Refining integrated pest management of eggfruit caterpillar

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Refining integrated pest management of eggfruit caterpillar

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Contents

Media Summary

Eggfruit caterpillar is an important pest of eggplant in Australia. The caterpillars live and feed inside the fruit and the internal damage they cause makes the fruit unusable.

This project aimed to improve integrated pest management of the pest by:

- identifying IPM compatible insecticides that were effective against eggfruit caterpillar;
- investigating if pheromone traps could be used to monitor for eggfruit caterpillar;
- learning more about the biology and ecology of the insect.

Ten insecticides were tested and several effective ones identified. These results should help in obtaining registration of these insecticides for use against the pest.

Monitoring is a basic part of IPM, but monitoring for eggfruit caterpillar eggs and larvae is difficult. Monitoring male moths in pheromone traps is easy and if the number of moths caught in traps is related to the number of eggs laid on fruit then traps could be used to determine when controls are needed. The results of several trials showed that the more moths caught in the traps the greater the percentage of egg-infested fruit, but unfortunately the results were very variable. They were too variable for moth catches to be used to accurately predict eggfruit caterpillar infestation levels to make treatment decisions.

Pheromone traps were used to show that eggfruit caterpillar is active all year round in the Bundaberg district, although numbers are lower in winter.

Tiny trichogrammatid wasps were reared from parasitised eggfruit caterpillar eggs. This is the first record of parasitism of eggfruit caterpillar.

Laboratory studies determined the effect of temperature on the rate of development of eggfruit caterpillar eggs, larvae and pupae. This basic biological information is important in understanding the insect.

The information gathered in this project enhances our understanding of the insect and its management. Further work to improve the IPM of all pests and diseases in eggplant crops is needed.

Technical Summary

Sceliodes cordalis (Doubleday) (Lepidoptera: Crambidae), the eggfruit caterpillar, is an important pest of eggplant in Australia. The neonate larvae tunnel into the fruit where they feed until mature, and then tunnel out to pupate nearby. The internal damage caused by the larval feeding makes the fruit unusable.

This project investigated the efficacy of insecticides to control *S. cordalis*; investigated whether pheromone traps could be used as a monitoring tool, and used pheromone traps to study the seasonal occurrence of *S. cordalis* at Bundaberg; and studied the effect of temperature on *S. cordalis* development.

The efficacy of insecticides in controlling *S. cordalis* in eggplant was tested in four small plot trials. Weekly applications of bifenthrin, flubendiamide, methoxyfenozide, chlorantraniliprole and spinosad and twice weekly applications of methomyl provided control as measured by a percentage of damaged fruit significantly lower than that in an untreated control. Twice weekly applications of methoxyfenozide, chlorantraniliprole or spinosad were not significantly more effective than weekly applications. *Bacillus thuringiensis kurstaki*, emamectin benzoate, indoxacarb, methomyl applied weekly and pyridalyl were ineffective, with percentages of damaged fruit not significantly different from the untreated control. There has been a very limited range of insecticides available to manage *S. cordalis*, but these trials have identified a number of insecticides that could be used, including several that would be compatible with integrated pest management programs in eggplant. The data have been provided to the agricultural chemical companies to facilitate the registrations of the new, effective insecticides for use against *S. cordalis* in eggplant crops.

Four experiments were conducted to test whether the numbers of *S. cordalis* male moths caught in traps baited with the female-produced pheromone accurately predicted the percentage of fruit with *S. cordalis* eggs. A close relationship would allow pheromone traps to be used to monitor for *S. cordalis* to help make management decisions, as monitoring for eggs or larvae is difficult. In each trial moth catches in traps in an eggplant crop were recorded weekly. Fruit were collected from the crop and examined for the presence of eggs. Regressions of percentage of fruit with eggs against numbers of trapped moths were not significant in three trials and only significant in the fourth because of an outlying data point. When data from three similar trials was combined the regression was significant but, with an R^2 of 0.45, there was too much variability for the trap catches to be used to predict the level of egg-infested fruit with sufficient accuracy to make management decisions. Ninety-eight percent of eggs were found on the calyx of the fruit. *Trichogramma* and *Trichogrammatoidea* egg parasitoids were reared from *S. cordalis* eggs collected during these trials. These appear to be the first records of parasitism of *S. cordalis*.

Pheromone trapping at five sites showed that *S. cordalis* was present through the whole year in the Bundaberg district. Numbers generally were higher in the warmer months than in winter and were higher when crops were present near the traps, although moths were trapped a considerable distance from crops.

S. cordalis eggs, larvae and pupae were reared at five constant temperatures from 20°C to 30°C to determine their developmental rates. The developmental zeroes and thermal constants derived from the thermal summation model are: eggs 11.22°C and 61.32 day-degrees; larvae 12.03°C and 179.60 day-degrees; pupae 14.43°C and 107.03 day-degrees. These basic measures of the insect's biology had not been determined previously.

Technology transfer activities included publication of a project newsletter, "Eggfruit Caterpillar Update", and presentations at grower workshops.

General Introduction

Eggplant growing is a small but important vegetable cropping industry in Queensland. The main production areas are in the Bowen – Burdekin district in north Queensland and in the Bundaberg district, with smaller areas of production near Rockhampton, in the Lockyer Valley and on the Granite Belt. Recently the value of eggplant production in Queensland was estimated at approximately $20M annually by Growcom and QDPI&F.

Eggplants are attacked by a number of insect and mite pests. The eggfruit caterpillar, *Sceliodes cordalis* (Doubleday) (Lepidoptera: Crambidae) is one of the most important and troublesome. The neonate caterpillar tunnels into the fruit and it feeds within the fruit as it develops and grows. The mature caterpillar emerges from the fruit to pupate, leaving a large exit hole and extensive tunnelling and frass inside the fruit.

Despite the importance of *S. cordalis*, relatively little work has been done on it. Davis (1964) briefly described the insect and its habits. Clearwater *et al.* (1986) and Galbreath and Clearwater (1983) discovered the *S. cordalis* pheromone and used it to monitor the seasonal occurrence of the insect in New Zealand, and Kay and Brown (2000) and Brown (2002, 2005) further investigated the pheromone in north Queensland. Martin and Workman (1985) reported that methomyl was effective against *S. cordalis* in New Zealand and Kay and Brown (1992) tested the efficacy of a range of insecticides against *S. cordalis* in eggplant in north Queensland. Brown (2002, 2005) studied its seasonal occurrence and the possible use of pheromones for mating disruption in north Queensland in two HAL projects.

The main aims of the project reported here were:

- To test a wide range of insecticides, particularly ones compatible with integrated pest management programs, to determine if they are effective against eggfruit caterpillar;

- To investigate if pheromone traps can be used to monitor for eggfruit caterpillar in crops.

As well, the project aimed to investigate the seasonal occurrence of *S. cordalis* in the Bundaberg district as part of the pheromone studies, and to study the effect of temperature on the insect's development.

The studies conducted to achieve these aims are reported in the sections "Insecticide Studies", "Pheromone Trapping Studies" and "Temperature and Development Studies" in this Final Report.

Insecticide Studies

Introduction

Insecticides are used to control *S. cordalis* although the insect's habits, with the larvae protected inside the fruit, make this difficult. Few insecticides are registered for use on eggplant, which is considered a minor crop because of the small areas grown and hence is an insignificant market for insecticides, a similar situation to that of some other vegetable crops (Kay 2007). Currently endosulfan is the only insecticide registered for use against *S. cordalis* on eggplant. There are restrictions on its use and Kay and Brown (1992) showed it was only moderately effective, so it was not included in these trials. Spinosad is used under permit on pepinos in Western Australia (APVMA 2008). Martin and Workman (1985) reported that methomyl applied weekly prevented damage to greenhouse pepinos in New Zealand. Kay and Brown (1992) tested a number of insecticides for their efficacy against *S. cordalis* in eggplant in north Queensland and found that weekly applications of esfenvalerate and fluvalinate and twice weekly applications of methomyl were the most effective. These insecticides have not since been registered for use against *S. cordalis* on eggplant and, as they are regarded as disruptive to beneficial insects (Llewellyn 2002; Wilson *et al.* 2005), they are unsuitable for use in integrated pest management programs.

Clearly there is a need for other insecticides to be available for use against *S. cordalis* on eggplant. It also is important that the insecticides should be minimally disruptive to the integrated pest management of other pests of the crop such as thrips and silverleaf whitefly (*Bemisia tabaci* (Gennadius) biotype B).

Four trials were done to test the efficacy of 10 insecticides against *S. cordalis*. Details of the insecticides used are given in Table I1. The frequency of spraying also was assessed for several of the insecticides. Bifenthrin was included as a positive check in each trial. The aim was to determine effective insecticides and generate efficacy data that could be used to obtain registration for their use against *S. cordalis* on eggplant.

Materials and methods

Trial 1

Trial 1 was conducted at Ayr Research Station from September to November 2006 in a crop of the variety Black Pearl grown using standard agronomic practices, with plants spaced 0.5 m apart in rows 1.5 m apart. The trial used a replicated block design with five replicates and plots of three rows by 7 m. Treatments were applied either weekly or twice weekly (i.e. every 3 and 4 days), and treatments were applied for 3 weeks before the first harvest. A further 4 weeks of sprays were applied before the second harvest.

Trials 2, 3 and 4

Trials 2, 3 and 4 were conducted at Bundaberg Research Station from April to May 2006, December 2006 to January 2007 and November to December 2007 respectively. In all three trials crops were grown using standard agronomic practices in rows 1.5 m apart, using the variety Shiner with a plant spacing of 0.8 m in Trial 2, and the variety Black Pearl with a plant spacing of 0.5 m in Trials 3 and 4. All trials were randomised block designs with four replicates, with plots of three rows by 7 m in Trials 2 and 3 and three rows by 6 m in Trial 4, with 1 m of guard between plots along each row. Treatments were applied weekly or twice weekly in all three trials. In Trial 2, four weeks of sprays were applied before fruit were harvested. Four weeks of sprays were applied before the first harvest and a further 3 weeks of sprays applied before the second harvest in both Trials 3 and 4.

Trials 1, 2, 3 and 4

In all four trials the insecticide treatments were applied in the equivalent of 1000 L of water ha^{-1} using a motorised sprayer fitted with a boom and Albuz brown hollow cone nozzles and operated at 690 kPa. Spraying started when all plants were flowering and small fruit were present on a few plants. At each harvest in each trial all fruit except the very small were picked from the middle 5 m of the centre row of each plot. All harvested fruit were returned to the laboratory, counted and cut into slices to detect the presence of larvae or damage so the percentage of damaged fruit could be determined. For each trial, analyses of variance were performed on the number of fruit and on the percentage of damaged fruit, following inverse sine transformation, for each harvest and for the harvests combined, with means separated with a protected least significant difference test, using GenStat 9.2.

Table I1

Active Ingredient, Formulation and Trade Name of Insecticides used in Trials 1-4

Active ingredient	Formulation	Trade name
Bacillus thuringiensis kurstaki Strain HD-1	32000 IU dry flowable	DiPel Forté
Bifenthrin	100 g L^{-1} emulsifiable concentrate	Talstar
Chlorantraniliprole (Rynaxapyr)	200 g L^{-1} suspension concentrate	Coragen
Emamectin benzoate	44 g kg^{-1} water dispersible granules	Proclaim
Flubendiamide	480 g L^{-1} suspension concentrate	Belt
Indoxacarb	400 g kg^{-1} (300 g kg^{-1} active S-isomer) water dispersible granules	Avatar
Methomyl	225 g L^{-1} emulsifiable concentrate	Lannate L
Methoxyfenozide	240 g L^{-1} suspension concentrate	Prodigy
Pyridalyl	100 g L^{-1} suspension concentrate	Alegro
Spinosad #	120 g L^{-1} suspension concentrate 240 g L^{-1} suspension concentrate	Success Success2

The 120 g L^{-1} formulation was used in Trials 2 and 3, and the 240 g L^{-1} formulation was used in Trials 1 and 4.

Results

The results are shown in Tables I2 – I5.

