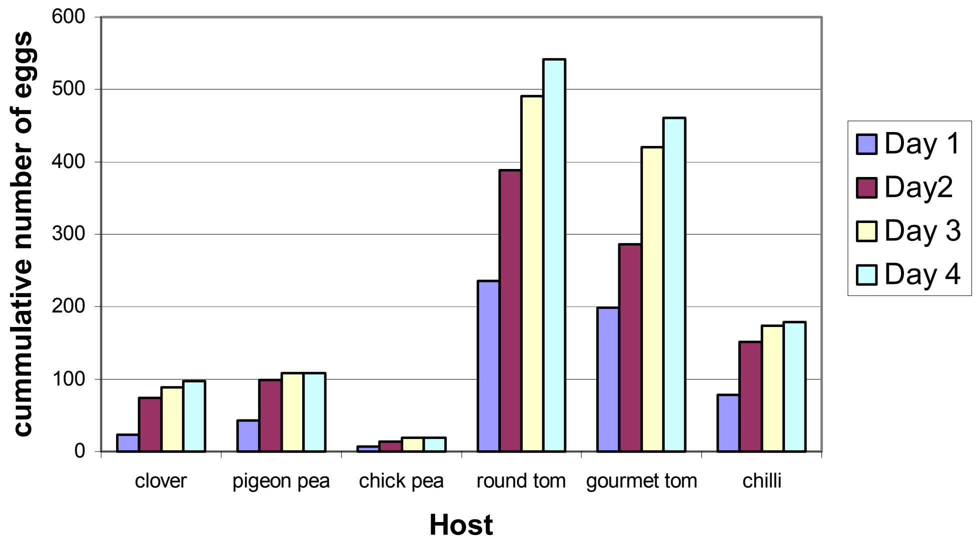

Figure 3: Cumulative number of *H. armigera* eggs on different hosts in first host preference experiment

3.2.2 Second Host Preference Experiment – Spring 2001

Significantly (p = 0.01 more eggs were laid on both the orange and yellow marigolds than on the capsicums (Table 5) in the second host preference experiment. Although the total number of eggs laid on tomatoes was smaller than on either of the marigolds (Figure 4) no statistically significant difference was found. There was also no significant difference between the number of eggs laid on the capsicum and the tomato plants.

Table 5 : Mean total number of eggs laid on different hosts in second host preference experiment

Host species	Mean total number of eggs laid (log 10 transformed)
Capsicum	1.296a
Tomato	2.250ab
Orange Marigold	2.499b
Yellow Marigold	2.528b

Means followed by different letters are significantly different: p = 0.019, Tukey's critical value = 5.76

Moth activity started at dusk with eggs being laid on both yellow and orange marigolds. Shortly after moths began to oviposit on the capsicums and tomatoes as well. Individual moths were observed laying eggs on marigolds, flying to capsicum plants and subsequently flying back to marigolds to recommence oviposition without landing on the capsicum. Other individual moths were observed flying to tomatoes, not landing and returning to marigolds to oviposit.

The cumulative numbers of eggs laid on each host species is shown in (Figure 4). It can be seen from this graph that orange marigolds received in excess of 350 eggs over the 4 days and yellow marigolds received more than 300. In contrast tomatoes received only 177 eggs and capsicums only 24.

