

REPORTS

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

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Project Title: Quantifying behavioural responses of Helicoverpa moths to trap crops for areawide management.

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Research Program: 3 Crop Protection

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1. Introduction and background

Trap cropping is an established technology within many IPM systems for a broad range of crops. Successful trap crops act as diversionary hosts for key pests, attracting and concentrating the pests and their eggs into a relatively small area where the population can be controlled. Typically trap crops are ‘suicide’ crops that are destroyed prior to harvest in order to kill pests trapped within them. Trap cropping programs aim to reduce egg densities on the primary crop(s) on an areawide basis, resulting in an overall reduction in management costs for individual farms.

Interest in establishing areawide trap cropping programs has grown within the Australian cotton industry, following the success of the Central Queensland trap cropping program initiated by Dr Richard Sequeira as part of the INGARD® resistance management plan. Results suggested that substantial populations of *Helicoverpa* could be captured and destroyed by chickpea and pigeon pea trap crops.

The current project set out to quantify the effectiveness of trap crops and measure the impact of trap crops on egg densities in surrounding cotton. Other aims included quantifying the spatial and temporal nocturnal behaviour of moths in relation to trap crops and to cotton, and to evaluate the relative effectiveness of different spatial configurations of trap crops. The optimal dimensions for trap crop fields are unknown, and the proportion of the total cotton area that should be sown to trap crops is also uncertain. *Helicoverpa* moths have high mobility - their unassisted flight speed is about 5 metres per second, and with their tendency to fly downwind they may exceed 15 metres per second. At these velocities patches and strips of trap crops within bulk fields of cotton may be ‘overshot’ before individual moths have time to recognise them and respond. Furthermore, small patches of trap crop have proportionally more perimeter edge per unit area than large blocks. This may affect the ‘holding power’ of trap crops because moths within a trap crop will encounter and fly over the edge more frequently in small blocks than they would in larger blocks. These issues are also relevant to the design and deployment of INGARD® refuges.

This project also set out to address the integration of trap crop phenology with seasonal *Helicoverpa* population dynamics. For each of the main cotton growing valleys, the HEAPS model was used to predict the timing of *Helicoverpa* spring emergence from diapause, and also the autumn induction of diapause at the end of the season. The APSIM crop model was also used to predict the likely flowering times of chickpea planted over a range of sowing dates, based on historical meteorological data.

2. Project Objectives

1. To quantify the effectiveness of trap crops.

Achieved: Over the course of the project regular sampling was conducted in over 50 trap crops to collect data on the temporal incidence and abundance of *Helicoverpa* eggs, larvae and pupae. This data clearly shows the effectiveness of spring, mid-season and late summer trap crops.

2. To quantify the impact of trap crops on egg densities in surrounding cotton.

Achieved: At each trap crop site sampling was also undertaken in the associated cotton crops, so that *Helicoverpa* densities could be directly compared. At some sites transects were completed to quantify egg densities in the cotton at a range of distances away from the trap crop.

3. To quantify egg production and temporal behaviour of moths within trap crops and in associated cotton crops.

Achieved: Night observations were undertaken to quantify *Helicoverpa* moth activity levels in both trap crops and their associated cotton. Counts of egg densities at each site were completed the morning after each night observation. Light traps were used to quantify the hourly incidence and abundance of each species of *Helicoverpa* moths relative to other night flying insects, and to quantify the activity patterns of male and female moths.

4. To apply the HEAPS simulation model in order to evaluate and improve area wide management strategies based on trap cropping.

Achieved: Modelling studies were undertaken to predict the timing of *Helicoverpa* spring emergence from diapause and the autumn induction of diapause at the end of the season. With respect to spring chickpea trap crops this information was matched to predictions of crop phenology generated by the APSIM crop model based on historical meteorological data. The HEAPS model was also used to predict larval development times at various localities and times of the season.

3. Methods

(a) Trap crops

Four main types of trap crops were examined over the course of the project: Chickpeas (cultivars: Amethyst, Barwon, Sona and mixed Kabuli types); Pigeon peas (Quest); Sorghum (Western red); and Sunflower (Advance). One crop of Mungbeans was also sampled. The chickpea trap crops were sown late in winter and timed to flower during spring in September and October at a time corresponding to the arrival of immigrating *H.punctigera* and the local emergence of *H.armigera* moths from over-wintering populations. This time also corresponds to the emergence of cotton seedlings. The pigeon peas, sunflower and mungbeans were sown in spring and timed to flower in mid-summer. The sorghum trap crops were sown in late spring to early summer and were timed to flower in late summer and early autumn, corresponding to the cut-out and defoliation of cotton crops. Observations and samples were also collected from Cotton crops associated with each trap crop.

(b) *Study sites*

During the three seasons spanned by the project, most observations and sampling were undertaken on 4 farms in the Namoi Valley: *Lowana*, *Auscott*, *Yarral* and the Australian Cotton Research Institute (*ACRI*). A number of trap crop fields on each farm were used in each season. In 1999 observations were also undertaken at *Myambra* near Collarenebri in the Gwydir valley. Table 1 provides a complete listing of the type, layout, dimensions, area, and time of season for all the trap crop fields from which observations and samples were collected on a regular basis. In the case of the Pigeon pea crops on *Yarral* in 1999-2000 and 2000-2001, they were grown as commercial crops for harvest rather than as trap crops per se. However because they were unsprayed for *Helicoverpa*, they were treated as being identical to trap crops for the purposes of this project.