In Trial 1 (Table I2) *S. cordalis* infestation levels were very low at the first harvest. In the second harvest and for the combined data only the spinosad, methomyl (twice weekly) and bifenthrin treatments had a significantly lower ($P<0.05$) percentage of damaged fruit than the untreated control. The percentages of damaged fruit in the indoxacarb, *Bacillus thuringiensis*, emamectin benzoate and methoxyfenozide treatments did not differ significantly ($P>0.05$) from the untreated control.

Fruit were harvested only once in Trial 2 (Table I3). There were no significant differences ($P>0.05$) in the percentage of damaged fruit between the untreated control and the emamectin benzoate, indoxacarb and *B. thuringiensis* treatments, while the spinosad, bifenthrin and methomyl (twice weekly) treatments had a significantly lower ($P<0.05$) percentage of damaged fruit than the untreated control.

In Trial 3 (Table I4) the spinosad, methoxyfenozide, chlorantraniliprole and bifenthrin treatments had a significantly lower ($P<0.05$) percentage of damaged fruit than the untreated control at both harvests and for the combined data. The indoxacarb treatment had less damage than the control at the second harvest but not at the first harvest or for the harvests combined. The percentages of damaged fruit in the pyridalyl, emamectin benzoate and methomyl (weekly) treatments did not differ significantly ($P>0.05$) from the untreated control.

The main aim of Trial 4 was to re-test the most promising insecticides (spinosad, chlorantraniliprole and methoxyfenozide) from the earlier trials and to investigate if increasing the frequency of application improved their efficacy in preventing damage by *S. cordalis*. Flubendiamide also was tested. All the insecticide treatments except methoxyfenozide had significantly lower ($P<0.05$) percentages of damaged fruit than the control at both harvests and for the harvests combined (Table I5). Methoxyfenozide applied either weekly or twice weekly did not differ significantly ($P>0.05$) from the untreated control at the second and first harvests respectively, but both had significantly lower ($P<0.05$) percentages of damaged fruit than the untreated control for the harvests combined. Increasing the frequency of application of any insecticide did not significantly ($P>0.05$) reduce the percentage of damaged fruit except for chlorantraniliprole in the first harvest.

There were no differences ($P>0.05$) in any trial between treatments in the numbers of fruit harvested except in the second harvest in Trial 1, when very low numbers of fruit were picked.

Discussion

Sceliodes cordalis infestation levels, as indicated by levels in the untreated controls, were low in Trial 1, due to very low levels of infestation at the first harvest, and in Trial 2 but moderate in Trials 3 and 4. Despite these low to moderate levels of infestation, effective insecticides significantly reduced ($P<0.05$) the percentage of fruit damaged compared to the untreated control in each trial. Some damage still occurred. The insect's habits mean that the eggs and neonate larvae are the only stages exposed to insecticides, with larvae protected once they have entered the fruit, making control with insecticides difficult.

Emamectin benzoate, indoxacarb, pyridalyl and *B. thuringiensis* were not effective against *S. cordalis* in these trials, with damage levels not significantly different (P>0.05) from the untreated controls. Weekly applications of methomyl were not effective (Trial 3) but twice weekly applications were effective (Trials 1 and 2), consistent with the results of an earlier study (Kay and Brown 1992). Methomyl has a short duration of activity and it is probable that eggs were laid, hatched and the larvae entered the protection of the fruit within a week, while twice weekly applications gave a short enough interval between sprays for the methomyl to be effective. Bifenthrin, chlorantraniliprole, spinosad and methoxyfenozide were effective in several trials, while flubendiamide was effective in Trial 4. Increasing the frequency of application from weekly to twice weekly did not significantly (P>0.05) improve the efficacy of spinosad, methoxyfenozide or chlorantraniliprole. However, there was a trend to less damage with twice weekly applications of spinosad and chlorantraniliprole. It would be economically and environmentally wasteful for growers to apply insecticides more frequently than necessary to get effective control, and it could increase the risk of having excessive residues on fruit.

Spinosad is registered for use against *Helicoverpa* spp. on eggplant so its use should effectively control both pests, as both may be present in a crop while it is fruiting. Methoxyfenozide, an insect growth regulator, is reported to be most effective against lepidopterous insects when ingested by the larvae, although it has some topical and ovicidal properties (Carlson *et al.* 2001). Possibly it is effective against *S. cordalis* through topical or ovicidal action as there is little opportunity for it to be ingested by the larvae. The same may be the case for methomyl, which also has ovicidal properties against lepidopterous insects (Waite 1981; Hargreaves and Cooper 1982). The ryanodine receptor modulators flubendiamide and chlorantraniliprole belong to new classes of insecticides, which reportedly are highly effective against lepidopterous pests (Nauen 2006).

Integrated pest management programs dependent on parasitoids and predators are being developed in vegetables, particularly against pests such as *B. tabaci* (Brown 2005; De Barro *et al.* 2006), while trichogrammatid wasps have been recorded parasitising *S. cordalis* eggs in this project. Bifenthrin and methomyl are regarded as disruptive to beneficial insects (Llewellyn 2002; Wilson *et al.* 2005). However spinosad, methoxyfenozide, flubendiamide and chlorantraniliprole are regarded as selective, with only low to moderate levels of impact on beneficial insects and mites (Carlson *et al.* 2001; Llewellyn 2002; Wilson *et al.* 2005; Ebbinghaus *et al.* 2007) and would be suitable for use against *S. cordalis* in integrated pest management programs on eggplant.

The results of these trials were provided to the relevant chemical companies (Dow, Du Pont, Bayer, and Sumitomo) and they have expressed interest in extending registrations to include *S. cordalis* in eggplant.

Table I2
Mean number of fruit harvested and mean percentages of fruit damaged by *S. cordalis* in Trial 1

Treatment (rate ha^{-1})	No. sprays per week	Harvest 1		Harvest 2		Combined	
		No. fruit	% damaged #	No. fruit	% damaged #	No. fruit	% damaged #
Untreated control (-)	-	87.8 a	1.55 a	29.2 abcd	28.24 a	117.0 a	8.10 a
Indoxacarb (75 g a.i. ha^{-1}) †	1	86.8 a	1.87 a	26.0 bcd	21.08 ab	112.8 a	6.82 a
B. thuringiensis kurstaki (1000 g product ha^{-1})	2	85.6 a	2.45 a	40.4 a	15.92 ab	126.0 a	6.32 ab
Emamectin benzoate (11 g a.i. ha^{-1})	1	85.2 a	1.36 a	29.2 abcd	16.93 ab	114.4 a	5.41 ab
Methoxyfenozide (408 g a.i. ha^{-1})	1	96.0 a	0.83 a	36.6 abc	14.75 ab	132.6 a	4.91 abc
Spinosad (96 g a.i. ha^{-1})	1	86.4 a	0.55 a	38.2 ab	9.04 bc	124.6 a	3.39 bc
Methomyl (450 g a.i. ha^{-1}) †	2	90.8 a	1.51 a	20.6 d	8.48 bc	111.4 a	3.27 bc
Bifenthrin (60 g a.i. ha^{-1})	1	93.8 a	1.51 a	24.4 cd	2.77 c	118.2 a	2.45 c

Back-transformed means following inverse sine transformation before analysis.
† A non-ionic organic surfactant was added to the indoxacarb and methomyl sprays at 0.025%.
In each column means followed by the same letter are not significantly different ($P>0.05$).
a.i., active ingredient.

Table I3
Mean number of fruit harvested and mean percentages of fruit damaged by *S. cordalis* in Trial 2

Treatment (rate ha^{-1})	No. sprays per week	No. fruit	% damaged #
Untreated control (-)	-	73.2 a	6.29 a
Emamectin benzoate (11 g a.i. ha^{-1})	1	76.5 a	7.32 a
Indoxacarb (75 g a.i. ha^{-1}) †	1	81.5 a	4.90 ab
B. thuringiensis kurstaki (1000 g product ha^{-1})	2	74.2 a	4.37 abc
Spinosad (96 g a.i. ha^{-1})	1	69.0 a	1.30 bc
Bifenthrin (60 g a.i. ha^{-1})	1	73.0 a	1.26 bc
Methomyl (450 g a.i. ha^{-1}) †	2	68.8 a	0.99 c

Back-transformed means following inverse sine transformation before analysis.
† A non-ionic organic surfactant was added to the indoxacarb and methomyl sprays at 0.025%.
In each column means followed by the same letter are not significantly different (P>0.05).
a.i., active ingredient.

Table I4
Mean number of fruit harvested and mean percentages of fruit damaged by *S. cordalis* in Trial 3

Treatment (rate ha^{-1})	No. sprays per week	Harvest 1		Harvest 2		Combined	
		No. fruit	% damaged #	No. fruit	% damaged #	No. fruit	% damaged #
Untreated control (-)	-	71.5 a	23.02 a	49.0 a	31.12 a	120.5 a	26.23 a
Pyridalyl (100 g a.i. ha^{-1})	1	74.8 a	24.14 a	51.2 a	24.42 abc	126.0 a	24.87 a
Emamectin benzoate (11 g a.i. ha^{-1})	1	77.5 a	20.64 ab	63.8 a	24.61 ab	141.2 a	22.62 a
Methomyl (450 g a.i. ha^{-1}) †	1	80.5 a	20.15 ab	62.8 a	24.61 ab	143.2 a	22.40 a
Indoxacarb (75 g a.i. ha^{-1}) †	1	75.8 a	23.14 a	45.2 a	16.93 bcd	121.0 a	20.82 a
Spinosad (96 g a.i. ha^{-1})	1	84.0 a	12.77 bc	70.2 a	15.20 bcd	154.2 a	13.86 b
Methoxyfenozide (408 g a.i. ha^{-1})	1	78.2 a	14.11 bc	65.5 a	10.45 d	143.8 a	12.69 b
Chlorantraniliprole (20 g a.i. ha^{-1})	1	85.5 a	8.53 c	59.2 a	14.23 cd	144.8 a	10.86 b
Bifenthrin (60 g a.i. ha^{-1})	1	70.2 a	8.06 c	68.5 a	2.55 e	138.8 a	5.27 c

Back-transformed means following inverse sine transformation before analysis.
† A non-ionic organic surfactant was added to the indoxacarb and methomyl sprays at 0.025%.
In each column means followed by the same letter are not significantly different ($P>0.05$).
a.i., active ingredient.

Table I5
Mean number of fruit harvested and mean percentages of fruit damaged by *S. cordalis* in Trial 4

Treatment (rate ha^{-1})	No. sprays per week	Harvest 1		Harvest 2		Combined	
		No. fruit	% damaged #	No. fruit	% damaged #	No. fruit	% damaged #
Untreated control (-)	-	56.5 a	23.04 a	73.0 a	17.65 a	129.5 a	20.08 a
Methoxyfenozide (408 g a.i. ha^{-1})	1	63.8 a	9.40 bc	71.2 a	10.45 ab	135.0 a	9.88 bc
Methoxyfenozide (408 g a.i. ha^{-1})	2	56.5 a	16.12 ab	80.8 a	8.49 bc	137.2 a	11.66 b
Flubendiamide (72 g a.i. ha^{-1})	1	59.8 a	12.28 bc	78.2 a	5.71 bcd	138.0 a	9.17 bcd
Spinosad (96 g a.i. ha^{-1})	1	56.5 a	10.17 bc	76.2 a	7.24 bcd	132.8 a	8.74 bcd
Spinosad (96 g a.i. ha^{-1})	2	54.0 a	11.39 bc	77.8 a	3.04 cd	131.8 a	6.81 bcde
Chlorantraniliprole (20 g a.i. ha^{-1})	1	62.5 a	8.92 c	74.8 a	4.51 bcd	137.2 a	6.51 cde
Chlorantraniliprole (20 g a.i. ha^{-1})	2	64.0 a	3.24 d	76.2 a	4.37 bcd	140.2 a	3.94 e
Bifenthrin (60 g a.i. ha^{-1})	1	58.5 a	7.19 cd	70.0 a	2.75 d	128.5 a	4.83 de

Back-transformed means following inverse sine transformation before analysis.
In each column means followed by the same letter are not significantly different ($P>0.05$).
a.i., active ingredient.