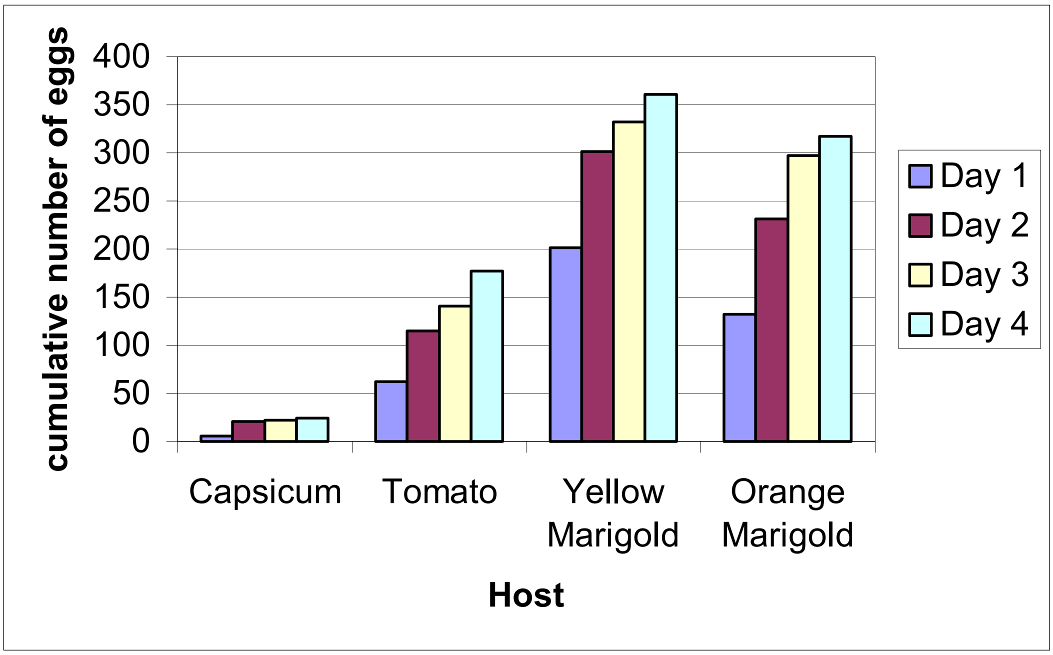

Figure 4 : Cumulative number of *Helicoverpa armigera* eggs on different hosts in the second host preference experiment.

3.3 Marigolds as a Trap Crop in Capsicum Crops

3.3.1 First Field Experiment

The experiment was sampled weekly for the presence of *Helicoverpa* spp. eggs and larvae. During the period between 14/12/01 and 13/2/02 only one *Helicoverpa* spp. egg was found. The complete lack of pest pressure made it impossible to evaluate the effectiveness of marigolds as a trap crop for capsicums. However, the experiment investigating assassin bugs as a biological management agent in capsicums was conducted in the same experimental area to make use of the crop.

3.3.2 Second Field Experiment

The experiment investigating marigolds as a trap crop for capsicums was repeated at Biloela to obtain higher *Helicoverpa* spp. pressure than occured in the Lockyer Valley the previous season. Unfortunately, the pest pressure in the Biloela experiment was only marginally better than for the Lockyer Valley experiment. Weekly samples identified very low levels of *Helicoverpa* spp. during the period of the experiment. The low pressure did result in some cumulative damage to the crop. A damage assessment was conducted at the end of the experiment. This did not detect any significant differences in either the total number of capsicum fruit per sample or the number of fruit damaged per sample in relation to proximity of sites to the marigold trap crops.

3.4 Investigation of the Influence of Learning on Host Selection Behaviour

3.4.1 Predominately Tomato Block

Helicoverpa spp. eggs were found in low numbers over the period of the experiment. This was typical of the general *Helicoverpa* spp. pest pressure in the Lockyer Valley at the time. The highest number of eggs recorded per site was 1.6 eggs on 6/1/01.

Despite the low egg numbers, some significant differences were detected between different areas of the block. However, these differences were not consistent between sample dates. Table 6 shows that on 8/12/00 significantly more eggs were laid on the tomatoes in the middle third of the block then in all other areas of the block ($p < 0.001$). However, the average number of eggs laid in the middle third of the block was still only 0.75/site, which is a reasonably low level and this difference was not detected again. Significantly ($p = 0.008$) more *Helicoverpa* spp. eggs were found in the eastern third of the block than in any other area on the 14/12/00. On 2/1/01 significantly ($p = 0.007$) more eggs were found in the eastern third and the middle of the block then in any of the pigeon pea areas or the western third of the block. All these significant differences, occurred with low average egg numbers. The highest average number of eggs found was only one egg/site.

Table 6 : Average numbers of *Helicoverpa* spp. eggs found per site in the predominately tomato block between the sample dates of 8/12/00 and 2/1/01

Date	Pigeon pea patches	Pigeon pea strips	Western tomato 3rd	Middle tomato 3rd	Eastern tomato 3rd	Level of significance
8/12/00	0.06ab	0.00a	0.25b	0.75c	0.25b	< 0.001
14/12/00	0.06a	0.18a	0.50ab	0.00a	0.75b	0.008
19/12/00	0.03	0.10	0.25	0.00	0.00	ns
2/1/01	0.11a	0.45ab	0.25ab	1.00b	1.00b	0.007

Numbers for each sample date followed by the same letter are not significantly different at the level stated (Tukey's test). ns = not significant.

The data presented in Table 6 were collected using the original data sampling plan where the tomatoes were divided into three areas (bulk area either end and area containing pigeon pea strips in the middle). The data in table Table 7 were collected according to the revised sampling plan where the middle section of tomatoes was checked as separate strips (and then the data averaged over these strips).

Table 7 : Average number of *Helicoverpa* spp. eggs found per site in the predominately tomato block between sample dates 3/1/01 and 6/1/01.

Date	Pigeon pea patches	Pigeon pea strips	Western tomato 3rd	Eastern tomato 3rd	Tomato strips	Level of significance
3/1/01	0.19	0.32	0.25	0.5	0.67	ns
4/1/01	0.44	0.22	0.75	0.25	0.53	ns
5/1/01	0.25	0.28	0.25	0.5	0.33	ns
6/1/01	0.5a	0.48ab	0.2ab	1.6ab	1.4b	0.018

Numbers for each sample date followed by the same letter are not significantly different at the level stated (Tukey's test). ns = not significant.