Pheromone Trapping Studies

Introduction

The components of the female produced *S. cordalis* pheromone were determined by Clearwater *et al.* (1986) in New Zealand. They identified the components as (E)-11-hexadecen-1-yl acetate and (E)-11-hexadecen-1-ol and reported that, in a 1:1 ratio, they strongly attracted males in the field. Galbreath and Clearwater (1983) used traps baited with the pheromone to trap *S. cordalis* males over two years in New Zealand. They recorded the presence of moths from October to April, with larvae entering prepupal diapause in April to overwinter until October.

Kay and Brown (2000) and Brown (2002, 2005) confirmed the components of the *S. cordalis* pheromone in moths from north Queensland and investigated the attractiveness of various ratios of the two components, and the attractiveness of different loadings of pheromones on the lures. Brown (2002) used the pheromone lures to assess the seasonal occurrence of *S. cordalis* in crops in the lower Burdekin district of north Queensland and recorded the presence of moths throughout the year.

The aims of this project's pheromone studies were to:

i) to undertake preliminary studies to determine the most effective traps to use and to determine the effective life of the lures;

ii) to determine the seasonal occurrence of *S. cordalis* in the Bundaberg district;

iii) to investigate whether pheromone traps could be used to monitor *S. cordalis* in crops as an aid to making management decisions.

Trap design can be an important factor in determining the number of moths caught in pheromone traps, but it appears that different trap designs have not been tested for their efficacy in catching *S. cordalis* moths. Both Galbreath and Clearwater (1983) and Brown (2002) used triangular traps (i.e. delta traps) to trap *S. cordalis* males in New Zealand and north Queensland respectively.

There are two commercially available traps, which could easily be obtained by eggplant growers, that are used for pheromone trapping of other lepidopteran pests and that could be used for trapping *S. cordalis*. They are the funnel trap and the delta trap, and their relative efficacy in trapping *S. cordalis* male moths was tested.

The efficiency of traps may change as the amount and rate of pheromone release alters as the lures age. To get consistent and meaningful results in occurrence and monitoring studies it is important to minimise any differences that may be caused by differences in the attractiveness of the lures. Trials were planned and conducted to test the attractiveness of lures aged for various lengths of time to determine the effective life of the lures. The results are used to determine the frequency of replacing the lures in traps.

Eggplant crops are grown for much of the year in the Bundaberg district, although the main growing seasons are from February to July and from October to December. While the seasonal occurrence of *S. cordalis* has been studied in north Queensland

(Brown 2002) and in New Zealand (Galbreath and Clearwater 1983), it was unknown in the Bundaberg district. Pheromone traps were used to study the seasonal incidence of *S. cordalis* in the Bundaberg district for a little over two years as part of this project.

Monitoring the levels of an insect pest in a crop to make informed decisions on whether or not to apply an insecticide treatment is one of the basic steps in IPM. Pheromone trap catches have been used to monitor pest activity in many crop-pest interactions and control methods have been applied following trap catches (Gregg and Wilson 1991). In South Carolina, a significant correlation was found between the numbers of *Heliothis virescens* captured in pheromone traps and egg counts in cotton fields, although the R^2 values were not high (Johnson 1983). Rothschild *et al.* (1982) reported that there was a highly significant correlation between pheromone trap catches of *Helicoverpa* species and egg counts in cotton in the Namoi Valley, NSW, but the confidence limits for predicting egg numbers from catch data were unacceptably large in practical terms.

Monitoring for *S. cordalis* is difficult. The eggs are small, flat and very hard to find on fruit in the field. The larvae are inside the fruit where their presence cannot be detected without cutting the fruit, and treatment decisions based on the presence of larvae in fruit are made too late to prevent damage. Monitoring for eggs and making treatment decisions based on egg numbers so *S. cordalis* could be controlled before the larvae enter and damage the fruit would be ideal. Monitoring for eggs is very difficult, while counting moths in pheromone traps is simple and easy and an accurate relationship between the two would allow pheromone traps to be used for monitoring *S. cordalis*. The relationship between trap catches and egg counts was investigated.

i) Trap Comparison and Age of Lures

Materials and methods

Lures used in all the pheromone studies reported here were obtained from Richard Vickers (richard.vickers@hotmail.com). Each lure was a short length of rubber septum impregnated with 500 µL of a 65:35 (acetate:alcohol) mix of the two components of the pheromone.

a) Trap design

The relative efficacy in trapping male *S. cordalis* of two commercially available traps, a funnel trap and a delta trap, which could easily be obtained by eggplant growers, was compared. The funnel trap used was the green plastic AgriSense funnel trap in which the lure is suspended over the funnel and covered by a lid. The funnel goes into a collecting bucket, which was lined with a sticky insert to trap the moths. The delta trap was the AgriSense Easiset™ trap. This is a plastic trap 28 cm long with a triangular cross-section (15 by 15 by 20 cm). The lure is suspended in the centre of the trap just above the base, which is covered by a removable sticky board that traps the moths.

Four trials were conducted in crops of mature eggplants on two farms at Bundaberg. In each trial five traps of each type were hung just above crop height from stakes positioned in two rows. Stakes along a row were separated by 50 m and 60 m on Farm A and Farm B respectively, with the rows 25 m and 30 m apart respectively. The stakes were offset in the two rows so the distance between any two traps was 35 m on Farm A and 40 m on Farm B. The traps were randomly allocated to stake positions and were re-randomised for each trial. In Trial 1 and Trial 2 the traps were examined after three days and the moths counted and removed, while Trials 3 and 4 each ran for six days.

A t-test was done on the mean trap catches for each trapping period on each farm to test for significant differences between catches in the two trap types (Genstat 8th edition).

b) Age of lures
Thirty lures were aged by placing them in delta traps hung in the open at Bundaberg Research Station. Six lures were recovered from the traps after each of 2, 4, 8, 12 and 16 weeks, wrapped in aluminium foil and stored in a freezer until needed in the field trials. Un-aged lures (0 weeks) were similarly stored.

A randomised block design with a Latin square sampling plan was used to test the effect of lure age on trap catch. Both randomised block and Latin square designs are suggested for testing lures (Cardé and Elkinton 1984) The plan was to test the six ages of lures (0, 2, 4, 8, 12 and 16 week old) with five replicates i.e. 6 by 5 randomised block. Four replicates only were completed.

As it is necessary to have the lures well separated in the field to minimise the risk of interaction between lures (Cardé and Elkinton 1984), and eggplant traps usually cover only a relatively small area, it was decided to do each replicate separately in different fields or at different times if necessary. To account for the possible uneven distribution of moths within a field, for each replicate a Latin square sampling plan was used to rotate lures (treatments) between trap positions to ensure that each trap position was visited once and in a random fashion.

In each replicate, funnel traps with lures were hung just above crop height on posts along a crop row. Traps were separated by 80 m in Replicates 1 and 2 and by 60 m in Replicates 3 and 4. Each trap contained a small dichlorvos block to kill trapped moths. The traps were left in one position for two days, the numbers of trapped moths counted and recorded, and the traps moved to the next position. It should be noted that the traps aged further during the course of this trial period i.e. lures were 12 days older by the end of the cycle.

Four replicates were completed with reasonable numbers of moths recorded in Replicates 1 and 2 but very few (3 moths in 36 positions) in each of Replicates 3 and 4. The trial was terminated.

Results

a) Trap design
The mean numbers of *S. cordalis* moths caught in funnel and delta traps in the trials are given in Table P1. At Farm B, with a low population of *S. cordalis*, there were no

significant differences (P>0.05) between numbers of moths caught in the two trap types. At Farm A, with a higher population of *S. cordalis*, the funnel traps caught significantly (P<0.05) more moths than the delta traps in three of the four trials.

b) Age of lures

The numbers of moths caught in Replicates 1 and 2 are shown in Table P2. Only 3 moths were caught in each of replicates 3 and 4. No analyses have been done on these data.

Table P2

Numbers of moths caught by lures of different ages

Replicate	Number of moths Age of lures (weeks)					
	0	2	4	8	12	16
1	97	150	103	93	54	72
2	144	82	81	82	61	92
Mean	120.5	116	92	87.5	57.5	82

Discussion

Both trap types caught male *S. cordalis* moths. The funnel traps caught more moths than the delta trap in several of the trials and so the funnel trap design was selected for use in the seasonal occurrence and monitoring work.

It is unfortunate that only two useful replicates were completed as the results were very variable, making interpretation very difficult. It was decided that lures should be replaced every four weeks in monitoring and seasonal occurrence work, almost equivalent to using 2 week old lures, as there was little difference between catches by 2 week old lures (that were exposed for a further 12 days in the course of the trial) compared with the catches by new lures.

The ageing trial will be repeated.

Table P1

Number of *S. cordalis* moths caught in funnel and delta traps in each trial.

	Farm and trial															
	A1		A2		A3		A4		B1		B2		B3		B4	
	funnel	delta	funnel	delta	funnel	delta	funnel	delta	funnel	delta	funnel	delta	funnel	delta	funnel	delta
Mean moths/trap	7.0	8.8	5.2	2.0	5.6	0.8	11.4	0.60	2.6	2.8	2.4	2.8	1.4	2.0	1.4	0.2
S.D	7.48	5.45	2.28	1.23	2.61	1.10	6.35	0.55	1.82	1.92	3.91	1.30	0.55	1.00	2.19	0.45
Range	2-20	4-18	2-8	0-3	4-10	0-2	5-19	0-1	1-5	1-6	0-9	1-4	1-2	1-3	0-5	0-1
t-value	0.43		2.76		3.79		3.79		0.17		0.22		1.18		1.20	
probability	0.675		0.025		0.005		0.019		0.87		0.834		0.273		0.292	

ii) Seasonal Occurrence

Materials and methods

Agrisense funnel traps, baited with pheromone lures and with the base section of the trap lined with a sticky insert to retain trapped moths, were placed at five sites around the Bundaberg district in August – September 2006. Each site was beside an eggplant crop and two traps were erected at each site, one on either side of the crop. Traps were hung 1 m above the ground from a stake. GPS coordinates for each trap are given in Table P3. The traps remained in these positions for the duration of the study as it was decided to leave the traps in the same positions when the initial eggplant crops had finished and been ploughed out rather than move them to new crop locations.

The traps were monitored fortnightly and the numbers of *S. cordalis* moths recorded. Lures were replaced every four weeks and the sticky inserts were replaced as necessary. The study concluded in December 2008.

Table P3

Locations of traps at each seasonal monitoring site

Site	GPS Coordinates	
	Trap 1	Trap 2
1	24° 57.94′ S; 152° 25.41′ E	24° 57.79′ S; 152° 25.36′ E
2	25° 03.00′ S; 151° 38.26′ E	25° 02.96′ S; 151° 08.30′ E
3	24° 47.14′ S; 152° 14.14′ E	24° 47.05′ S; 152° 14.25′ E
4	24° 49.20′ S; 152° 14.68′ E	24° 49.10′ S; 152° 14.50′ E
5	24° 51.04′ S; 152° 24.10′ E	24° 51.10′ S; 152° 24.10′ E

Results

Figures P1-P5 show the fortnightly *S. cordalis* moth catches for each trap at Sites 1-5 respectively. Periods when eggplant crops were beside or close to the traps are marked. Frogs entered traps occasionally, destroying the caught moths. The numbers of moths in the traps on these occasions was recorded but those data points probably are not accurate. Catches in the two traps at the same site often differed considerably, perhaps due to differing infestation levels near each trap, wind direction affecting the direction of the pheromone plume, or the distance of the trap from a source of moths.

Site 1 (Figure P1)
Quite large areas of eggplant were grown on this farm and crops were present for much of the trapping period. *S. cordalis* moths were trapped at all times of the year, with very high numbers trapped in early 2008 at the end of a crop cycle, and late in 2008. Moths were trapped during winter months, with some reasonably high catches in June and August 2007 and in July 2008. Frogs affected catches in Trap 2 from mid March to late May 2008 and from mid to late September 2008.