The only significant difference detected in the numbers of *Helicoverpa* spp. eggs found after the revision of the sampling plan occurred on the 6/1/01 (Table 7). At this sampling date significantly more eggs were found in the tomato strips than in the pigeon pea patches. However, there were no significant differences detected between any of the areas of tomatoes or between the pigeon pea strips and any of the tomato areas.

3.4.1 Predominately Pigeon Pea Block

The change in sampling method from counting numbers of eggs/site to counting the number of eggs/m allowed for an easier comparison between *Helicoverpa* spp. eggs on tomatoes and eggs on pigeon pea. In the predominately pigeon pea block significant differences were found in the numbers of eggs/m in different areas of the block (Table 8). In contrast to the predominately tomato block, these significant differences were found consistently over several sample dates. On three out of the five sampling dates the number of eggs found on the strips of pigeon pea (in the middle section of the block) were significantly higher then the numbers of eggs found in either the tomato strips or patches.

Table 8 : Average number of *Helicoverpa* spp. eggs per metre found in the predominately pigeon pea block between 19/2/01 and 5/3/01

Date	Pigeon Pea Strips	Tomato strips	Tomato Patches	Level of significance (Tukey's Test)
19/2/01	2.60a	0.07b	0.06b	0.007
22/2/01	0.80a	0.73a	0.39a	ns
26/2/01	4.27a	1.07a	0.61a	ns
1/3/01	1.87a	0.20b	0.00b	0.001
5/3/01	2.13a	0.20b	0.00b	0.001

Numbers for each sample date followed by the same letter are not significantly different at the level stated (Tukey's test). ns = not significant.

The only transect that showed any trend in the data was the east-west transect of the eastern third on the 26/2/01 ($R^2 = 0.87$). This transect showed an increase in *Helicoverpa* spp. eggs with increasing distance away from the middle third of the block towards the edge of the block. This trend was only found on one sample date however. Of all the other transects the highest R^2 value recorded was 0.63 in the north south transect in the eastern third of the block.

3.4.3 Observational Data

In the predominantly tomato block, several individual female *H. armigera* moths were followed and their activities recorded. Observational data was recorded only after a moth had begun oviposition. Many moths were observed without any record of oviposition being taken. Often these moths were observed feeding from pigeon pea flowers.

On the first night of observations (2/1/01) moths were observed (and recorded) laying eggs on both pigeon pea plants and tomato plants. At this time, moths were also observed feeding on nectar from the flowers of pigeon pea plants. One moth was observed laying eggs on both pigeon pea and tomato as well as rejecting tomato for oviposition and feeding on pigeon pea. Feeding events observed were of both short and longer durations. Some moths were observed feeding for only seconds at a time while others were observed feeding for several minutes. After short bouts of feeding, moths often continued oviposition activity. Moths that were observed feeding for longer than approximately 3 minutes were not generally observed performing any oviposition activity after feeding and sometimes were observed resting after feeding.

One moth was observed both dragging its ovipositor along the surface of a pigeon pea leaf while extending its proboscis, suggesting stimulation for both feeding and ovipositon simultaneously.

Observations of moth behaviour were attempted in the predominantly pigeon pea block but due to the height the pigeon pea plants grew in this block, observations were very difficult. Due to the replanting of this block, the photoperiod the plants were growing under resulted in much taller plants, up to 1.6 m in places. Observations were attempted on several occasions but abandoned due to the difficulties involving plant height and also a lack of *H. armigera* pressure.

3.5 Assassin Bugs for the management of *Helicoverpa* spp. in Capsicums

One day after the release of the *H. armigera* larvae, the *P. plagipennis* nymphs had significantly reduced the number of larvae present in all predator treatments compared to the control (Table 9).

Table 9 : Average number of *H. armigera* found in each treatment one day after release of the larvae. (ANOVA $p < 0.001$)

Number of *P. plagipennis* released	Average number of *H. armigera* larvae
0 bugs/m	2.00a
1 bug/m	0.89b
3 bugs/m	0.56b
5 bugs/m	0.34b

A strong relationship between the number of larvae surviving and the number of predators released was evident ($R^2 = 0.958$) (Figure 5). Increasing predator numbers resulted in decreasing survival of larvae.

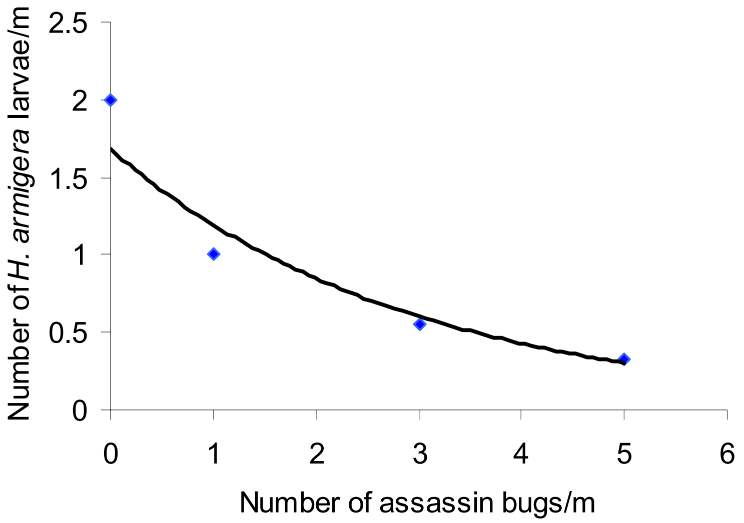

Figure 5 : Effect of the number of *P. plagipennis* released per row on the number of *H. armigera* larvae recovered ($y = 1.6787e^{-0.3416x}$, $R^2 = 0.958$)

The reduction in numbers of *H. armigera* larvae in plots with *P. plagipennis* can be seen in Table 10. In this table, the frequency of samples recording between 0 and 5 (the largest number found) *H. armigera* larvae is shown for each of the treatments (out of a total of 18 samples). In the control treatment (0 bugs/m) the frequency of finding no *H. armigera* larvae was 2 where as with the introduction of 1 bug/m this increased to 7 samples where no larvae were found. The frequency increased to 10 and 13 samples when 3 bugs/m and 5 bugs/m respectively were introduced. Similarly, the only treatment to record 5 larvae/m in a sample was the control treatment, the highest number of larvae recorded in a *P. plagipennis* treatment was 3 and this occurred only once in the one bug/m treatment.

Table 10: Cross tabulation frequency table – number of *H. armigera* larvae vs number of *P. plagipennis* per metre (in each of the 18 x 1m samples)

	Number of *H. armigera* larvae						
Number of P. plagipennis bugs/m	0	1	2	3	4	5	Total larvae
0	2	5	4	6	0	1	36
1	7	7	3	1			16
3	10	6	2				10
5	13	4	1				6

The retention of *P. plagipennis* in the experimental plots can be seen in Figure 6. One day after the release of the bugs, the treatments of 3 and 5 bugs/m retained approximately 2 and 3 bugs/m respectively. By the 25/2/02, predator retention was approximately 2 bugs/m in both the 3 and 5 bugs/m treatments, while 1 bug/m was still found in 1 bug/m treatment. On the 28/2/02, retention in the 3 and 5 bugs/m treatments had declined slightly while numbers in the 1 bug/m treatment had dropped to less then 1 bug every 2m.

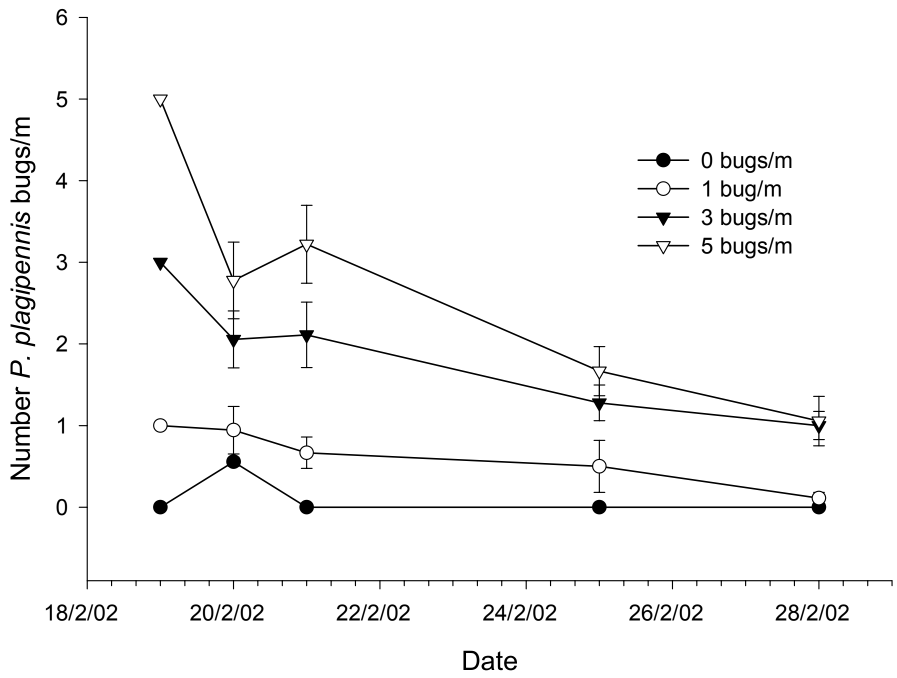

Figure 6 : Time series showing retention of *P. plagipennis* in capsicum crop. Bars denote treatment s.e.

An assessment of the damage done to capsicum fruit in the experiment showed a trend towards decreasing damage with increasing numbers of *P. plagipennis*. However, this data is inconclusive due to complications in sampling for damage. A large amount of Queensland fruit fly (*Bactrocera tryoni*) damage was apparent resulting in rotting of fruit in a similar manner as happens when damaged by *H. armigera*.