Site 2 (Figure P2)
Site 2 is a little further inland and more elevated than the other sites, in an area that has quite cool winters. The farm is small and the areas planted to eggplant were small. Frogs affected catches in both traps in mid February 2007, in Trap 2 from mid April to mid June 2007 and in both traps from late October to mid December 2008. Large numbers of moths were trapped in late 2006 to February 2007 when a crop and its residues were present. Moderate numbers were caught from August to December 2007 and in late 2008 (although frog affected) when crops were present. Small numbers of moths were caught at other times, even during the cooler times from mid June to mid August each year.

Site 3 (Figure P3)
Frogs were a major problem in Trap 1 at this site and the trap was abandoned in April 2007. Trap 2 fell and had frog problems in February – March 2008, resulting in zero catches for that period. Moths were trapped while crops were present, with high numbers caught as crops finished and were slashed. Very few were caught in July 2007, despite the presence of an eggplant crop. For most of 2008 Trap 2 was surrounded by forage sorghum on one side and by tall weeds or pumpkins on the other but despite this low numbers of *S. cordalis* moths were trapped all through the year, even in the winter months, and numbers increased a little from late October through December.

Site 4 (Figure P4)
The initial crop at this site was ploughed out in November 2006. The second crop recorded in Figure P4 was located several hundred metres from the traps. Large numbers of moths were caught from November 2006 to May 2007, from October 2007 to February 2008, and catches were increasing in late 2008 although no crops were known of nearby. Numbers were low in July 2007.

Site 5 (Figure P5)
Site 5 is Bundaberg Research Station. Eggplant crops were small (approximately 0.13 ha). Reasonable numbers of moths were trapped while crops were present, while low numbers were caught at other times, particularly in the winter months of June and July in both years. Numbers increased in late 2008. Plots of tomatoes and capsicums, which are occasional hosts of *S. cordalis* (Davis 1964), were grown adjacent to the traps from August to December 2008.

Discussion

The trapping data show that *S. cordalis* moths are present all year round in the Bundaberg district, particularly in association with eggplant crops. This is most apparent in the results from Site 1 (Figure P1) that shows that moths were caught in every trap period from August 2006 to December 2008, with the exception of one period in mid June 2008. Brown (2002) reported that *S. cordalis* was present all year round in north Queensland.

Trap catches were affected by weather, with rain periods reducing catches and wind direction and strength affecting catches in traps. These factors caused fluctuations in catches between collection dates. Frogs, particularly green tree frogs, entered traps and consumed the moths inside, spoiling the data for those dates. Sticky bands around the support stakes did not deter them, and they tended to return to a trap unless relocated more than a hundred metres from the trap.

Not surprisingly, numbers of moths caught were higher when eggplant crops were present close to the traps. Obviously the insect is more likely to be present when its main host is available. Frequently the catches were highest at the end of a crop cycle, as the crops were abandoned and wilted or were slashed and eventually ploughed in. Presumably the moths were moving from the old crop to look for new hosts and were trapped as they migrated.

Few moths were caught during the winter months, June – August, at most sites. The current knowledge of the insect's biology and ecology does not allow definite understanding of why but speculation as to the causes is possible. The absence of crops during these months at some sites in one or both years obviously would have contributed, but catches were low at Sites 2 and 3 in winter 2007 despite the presence of an eggplant crop. Insects are poikilothermic so their development is slower at lower temperatures and this may have contributed to slower population build up and lower catches during winter. Another possibility is that some of the *S. cordalis* population entered diapause in autumn and spent the winter in that state. Galbreath and Clearwater (1983) reported that *S. cordalis* entered prepupal diapause in April to overwinter until October in New Zealand. Several of the larvae reared at 20° C and a 12:12 L:D photoperiod in the developmental studies conducted in this project (see "Temperature and Development Studies") had arrested development at the prepupal stage, presumably diapause. Average monthly temperatures at Bundaberg are less than 20°C from May to August (www.bom.gov.au). Diapause in *S. cordalis* in New Zealand is induced by a combination of temperature and daylength (Martin pers. comm. 2008), and these factors commonly are responsible for diapause induction in lepidopteran insects, for example in *Helicoverpa* spp. (Komarova 1959, Cullen and Browning 1978, Roome 1979). It is quite possible that a proportion of the *S. cordalis* population at Bundaberg overwinters in diapause.

The trapping results also suggest that *S. cordalis* moths must move over a reasonable distance. From February 2008 both traps at Site 4 were a considerable distance, at least 5 km, from any host crop, and were surrounded by forage sorghum, cucurbits or bare ground, yet they continued to trap *S. cordalis* moths. Quite high numbers were trapped in late November – early December, indicating greater flight activity by the moths. Similarly, increased moth catches were recorded at Sites 3 and 5 in the absence of crops in November – December 2008.

Figure P1
Numbers of *S. cordalis* moths caught in pheromone traps each fortnight: Site 1.

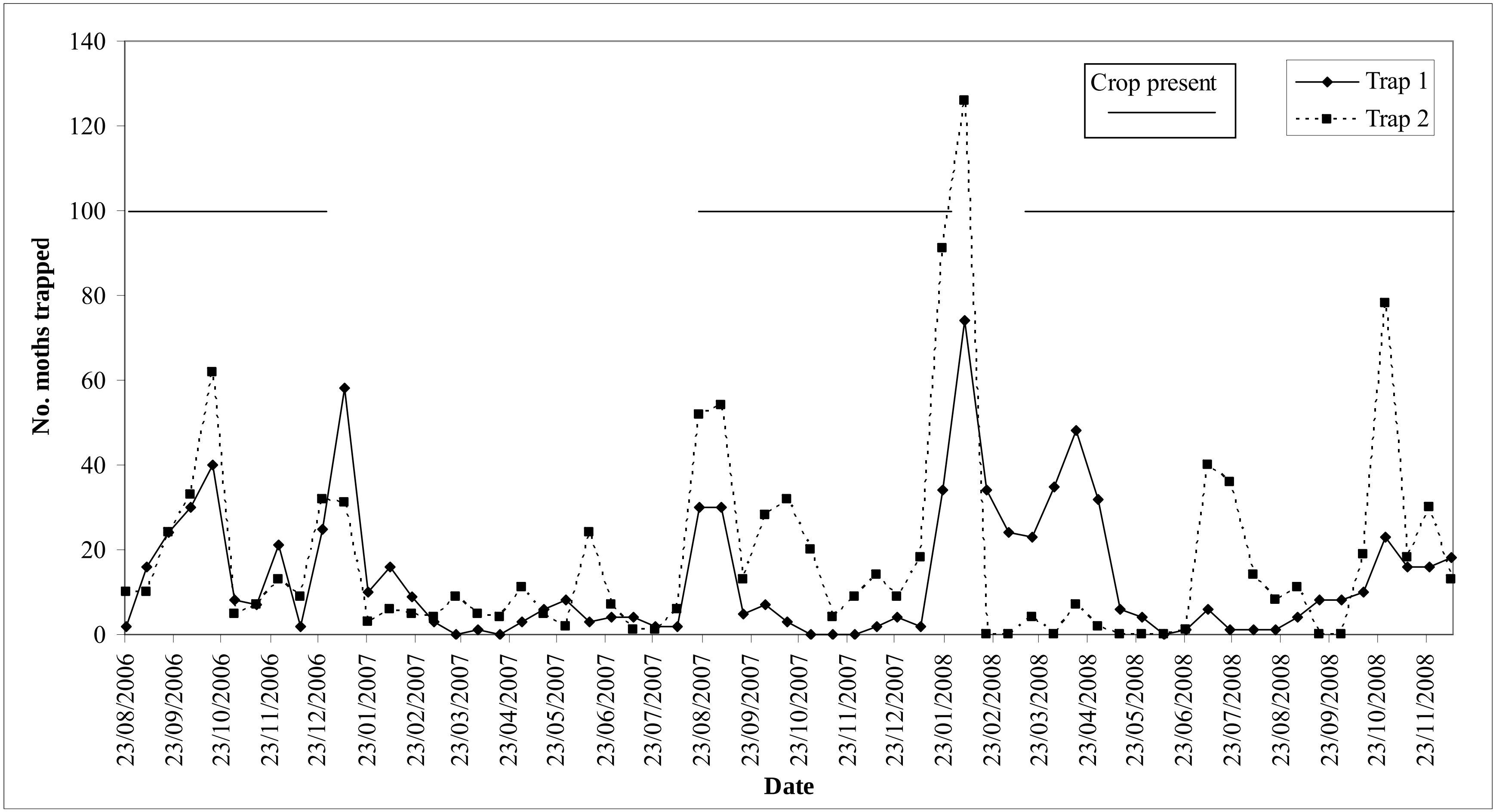


Figure P2
Numbers of *S. cordalis* moths caught in pheromone traps each fortnight: Site 2.

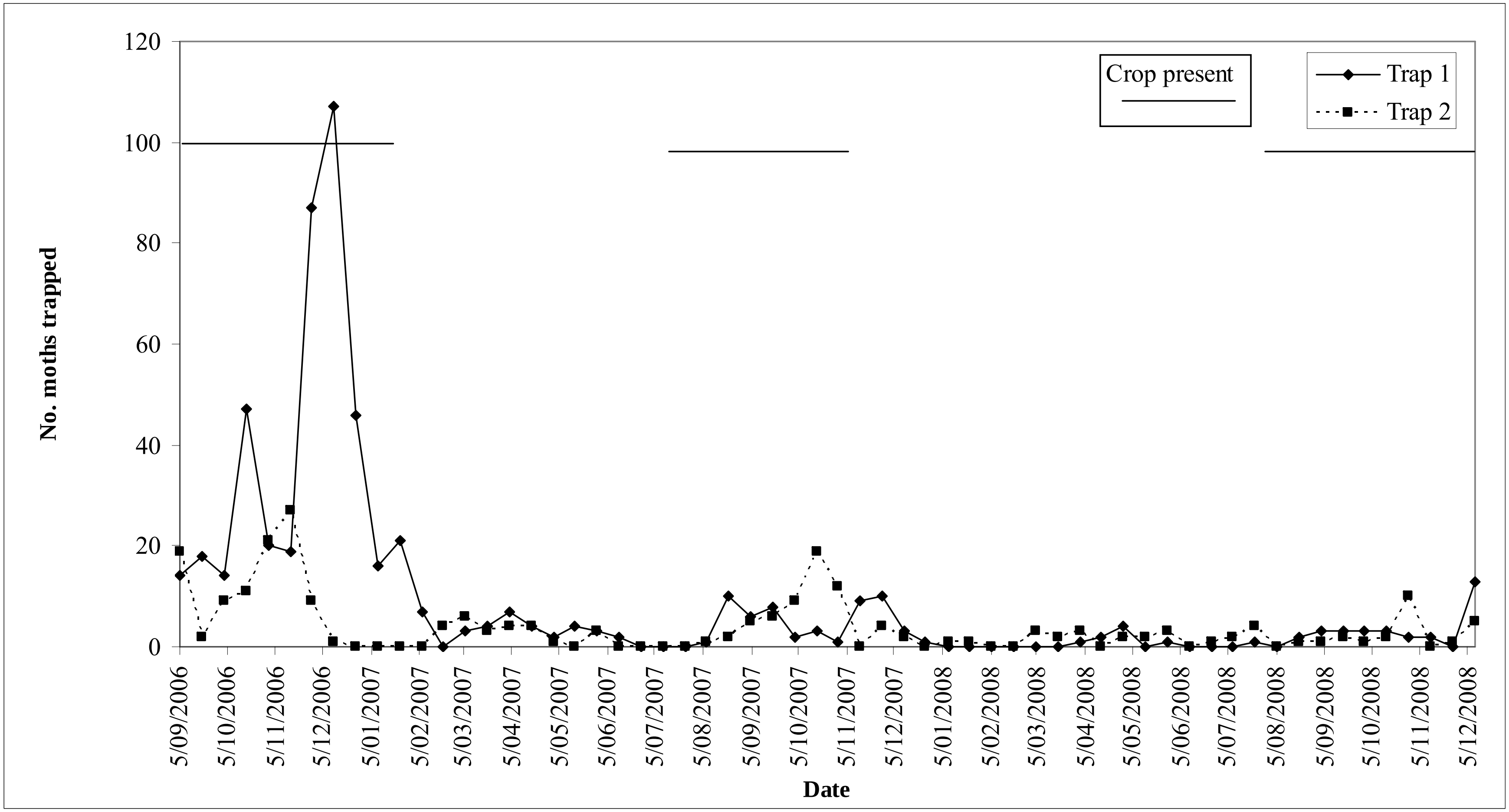


Figure P3
Numbers of *S. cordalis* moths caught in pheromone traps each fortnight: Site 3.

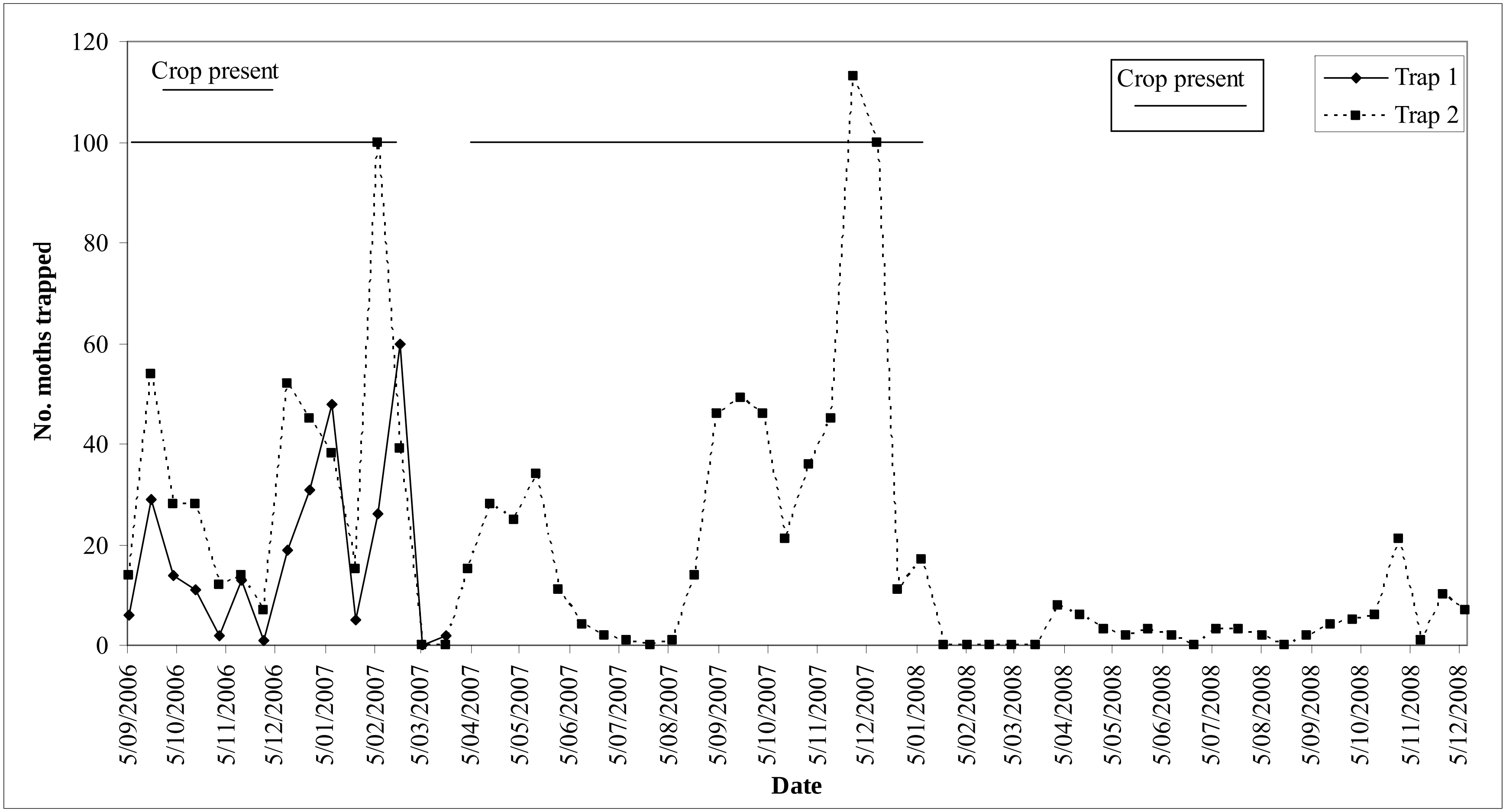


Figure P4
Numbers of *S. cordalis* moths caught in pheromone traps each fortnight: Site 4.

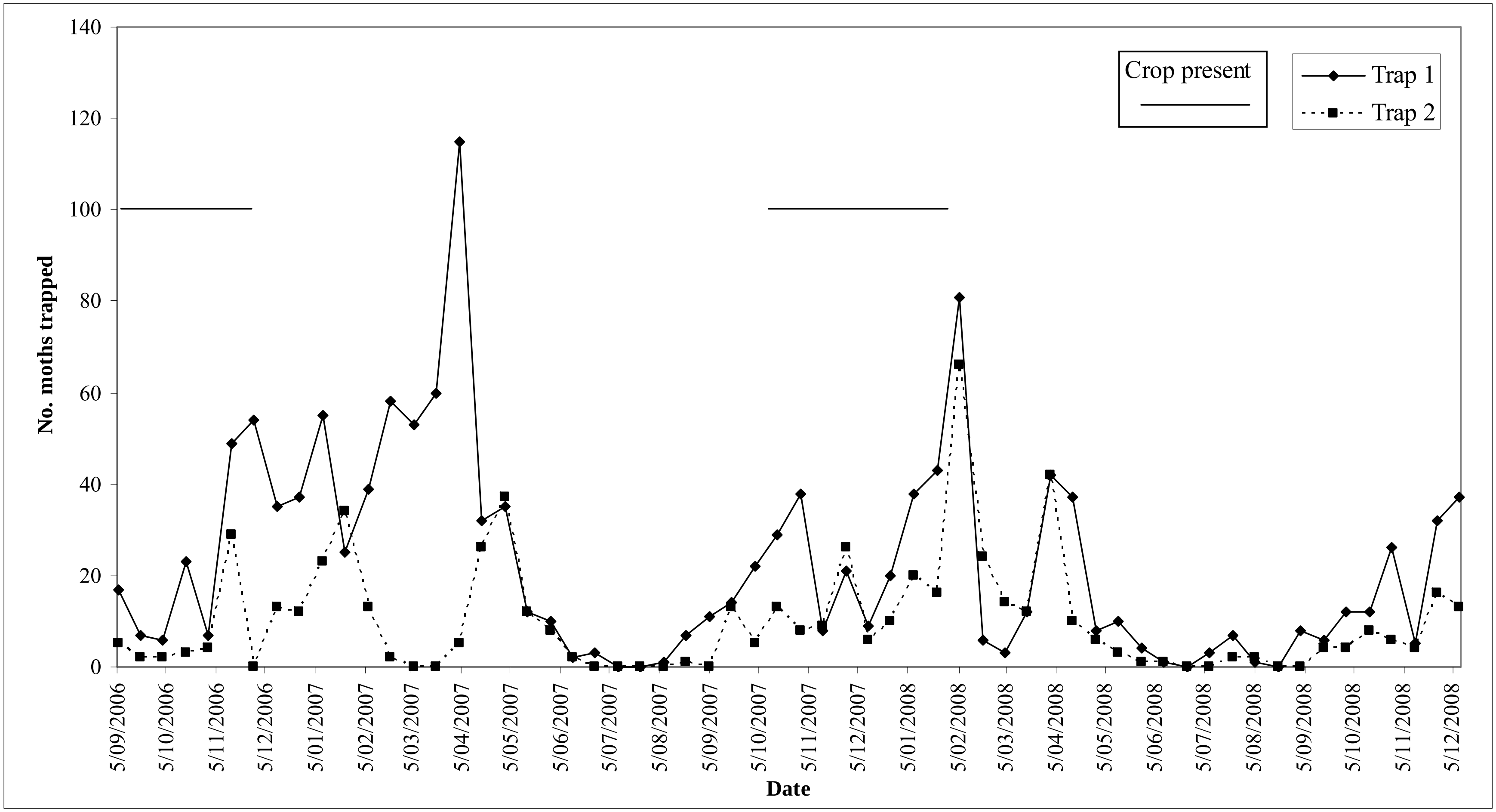
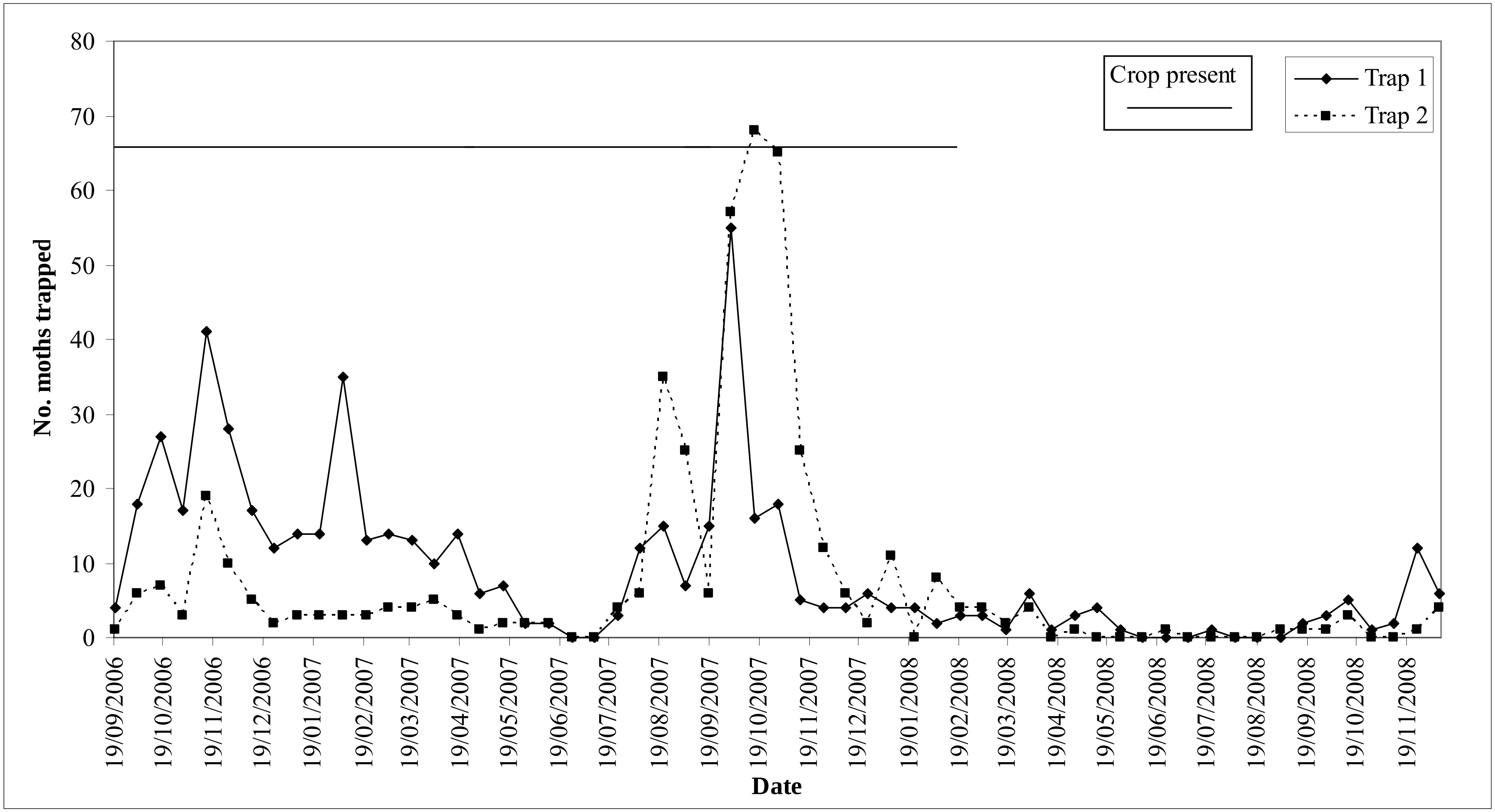


Figure P5
Numbers of *S. cordalis* moths caught in pheromone traps each fortnight: Site 5.



iii) Pheromone trap catches and egg counts

Materials and methods

Four trials were conducted between September 2006 and December 2007 to establish the relationship between *S. cordalis* moth catches in pheromone traps and the level of oviposition in eggplant crops. In each trial three pheromone traps were hung just above the top of the crop on stakes in a line approximately in the middle of an eggplant crop. The traps were spaced at equal distances apart (these ranged from 50 m to 175 m in various trials) with the end traps 30 – 50 m from the edges of the crop. The traps were checked weekly and the numbers of moths recorded. Lures were replaced every four weeks and the sticky inserts when necessary.