3.6 Pest Repellant Plants

3.6.1 Glasshouse Experiments

None of the companion plants trialed successfully repelled *H. armigera* moths and prevented them laying eggs on the potted tomato plants (Table 11). The only significant difference ($p = 0.009$) detected was in the second Tansy experiment where there were actually significantly more eggs laid on tomatoes with a Tansy companion than on tomatoes alone.

Table 11 : Results of Pest Repellent Plant Experiments – Average numbers of eggs laid on tomatoes + companions and tomatoes alone.

Experiment	Experiment number	no female moths	Average number of eggs		level of significance
			tomato only	tomato + companion	
Tansy	1	18	104	116	0.69
Tansy	2	18	146	279	0.009*
Coriander	1	15	52.6	53.6	0.961
Coriander	2	15	90	68	0.518
Catnip	1	15	29.5	18.2	0.616
Catnip	2	+	+	+	+
Basil	1	15	119	109	0.762
Basil	2	14	24.6	15.2	0.447

* significantly different $p \leq 0.05$ (ANOVA)
+ experiment being completed

4.0 Discussion

4.1 Sorghum as a companion for tomatoes

4.1.1 First Field Experiment

The lack of significant *Helicoverpa* spp pressure throughout this experiment made interpretation of the results difficult and inconclusive. However, the significantly higher numbers of larvae found in the sorghum heads compared to the tomatoes on the 10/2/00 was an interesting result. On this sampling date the sorghum heads were flowering and were highly attractive to ovipositing *Helicoverpa* spp. moths. As there were no significant differences in numbers of eggs or larvae found in any of the tomato samples between the treatments, it would appear that moths were more attracted to the flowering sorghum than the tomatoes. It could be concluded that sorghum was acting as a trap crop.

Based on these finding a second experiment investigating the effectiveness of sorghum as a trap crop was conducted in a commercial field situation at Bundaberg.

4.1.2 Second Field Experiment – Sorghum and Capsicums

The use of sorghum as a trap crop for capsicums in a commercial cropping situation was unsuccessful. Sorghum failed to reduce the numbers of *Helicoverpa* spp. eggs and larvae found on the capsicum plants.

On one sampling date, the sorghum significantly increased the number of eggs found in the capsicum plants. In view of the results of other experiments in this project (see section 3.4) it seems possible that the sorghum initially attracted the moths into the area and then moths laid eggs on both the sorghum and the capsicum plants.

4.2 Host Preference Experiments

The results of the first experiment suggest that none of the species trialed would be suitable as a trap crop for *Helicoverpa armigera* in tomatoes. Pigeon pea is gaining popularity as a trap crop in the cotton industry but on the basis of this experiment it would not be suitable for tomato cropping systems. However, the small scale nature of this trial needs to be noted. In field situations the ovipositional preference of *H. armigera* may alter with factors such as crop to trap crop ratio, shape and position of trap crop and ovipositional experience of moths.

The low numbers of eggs found on the chickpea was surprising considering the amount of moth activity observed around the plant. The observations of the moth behaviour around chickpea are curious as chickpea is currently being used as a trap crop in cotton production systems. Chickpea is employed as a spring trap crop to reduce *Helicoverpa* spp. populations before the planting of the cotton crop. High numbers of *Helicoverpa* spp. larvae have been recorded on chickpea. Up to thirty larvae per metre square were recorded in the 1998-1999 cotton season (Waters and Sequeira 2000)

In the second host preference experiment significant differences in egg counts between marigolds and capsicums suggest that marigolds may be a suitable trap crop for capsicum crops. The differences in egg counts between capsicums and both the orange and yellow flowering marigolds were large. In addition, moths were observed rejecting capsicum plants as hosts in favour of marigolds. These factors warrant further investigation of marigolds as a trap crop for capsicums in a field situation.

The lack of a significant difference between egg counts for the tomatoes and marigolds was surprising. In India, marigolds were successfully used as a trap crop for marigolds (Srinivadan et al. 1994). Their experiments were conducted under field conditions. Given these results, a significant difference between eggs laid on marigolds and tomatoes was expected. The host preference experiments were conducted under controlled glasshouse conditions with equal ratios of each host plant available for ovipositing moths. It would be expected that larger differences would be observed under these controlled conditions than would be apparent in the field.

The suitability of marigolds as a trap crop for tomatoes may be increased in a field situation through spatial design and trap to crop ratio. However, no field investigations examining at marigolds as a trap crop for tomatoes were conducted as, given the results of this experiment, marigolds are more likely to benefit capsicum crops.

4.3 Marigolds as a Trap Crop in Capsicum Crops

Experiments investigating marigolds as a trap crop for capsicums were unsuccessful due to extremely low populations of *Helicoverpa* spp. during the seasons the experiments were conducted. However, given the results of the second host preference experiment, further investigation of marigold trap crops is recommended.