Each week, on the same day the traps were checked, fruit were collected from the crop by picking fruit haphazardly along a zigzag path from one end of the crop to the other. Twenty-five fruit were collected each sample day in Trial 1 and 50 fruit were collected each week in Trials 2, 3 and 4. The fruit were returned to the laboratory where they were measured, cut into thirds and carefully examined under magnification for the presence of eggs. The number of eggs and their location on the fruit (calyx, basal third, middle third or tip third) were recorded. A few eggs were "black" when collected, which is often an indication that they are parasitised. These eggs were held in containers until the parasitic wasps emerged. The wasps initially were identified to genus and a sample sent to Dr L Thomson, Center for Environmental Stress and Adaptation Research, Zoology Department, University of Melbourne, for further identification.

Regression analyses of percentage of fruit with eggs against mean number of moths caught per trap were conducted using Genstat Release 11.1.

Results

Figures P6, P7, P8 and P9 show the regressions of percentage of fruit with eggs against mean numbers of moths trapped for Trials 1, 2, 3 and 4 respectively. The regression in Trial 1 is significant ($P<0.05$) but this results should be treated with caution as one point had a very high leverage. The regressions in Trials 2, 3 and 4 were not significant ($P>0.05$). As the same methods were used in Trials 2, 3 and 4 the data were combined and the regression line is shown in Figure P 10. The regression is significant ($P<0.05$).

The majority of eggs were found on the calyx, with very few found on other sections of the fruit (Table P4). Most fruit had one, two or three eggs on them, although one fruit had 10 (Table P5).

Trichogramma and *Trichogrammatoidea* wasps were reared from parasitised eggs. The *Trichogramma* specimens sent to Dr Thomson could not be identified to a species. The morphological examination and the molecular marker tests suggested they were not among the known Australian species (L. Thomson pers. comm. 2007).

Table P4

Number and percentage of eggs on sections of the fruit

	Location on fruit			
	Calyx	Basal third	Mid third	Tip third
Number of eggs	233	1	2	2
% of eggs	97.9	0.4	.08	0.8

Table P5

Numbers of eggs on individual fruit

	Number of eggs					
	1	2	3	4	5	10
Number of fruit	101	33	13	3	2	1
% of fruit	66.0	21.6	8.5	2.0	1.3	0.7

Discussion

These trap catch – egg count trials were designed to simulate the effort a commercial consultant might use in monitoring an eggplant crop. Hence three traps were deployed, which gave some replication through the field but were not too many traps to service, and weekly checks were made.

There was not a significant relationship between the numbers of moths caught in pheromone traps and the percentage of fruit with eggs on them in individual crops, with the exception of Trial 1. While the regression was significant in Trial 1, this probably was an artefact caused by one outlying point. There were relatively few data points in each of Trials 1 – 4, but when the data from Trials 2, 3 and 4 were combined, making 23 data points, then a highly significant regression resulted. However, as can be seen clearly in Figure P10, the data points are very variable around the regression line, with a R^2 value of 0.4486. Monitoring more frequently or taking more than 50 fruit possibly may have reduced this variability.

It had been hoped that the numbers of moths caught in the pheromone traps might give a good indication of the proportion of fruit that was infested with *S. cordalis* eggs, which would have allowed the traps to be used to make treatment decisions. The results showed that the more moths caught in the traps, the greater the percentage of egg-infested fruit. However, the data were very variable, and too variable for moth catches to be used to accurately predict infestation levels to make treatment decisions. These conclusions are similar to those of Rothschild *et al*. (1982) for *Helicoverpa* on cotton. However, it would be worthwhile for growers or their consultants to use pheromone traps around crops to monitor the activity of *S. cordalis* adults. This will give a good indication of what is going on with the *S. cordalis* population, although it will not allow treatment decisions to be made.

Ninety-eight percent of the eggs found during this study were found on the calyx (Table P4). The few eggs found on the basal and mid thirds of the fruit were on rough, scarred patches of skin and those on the tip third were on the petal scar. No eggs were found on the smooth skin of the fruit. In contrast, Brown (2005) reported that most eggs were laid on the tip and sides of the fruit. The reasons for this discrepancy are not known. It is possible that, in the trials reported here, eggs were dislodged from the smooth skin of the fruit as the fruit were picked and transported from the field to the laboratory, while the method section in Brown (2005) indicates, but does not state clearly, that observations were done in the field. Although moths in a laboratory colony laid some eggs on the smooth plastic sides of their container, most eggs were laid on the fine mesh lid or on crumpled paper towelling in the container, indicating that the moths prefer to oviposit on a rough surface.

Most fruit had only one or two or three eggs on them (Table P5), figures similar to those in Brown (2005) who reported approximately 60%, 20% and 10% of fruit with one, two or three eggs respectively.

The records of *S. cordalis* egg parasitism by *Trichogramma* and *Trichogrammatoidea* appear to be the first records of parasitism in *S. cordalis*. Of 19 parasitised eggs, *Trichogramma* wasps were reared from 10 and *Trichogrammatoidea* wasps from nine, usually with two wasps emerging from each egg (range 1-3). The identity of the *Trichogramma* wasps submitted for identification could not be determined, but they were not the commercially available *T. pretiosum*, which has been released widely in the district (L. Thomson pers. comm. 2007). Not all the *Trichogramma* specimens reared were submitted so it is possible that several species may be involved. It is valuable to know that trichogrammatid wasps are parasitising *S. cordalis* eggs. These are important biological control agents that should play a valuable role in IPM programs in eggplant crops.

Figure P6

Regression of % of egg-infested fruit against numbers of moths trapped in Trial 1

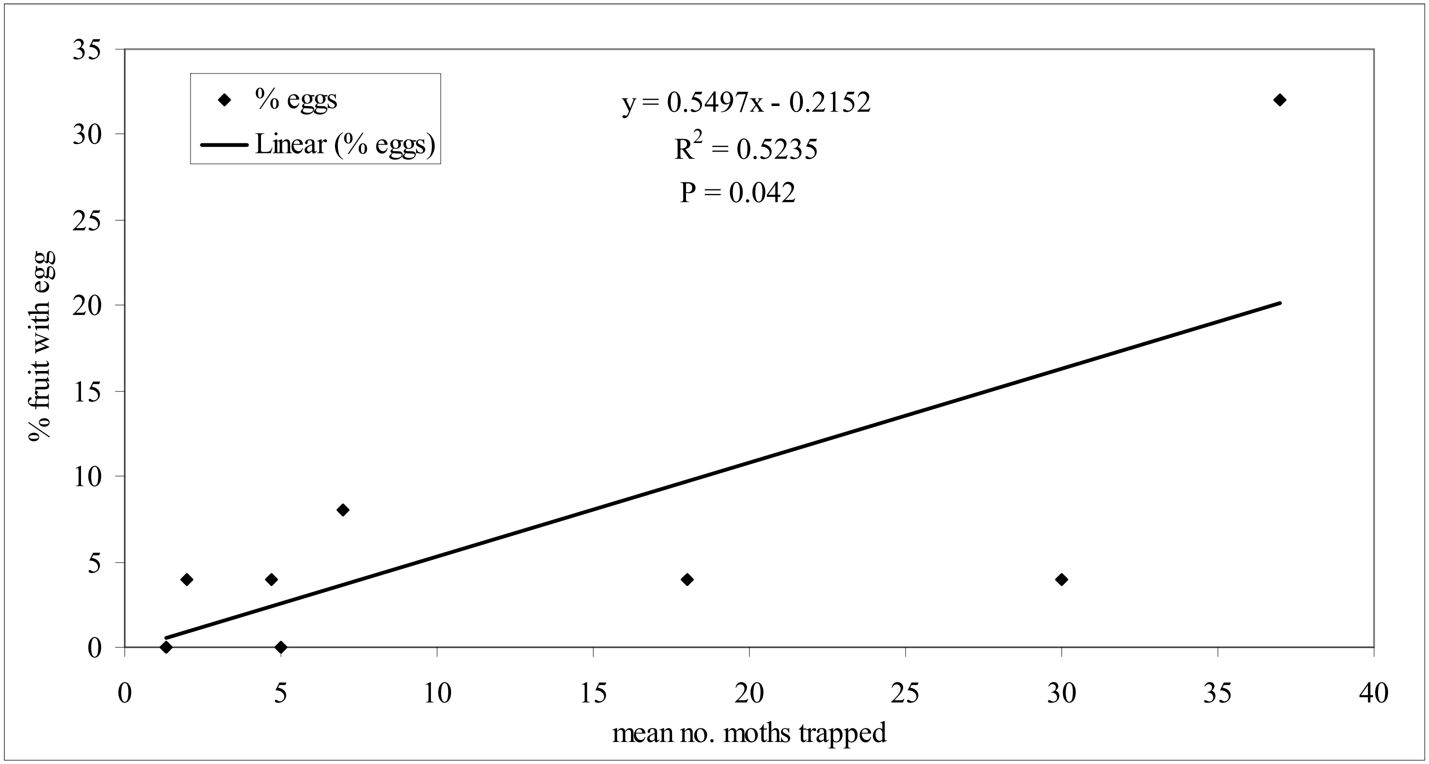


Figure P7

Regression of % of egg-infested fruit against numbers of moths trapped in Trial 2