4.4 Investigation of the Influence of Learning on host selection behaviour

No evidence of learning in the oviposition of *Helicoverpa* spp. moths was found in this experiment. Although significant differences in egg numbers were sometimes discovered between the different plant species and areas of the blocks, these could not be linked to differences in learned host preferences of the insects. The major limiting factor to the experiment was the low numbers of *Helicoverpa* spp. moths present over the duration of the experiment.

In the predominately tomato block, the significant differences found between egg numbers on the middle and eastern sections of the block may have resulted from an individual moth or a small number of moths ovipositing in those particular sections. All the average numbers of eggs found per site were very small and the differences are between 0 and 0.25 or 0 and 0.75 eggs/site. With these low averages, conclusions about significant differences between areas are difficult to make. Within a population of *H. armigera*, individual female moths may differ in their host-plant specificity, with some individuals being more generalist than others (Jallow and Zalucki 1996). So, conclusions drawn from such low average egg numbers may be unreliable. The low numbers may also explain the lack of consistency between the significant differences over different sampling dates. If a very small number of individuals are contributing to the egg numbers recorded, consistency between sample dates is less likely due to within population variation.

In the predominately pigeon pea block, three of the five samples dates showed significantly more eggs in the pigeon pea strips than in the tomato strips or patches. This is an interesting result as in the glasshouse host preference experiment, tomato varieties received significantly more eggs than pigeon pea, making tomatoes a more preferred host. While the possibility of learning in host preferences can not be discounted, the more likely explanation is the differences in height of the two host plants.

Due to replanting of the pigeon pea block, the plants were growing under conditions of decreasing day length. The pigeon pea plants in the predominately tomato block were grown under conditions of increasing day length. All other conditions the plants were grown under were similar. The difference in day length resulted in the pigeon pea in the predominately pigeon pea block growing to heights of up to 1.6m whereas the pigeon pea in the predominately tomato block only grew to approximately 0.7m. Tomatoes in both blocks were not trellised and were of a similar height to the pigeon pea in the predominately tomato block.

Plant height has an influence on the selection of a host for oviposition *by H. armigera* females. It has been shown that plant height can positively influence the number of eggs laid by *H. armigera* moths (Firempong 1987). Also, taller plants are 'discovered' earlier by moths. It has been inferred that moths use plant silhouettes to locate host plants and that taller plants have a greater chance of being 'discovered' earlier and therefore receive more eggs (Firempong 1987). It has been argued that this effect is not likely to alter the basic hierarchy of host preference because this is genetically determined (Firempong 1987, Firempong and Zalucki 1990). Sequeira (2002) found that taller plants in a chickpea crop such as weeds attracted much higher numbers of eggs than surrounding crop plants. He suggested that taller plant species could be sown as companion plants in a range of commercial crops. In further experiments he showed that in spite of innate host hierarchal preferences, canola attracted greater oviposition than chickpea in the early seedling stages (Sequeira and Moore 2003). This resulted from the differential in height between canola and chickpea (canola being taller), leading to canola being a more ‘apparent’ host.

If as Firempong (1987) suggests, *H. armigera* moths use silhouette to locate hosts, the tomato plants in the pigeon pea block would have been difficult for moths to find. The tomato patches and strips were areas that were small in size compared to the overall block, and the tomato plants were much shorter than the main crop. So a moth using silhouettes to locate a host would not have seen a silhouette of the tomato plant. In this way, pigeon pea plants became the more ‘apparent’ of the two hosts thereby attracting greater oviposition then the normally more preferred tomatoes.

Many moths were observed feeding from pigeon pea flowers in the predominantly pigeon pea block. Observational data were not collected on a moth until it had been observed ovipositing. In trying to find moths that were ovipositing, a large proportion of moths present were observed feeding from pigeon pea flowers. At no time were moths observed feeding from tomato flowers.

Learning has been demonstrated in feeding behaviour of *H. armigera* under laboratory conditions (Cunningham et al. 1998a). These authors propose that the combination of learning in feeding and oviposition behaviour may greatly influence the preferred choice of oviposition hosts in the field. If a female moth develops a learnt feeding preference for a particular host, once oviposition begins it is more likely to return to that host for both feeding and oviposition.

Even though a large proportion of moths were observed feeding from pigeon pea flowers in the predominantly tomato block, on no sampling date were more eggs recorded on pigeon pea than on tomato. This suggests that learning in feeding behaviour did not influence the oviposition host choice of female moths. While average numbers of eggs laid on the two hosts were generally low, if the effect of learning in feeding behaviour was a strong influence on oviposition behaviour, larger numbers of eggs would have been expected on pigeon pea. However, this was not recorded. All significant differences in egg numbers in the predominantly tomato block related to higher numbers of eggs on tomatoes than on pigeon pea.