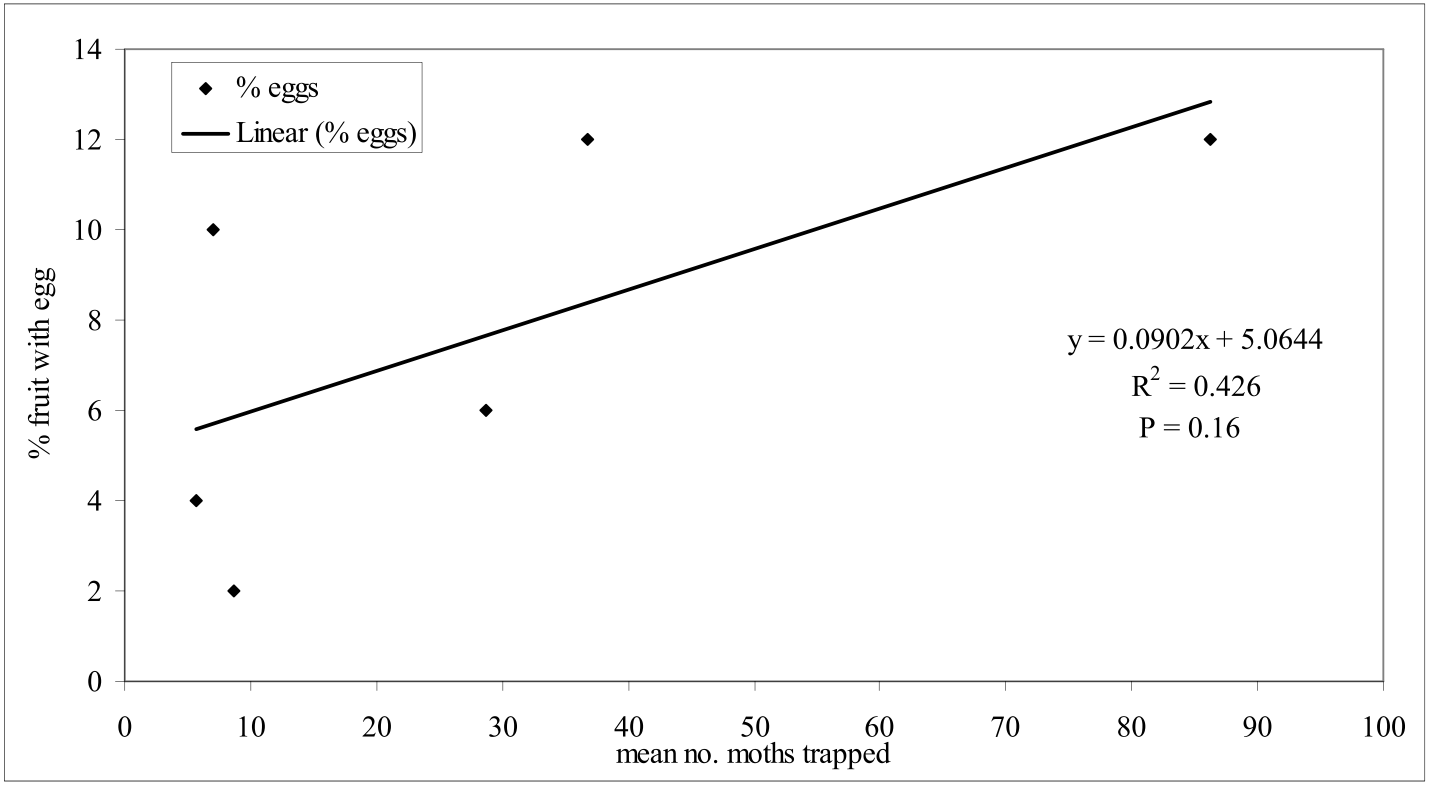


Figure P8

Regression of % of egg-infested fruit against numbers of moths trapped in Trial 3

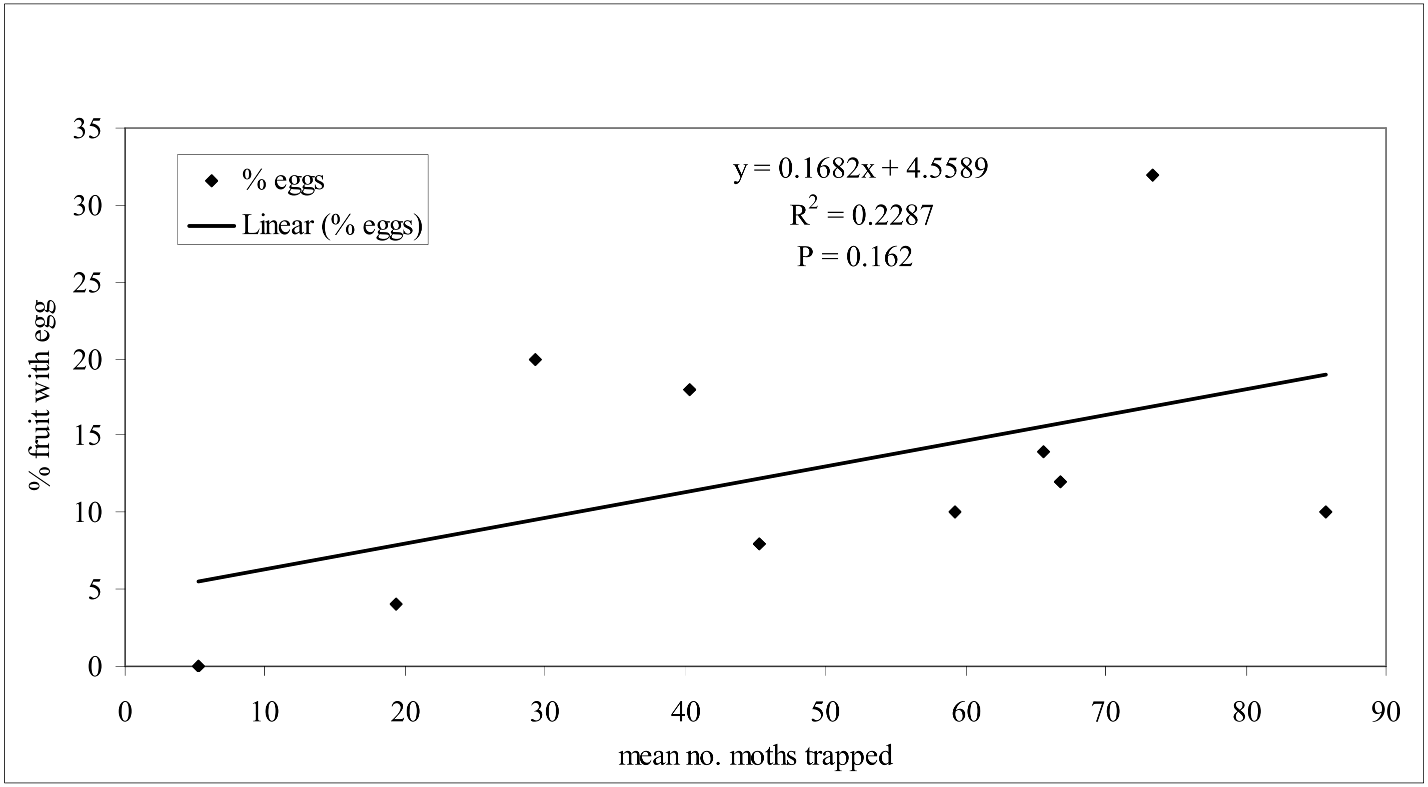


Figure P9

Regression of % of egg-infested fruit against numbers of moths trapped in Trial 4

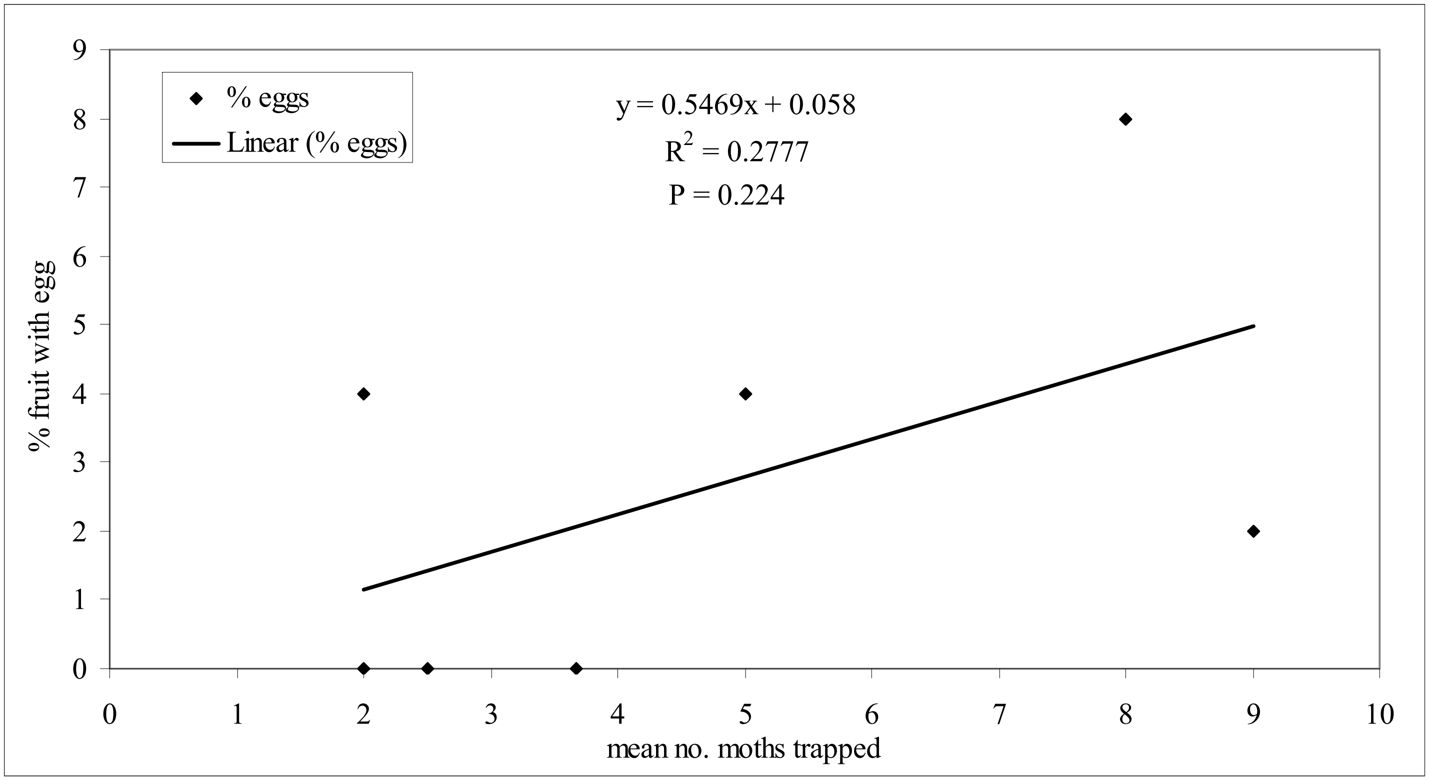
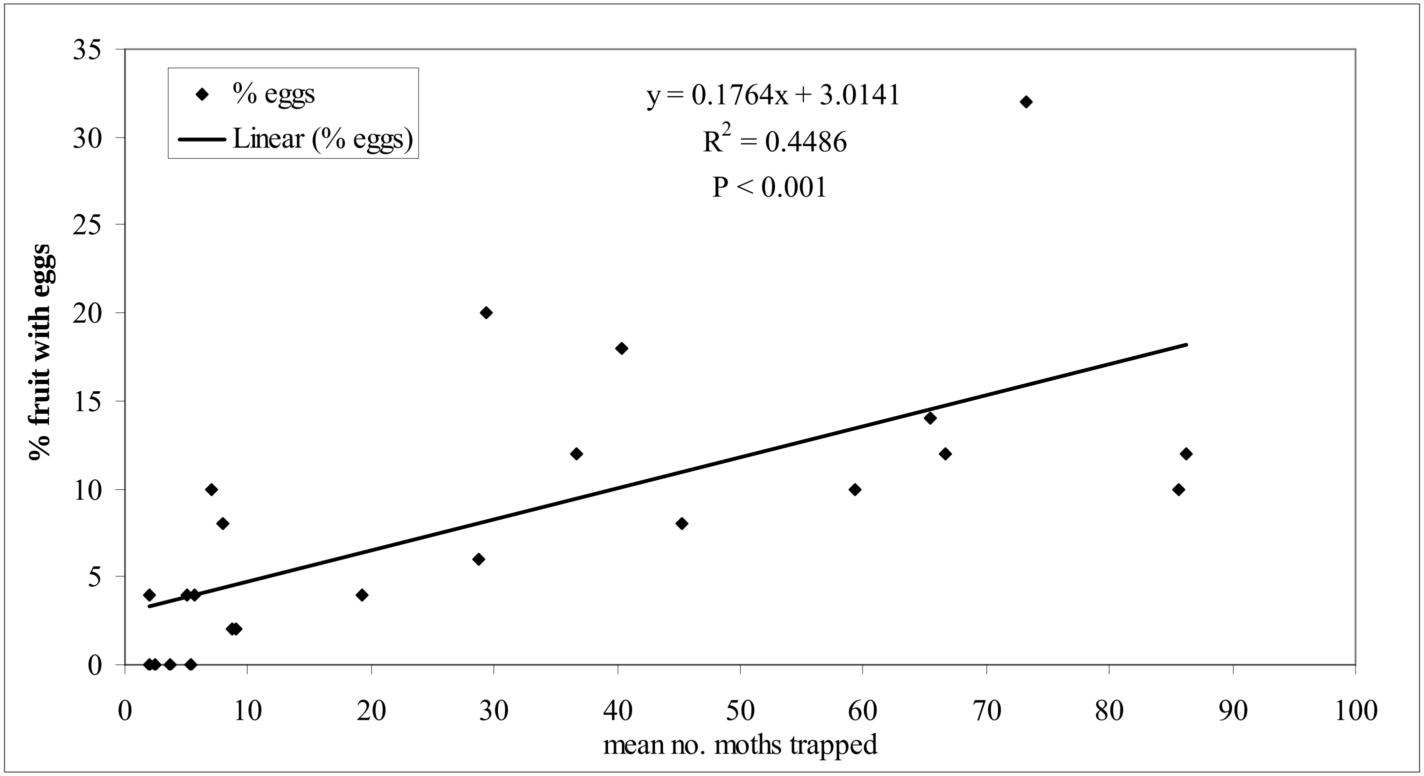


Figure P10

Regression of % of egg-infested fruit against numbers of moths trapped in Trials 2, 3 and 4 combined



Temperature and Development Studies

Introduction

Insects are essentially poikilotherms. Their body temperature varies with that of the surrounding environment, although many are capable of some degree of thermoregulation (May 1979). Temperature is the most important environmental factor that influences the physiology and development of insects and the temperature-mediated "time-scale" experienced by insects as poikilotherms is the fundamental driving variable in the population dynamics of insects (Kitching 1977).

Many models have been derived to describe the time for development versus temperature or rate of development versus temperature curve. The classical thermal summation principle is widely used as it requires minimal data for formulation, is easy to calculate and apply, and often yields approximately correct values (Wagner *et al.* 1984). It assumes a linear relationship and is represented by the equation $y = a + bT$, where y is rate of development, T is temperature and a and b are constants. The model is characterised biologically by the developmental zero or threshold below which there is no development, and the thermal constant which is the number of day-degrees above the threshold required for development. Clearly the model is accurate only in the linear portion of the developmental rate curve and it becomes inaccurate at extremes of temperature where the curve is distinctly non-linear. It should be developed using at least five temperatures within the linear response and with a significant number of individuals at each temperature (Bergant and Trdan 2006). This linear model is simple and useful, particularly where field temperatures lie within the straight line portion of the curve (Jones *et al.* 1987, Kitching 1977).

Davis (1964) briefly described the duration of the life cycle stages of *S. cordalis*, stating that in the warm conditions of spring and early summer in north Queensland the egg stage occupies 4-5 days, the larval stages 10-13 days and the pupal stage 7-14 days.

Apart from the Davis (1964) information, it seems that the effect of temperature on the developmental rate of *S. cordalis* has not been investigated, a key omission in the information needed to understand its population dynamics. Accordingly, the effect of temperature on the developmental rate of *S. cordalis* eggs, larvae and pupae was studied and the data fitted to the thermal summation model.

Materials and methods

A laboratory colony of *S. cordalis* was established by rearing moths from fruit from an unsprayed block of eggplants on Bundaberg Research Station. The moths were held in plastic containers (350 mm by 250 mm by 140 mm) with material mesh lids, and fed a sugar solution. The moths laid eggs on the mesh and the resulting larvae were provided with eggplant fruit in which to tunnel and feed.

Eggs, larvae and pupae were reared at five constant temperatures from 20°C to 30°C at a 12:12 L:D cycle in Lindner and May temperature cabinets.

Eggs
New mesh material was used for the colony container lids and then removed 12 hours later. Hence all eggs on the mesh were a maximum of 12 hours old. The mesh was cut into pieces with eggs and the pieces were placed onto filter paper in 90 mm diameter plastic Petri dishes, which were then sealed with Parafilm. Petri dishes containing approximately 50 eggs were placed in each temperature cabinet, examined every 12 hours and the numbers of hatched eggs recorded.

Larvae and pupae
Three eggplant fruit were placed into each container. Four neonate larvae (<1 day old) from the colony were placed on each fruit and the containers covered with the mesh lid. Two containers (i.e. with 24 larvae) were placed in the cabinets at each temperature. The containers were examined each day at the same time and the emergence of larvae recorded. The end of the larval stage and the start of the pupal stage was deemed to have occurred when the larva had woven and was enclosed by its silken cocoon. The larvae usually pupated along the edge of the mesh or occasionally under the calyx lobes of the fruit. The pupae were removed carefully from these sites by cutting the mesh or calyx, and then were placed in glass livestock tubes, which were held in the temperature cabinets and examined daily to record the days to moth emergence. Occasionally newly developed pupae from the colony were used as well. (There is a pre-pupal stage but it was not possible to see through the silken cocoon to determine when the change from pre-pupa to pupa occurred. Hence the pupal stage recorded here includes both the pre-pupal and pupal stages.)

Linear regression lines were fitted to the data for each stage using Genstat Release 9.2.

Results

The times taken for the development of each stage are given in Table T1.

The linear regression equations for each stage for the thermal summation model are:

Eggs:

$y = 0.0163T - 0.183 \quad (R^2 = 0.896)$

Larvae:

$y = 0.00557T - 0.067 \quad (R^2 = 0.669)$

Pupae:

$y = 0.00934T - 0.135 \quad (R^2 = 0.842)$

Developmental zeroes and thermal constants are shown in Table T2.

Table T1

Development time of *S. cordalis* eggs, larvae and pupae at constant temperatures.

Temperature °C	Development time (days) Mean (n)	± SD	Range
Eggs			
20.5 ± 0.5	7.38 (37)	0.321	6.5 – 8.0
23.5 ± 0.5	4.97 (43)	0.253	4.0 – 5.5
25.0 ±0.5	4.11 (36)	0.295	4.0 -5.5
28.0 ± 0.5	3.50 (47)	0.0	3.5 – 3.5
30.5 ± 0.5	3.41 (38)	0.196	3.0 – 3.5
Larvae			
20.5 ± 0.5	22.58 (19)	2.46	18.0 -26.0
23.5 ± 0.5	16.08 (26)	2.58	12.0 – 21.0
25.0 ±0.5	13.40 (20)	2.11	10.0 – 17.0
28.0 ± 0.5	11.58 (19)	2.17	9.0 – 18.0
30.5 ± 0.5	10.19 (21)	1.83	8.0 – 14.0
Pupae			
20.5 ± 0.5	19.53 (15)	1.73	18.0 – 25.0
23.5 ± 0.5	12.31 (26)	1.12	10.0 – 15.0
25.0 ±0.5	9.45 (20)	1.50	6.0 -14.0
28.0 ± 0.5	7.68 (26)	0.82	6.0 – 9.0
30.5 ± 0.5	7.00 (21)	0.55	6.0 – 8.0

Table T2

Developmental zeroes and thermal constants for *S. cordalis* eggs, larvae and pupae.

	Eggs	Larvae	Pupae
Developmental zero (°C)	11.22	12.03	14.43
Thermal constant (day-degree)	61.32	179.60	107.03

Discussion

Basic information on the developmental rates of *S. cordalis* at constant temperatures is now available. This information can be used to understand the development of the insect in the crop, to model its population dynamics, or to decide on the spray frequency needed to kill eggs and neonate larvae before the larvae tunnel into the fruit if an insecticide program is being used.

More detailed studies of the effect of temperature on development, using a greater range of temperatures so those near the low and high extremes are included, are needed to better understand the effects of temperature. This would allow more complicated empirical and biophysical models to be used to describe the temperature – development relationship.

Moths had failed to emerge from four of the "pupae" being reared at 20°C four weeks after the other pupae had developed. The cocoons were opened carefully and it was found that the insects were still in the pre-pupal stage. The temperature was raised to 25°C and one insect pupated and emerged as an adult within three weeks. The remaining three stayed as pre-pupae for seven weeks, so the temperature was reduced to 20°C for four weeks and then to 17°C for five weeks before being increased to 25°C and the photoperiod increased to 16:8 D:L. Two of the pre-pupae then pupated and developed into adults in two and four weeks. The final insect was discarded after no change in a further two weeks. The behaviour of these insects indicates that they entered a state of diapause. Galbreath and Clearwater (1983) reported that in New Zealand *S. cordalis* larvae entered pre-pupal diapause in April to overwinter until October, and Martin (pers. com. 2008) suggested that diapause is induced by a combination of temperature and daylength. It is not known whether the 20°C temperature or the 12:12 L:D daylength was most responsible for inducing diapause in these insects. This demonstrated ability of members of an Australian population of *S. cordalis* to enter diapause shows they have the ability to survive cold winters. Further studies are needed to understand the factors that induce and break diapause in *S. cordalis*.

Technology Transfer

The main efforts in the project have been aimed at conducting research into the management of eggfruit caterpillar. As well, considerable effort has been made to inform growers, consultants and agribusiness about the project, its activities, results, outputs and outcomes so that information from the project is used for the benefit of growers.

Technology transfer activities undertaken as part of the project have included:

1. A project newsletter, "Eggfruit Caterpillar Update", containing information on the project's activities and results was written and distributed. Three issues were produced; Issue 1 in December 2006, Issue 2 in September 2007 and Issue 3 in November 2008. Each Issue was posted to 45-50 growers and agribusiness people in Queensland eggplant production districts and emailed to approximately 25 consultants and agribusiness people. Copies were sent to Vegetable Industry Development Officers in each state, with the request that they distribute the Updates to growers in their states.

2. Talks on the project's results were given to growers, consultants and agribusiness personnel at Pest and Disease Management Seminars: Bundaberg 14th March 2007; Bowen, Gumlu and Ayr 27th – 29th March 2007; Bowen, Gumlu and Ayr 11th – 13th March 2008; Bundaberg 27th May 2008.

3. An article summarising the talks at the 2007 Bundaberg Pest and Disease Management Seminar appeared in Fresh Pickings 12 (3), the newsletter of the Bundaberg Fruit and Vegetable Growers Cooperative.

4. A poster, "Refining IPM of Eggfruit Caterpillar", that presented the project's activities and results was displayed at the Australian Vegetable Industry Conference in Sydney, 29th – 31st May 2007.

5. A talk on this eggfruit caterpillar project was given at the Northern Farming Systems IPM Researchers' Forum in Toowoomba in July 2007. This forum was attended by cotton and grains researchers from NSW and Queensland and representatives from GRDC, so information on the project was presented to a wider scientific audience.

6. An interview about the project was broadcast on ABC Wide Bay Rural Report in March 2008.

7. "Beat the invisible assassin", an article on the project written by Angela Brennan, was published in Vegetables Australia 3.5, March – April 2008.

8. A talk on the project's activities and results was given to a group of 17 young Granite Belt growers touring the Bundaberg district in July 2008.

9. Copies of reports of insecticide trials were sent to the chemical companies whose products were included in the trials. Companies have expressed interest in pursing registrations for these chemicals.

10. The following scientific manuscript has been written: Kay, IR and Brown, JD (in press). Evaluating the efficacy of insecticides to control *Sceliodes cordalis* (Doubleday) (Lepidoptera: Crambidae) in eggplant. *Australian Journal of Entomology*. A paper on the effect of temperature on the rate of development of *S. cordalis* is in preparation.

11. Information on pheromone trapping (seasonal occurrence, relationship to egg counts) has been supplied to the growers who cooperated in the surveys.

12. As well as the formal activities reported above, information on the project, its purpose, progress and results has been disseminated widely to growers, extension staff, crop consultants and scientific and agricultural industry colleagues through informal personal contact.

Recommendations

1. Insecticide companies should be further encouraged to register for use the insecticides shown to be effective against *S. cordalis* in this project.

2. Ways of effectively monitoring for *S. cordalis* in crops need to be developed so that sensible management decisions can be made. Further research on this should be conducted.

3. Trichogrammatid wasps were recorded parasitising *S. cordalis* eggs for the first time in this project. Their importance in providing biological control of *S. cordalis* should be further investigated, and surveys conducted to look for other beneficial insects attacking *S. cordalis*.

4. Management methods for all pests and diseases of eggplant crops should be further investigated and integrated to develop a true IPM program for the crop.

5. The biology of *S. cordalis* is still poorly understood. Studies to provide an understanding of the insect's biology and ecology are warranted.

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