Moths were observed feeding on pigeon pea flowers and then ovipositing on both pigeon pea and tomatoes. Given the large proportion of moths observed feeding on pigeon pea, it was apparent that pigeon pea is an attractive host for nectar foraging. It seems likely that pigeon pea was attracting moths into the experimental area, because feeding was often the first behaviour of a moth was observed performing. Ovipositing females then remained in the experimental area and laid eggs on both pigeon pea and tomatoes.

On some sampling dates more eggs were recorded on sections of tomato than on pigeon pea. This suggests that when selecting a host to be used as a companion to the main crop the attractiveness of that plant for feeding needs to be carefully considered. By using a highly attractive crop for nectar foraging it is possible that increased numbers of moths are attracted into the area. These moths may then stay to oviposit indiscriminately on both crop and companion plants.

4.5 Assassin Bugs for the management of *Helicoverpa* spp. in Capsicums

This preliminary investigation suggests that the use of *P. plagipennis* in capsicums as a biological pest management agent of *H. armigera* has some potential. *P. plagipennis* nymphs quickly and significantly reduced the number of *H. armigera* larvae in the crop following their introduction.

The retention of the predator within the crop was reasonable, considering the lack of potential prey. Within two days of the release of the *H. armigera* larvae, most of the surviving larvae had burrowed into the fruit making them inaccessible to *P. plagipennis*. The larvae used in the experiment were at 3rd instar. Larvae of this size often hide inside capsicum fruit in commercial crops. Younger *H. armigera* larvae however, are found in and around the growing points and flowers of the crop, where they would be accessible prey for *P. plagipennis*. The crop area used for the experiment had very low levels of insect activity meaning few alternate prey species were available to the predators.

In this experiment, the mean numbers of predators remaining at the end of sampling in the 3 and 5 bugs/m treatments were the same (approximately 1 bug/m). As there was no significant difference in *H. armigera* numbers between any of the *P. plagipennis* treatments (ANOVA $p< 0.01$), there would be no advantage in releasing 5 bugs/m over releasing 3 bugs/m. The 1 bug/m treatment resulted in levels of less then 1 bug every 2m (0.11 bugs/m) at the end of the experiment. This suggests the best release rate in this experiment was 3 bugs/m as this maintained higher levels of the predator for longer.

The ability to use *P. plagipennis* in capsicums would provide a biological management agent capable of controlling the key insect pest of the crop, *H. armigera*. Currently the only commercially available biological management agents for this pest are *Tricogramma* spp. (Llewellyn 2002). Currently, the commercial production of *P. plagipennis* is under development.

Further investigation into the use of *P. plagipennis* as a biological pest management agent is needed. It is important to establish the effectiveness of the predator on natural infestations of *H. armigera*. The predator is compatible with the use biological insecticides. The effect of *Bacillus thuringiensis* on *P. plagipennis* through ingestion in the food chain has been investigated (Grundy 2000). It was found that the predation of *H. armigera* larvae infected with *B. thuringiensis* by *P. plagipennis* did not have any effect on the survival or development of the predator. Currently *B. thuringiensis* is registered for use in capsicums. Another biological insecticide that may be compatible with *P. plagipennis* is Gemstar®. The effect of Gemstar® on *P. plagipennis* and the integration of the two management methods needs further investigation.

An experiment investigating the use of *P. plagipennis* on natural populations of *Helicoverpa* spp. was planned. This experiment was also to investigate the use of the predator in conjunction with both Gemstar® and Bt.. The experimental area to be used was the same area being used for the second experiment on using marigolds as a trap crop for capsicums. However, the level of infestation of *Helicoverpa* spp. in the crop was again insufficient to warrant a release of *P. plagipennis*.

4.6 Pest Repellant Plants

Neither the glasshouse experiments nor the olfactometer experiments found any repellent activity of the herbs tested to *Helicoverpa armigera*. In the glasshouse experiment, average egg numbers for most experiments were similar for tomatoes with and without herb companions. The only significant difference found suggested that Tansy actually resulted in more eggs being laid on their accompanying tomato plants then the tomato plants alone.

In companion planting and herb books written for home gardeners Tansy is said to have strong pest repellent qualities (Riotte 1992, French 1997, Woodward 1997). Scientifically, Tansy has been used successfully as an intercrop to decrease the population of pea thrips (*Kakothrups robustus*) and pea weevils (*Sitona* sp.) (Wnuk 1988). Tansy has also been used successfully as a repellent and antifeedant to colorado potato beetles (*Leptinotarsa decemlineata*) (Schearer 1894, Panasiuk 1984, Hough-Goldstein 1990). It obviously does not deter *H. armigera* moths from ovipostion activity. The increase in egg numbers observed on tomatoes with tansy companions may be due simply to an increased plant volume in the tansy treatments (3 plants as compared to only 1 tomato plant). It is possible that tansy is reasonably attractive to *H. armigera* moths. However, from observations made after the moths were released, while there was oviposition activity on the tansy plants, moths were spending more time on tomato plants with tansy companions.

It has been shown in other experiments that marigolds are highly attractive to *H. armigera* moths. However, marigolds are also listed in home gardener books as being pest repellent (Woodward 1997). Given the results of the repellent plant experiments and the attractiveness of marigolds to *H. armigera*, it is not likely that herbs will be found to be repellent to ovipositing moths. The wide host range of this pest means that finding a plant that is not acceptable for oviposition and is actually capable of repelling moths away from itself or another host is unlikely.

It was hoped that an olfactometer system would be developed allowing the screening of potential repellent plants quickly and easily. However, it proved extremely difficult to devise a system that was capable of discriminating between different moth behaviours. To measure the relative attractiveness of different hosts in an olfactometer system is relatively easy but to show true repellent activity proved difficult. Many different techniques and systems were trailed over a period of more than 12 months without success.

5.0 Technology Transfer

Throughout this project, comment and input has been sought from various members of the horticultural industry. Integrated pest management consultants in both the Lockyer Valley and at Bundaberg were consulted on the design of experiments and results were discussed throughout the life of the project (Julian Winch of Valley Crop Monitoring Service, (Gatton) and the pest management team at Crop Tech (Bundaberg). Meetings took place with some growers directly on an informal basis through either farm visits (Don Halpin, Bundaberg) or meetings with consultants (Andrew Phillip, Bundaberg). Contact was also maintained with the QFVG and Bayer Crop Science (who both contributed funds) through Mr Andrew Phillip and Ms Sue Cross.

5.1 Poster Displays

Herde, R. Harden, J Wearing, A and Maelzer, D. Companion and Inter-row Planting as Part of Sustainable Vegetable Production Hort Expo 14 – Lockyer Valley Field day at University of Queensland, Gatton, 2000 (including discussion of results on an informal basis to interested growers and one page flyer on project)

Herde, R. Harden, J Wearing, A and Maelzer, D. Companion and Inter-row Planting as Part of Sustainable Vegetable Production Australian Entomology Society 31st Annual General Meeting and Conference Darwin 25-30 June 2000

5.2 Seminar Presentations

Herde, R. Grundy, P. Maelzer, D. Wearing, A. Assassin Bugs (*Presthesancus plagipenns*) as Biological Pest Management Agents in Capsicums Australian Society of Horticultural Science Conference, Sydney 2 October 2002

Herde, R. Grundy, P. Maelzer, D. Wearing, A. Assassin Bugs (*Presthesancus plagipenns*) as Biological Pest Management Agents in Capsicums Faculty of NRAVS Research Conference, University of Queensland, St Lucia, October 2002

5.3 Other publications

Herde, R. Inter-row planting's for Vegetable Crops, Bundaberg Region Horticultural Newsletter, April 2000

Herde, R. Search is on for Crop Companionship, Queensland Fruit and Vegetable News 71:6 June 2000

Herde, R. New management tools for heliothis in capsicums, Queensland Fruit and Vegetable News, 73:7 July 2002

5.4 Other Conferences

10th Australian Cotton Conference, Cotton Meeting the Challenge, 16-18 August 2000, Brisbane

National Science Writers Festival, Brisbane 2001
(including being interviewed for inclusion on CD to be distributed to radio stations)

5.5 Consultation and Co-operation with other Researchers

The project was discussed with Prof. Myron Zalucki (University of Queensland St Lucia) and Dr. Paul Cunningham (University of Edinburgh) on several occasions. Prof. Zalucki has worked on Heliothis management and behaviour for a number of years and Dr. Cunningham is a visiting academic doing post-doctoral research in insect learning behaviour. Both assisted with experimental designs.

QDPI entomology staff in Toowoomba also gave advice on procedures for experiments and results were discussed with them.

6.0 Recommendations

1. Further experiments are needed to assess the value of incorporating trap cropping into tomato and capsicum growing systems. Results of project experiments indicate that trap crops either have little value or may in fact result in increased numbers of *Helicoverpa* spp. eggs being laid on the crops they are meant to protect.

   The use of marigolds as a trap crop for capsicums should be further investigated. Marigolds are significantly more attractive to ovipositing *H. armigera* moths than capsicums. This is a key criteria if a trap cropping system is to be successful. Particular attention needs to be paid to the behaviour of *Helicoverpa* spp. moths in relation to feeding and oviposition to ensure more moths then normal are not being attracted into the area and staying to lay eggs.

2. Assassin bugs may be suitable predators for use in the management of *Heclioverpa* spp. in capsicums at the release rate of 3 bugs/m. The suitability of the predator under conditions of natural *Helicoverpa* spp. pressure needs investigation and the release rate needs revision under these conditions. The integration of assassin bugs and other available biological management agents and compatibility with biological and conventional pesticides need further investigation.

3. It is unlikely that pest repellent herbs will be useful in *Helicoverpa* spp. management due to the highly polyphagous nature of the pest.

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