(c) *Sampling Helicoverpa eggs and larvae*

Counts of *Helicoverpa* egg and larvae densities were made at 7 to 14 day intervals in each trap crop and in its associated cotton crop. Sampling was conducted visually on cotton and pigeonpea, and by both visual counts and sweepnet in chickpea. Visual sampling (Photos 1 and 2) involved carefully inspecting every part of whole plants in one metre sections of crop row to count the number of *Helicoverpa* eggs and larvae present. Five to six metres were sampled in each crop per check. Sweep net sampling (Photo 3) involved vigorously sweeping the net along and through the crop canopy whilst walking along the crop row. Each pair of forward and backward passes was counted as two sweeps, and each field check comprised a total of 100 sweeps, usually completed as 4 sets of 25 sweeps with the contents of the net examined after each set. Sorghum was sampled visually prior to head emergence. After head emergence, sorghum crops were sampled by collecting 30 random heads. The heads were processed in the laboratory by spinning each head into a bucket and examining the material shaken off under a magnifying glass to count eggs and larvae. To determine species (*H.armigera* or *H.punctigera*), incidence of parasitism and NPV infection status, the collected larvae were placed on artificial diet in the laboratory and reared at 25°C until they emerged as moths, or until a parasite emerged or they died.

At a number of sites, counts of *Helicoverpa* egg and larval densities were made in cotton crops at a range of distances away from the trap crop. Typically counts were made in the trap crop, and at 5, 50, 100 and 200 metres into the cotton away from the border with the trap crop.

(d) *Sampling Helicoverpa pupae*

Counts of *Helicoverpa* pupae densities in the soil beneath trap crops were made in trap crops in which large larvae were detected, in trap crops that had been slashed, and in cotton crops associated with trap crops. Typically 14 square metres were randomly sampled for pupae in each crop. A trowel was used to scrape the surface soil away from 1 square metre straddling the crop plant line (Photo 4). The subsurface was examined for the tell-tale emergence tunnels associated with pupating *Helicoverpa*. Tunnels were excavated to determine whether there was a live pupae present, or the remains of a pupal case. Emerged pupal cases were examined to determine whether a moth had emerged (by splitting the case longitudinally), or a parasitic wasp (by a circular decapitation of the pupal case). Once all tunnels had been excavated, the remaining soil in each metre being sampled was dug up to a depth of 5cm searching for any further pupae or pupal cases.

Table 1. A list of the major field sites used over the course of the project 1999 to 2002.

Season	Farm	Field	Trap crop	Period	Layout	Size (metres)	Area (Ha)
1999/2000	ACRI	A2	Pigeon pea (Quest)	Summer	6 patches	12 x 12	0.086
1999/2000	ACRI	A2	Pigeon pea (Quest)	Summer	2 strips	12 x 180	0.432
1999/2000	ACRI	F18	Sunflower (Advance)	Summer	2 strips	4 x 210	0.168
1999/2000	ACRI	Leitch 1	Pigeon pea (Quest)	Summer	block	54 x 500	2.7
1999/2000	Auscott	F6	Chickpea	Spring	block	400 x 430	17.3
1999/2000	Auscott	F9	Chickpea	Spring	block	300 x 550	16.4
1999/2000	Auscott	F10	Chickpea	Spring	block	300 x 550	16.1
1999/2000	Auscott	F31	Sorghum (West Red)	summer 1	block	64 x 800	5.12
1999/2000	Auscott	F31	Sorghum (West Red)	summer 2	block	64 x 800	5.12
1999/2000	Lowana	F4	Chickpea (Amethyst)	Spring	block	200 x 800	16
1999/2000	Lowana	F4	Chickpea (Barwon)	Spring	block	200 x 800	16
1999/2000	Lowana	F5	Pigeon pea (Quest)	Summer 1	block	200 x 800	16
1999/2000	Lowana	F5	Pigeon pea (Quest)	Summer 2	block	200 x 800	16
1999/2000	Yarral	F11	Pigeon pea (Quest)	Summer	block	800 x 630	50.5
2000/2001	ACRI	A1	Chickpea (Amethyst)	Spring	6 patches	12 x 12	0.086
2000/2001	ACRI	A1	Chickpea (Amethyst)	Spring	2 strips	12 x 180	0.432
2000/2001	ACRI	A1	Chickpea (Amethyst)	Spring	block	80 x 180	1.44
2000/2001	ACRI	A1	Pigeon pea (Quest)	Summer	6 patches	12 x 12	0.086
2000/2001	ACRI	A1	Pigeon pea (Quest)	Summer	2 strips	12 x 180	0.432
2000/2001	ACRI	A1	Pigeon pea (Quest)	Summer	block	80 x 180	1.44
2000/2001	ACRI	F17	Sunflower (Advance)	Summer	9 strips	4 x 210	0.756
2000/2001	ACRI	Leitch 2	Chickpea (Sona)	Spring	block	24 x 680	1.6
2000/2001	ACRI	Leitch 2	Chickpea (Kabuli)	Spring	block	24 x 680	1.6
2000/2001	ACRI	Leitch 2	Chickpea (Amethyst)	Spring	block	24 x 680	1.6
2000/2001	ACRI	Leitch 2	Pigeon pea (Quest)	Summer	block	72 x 680	4.8
2000/2001	Auscott	F8	Sorghum (West Red)	Spring	block	240 x 970	23.6
2000/2001	Auscott	F23	Soybean	Spring	block	190 x 190	36.9
2000/2001	Lowana	F1	Chickpea (Amethyst)	Spring	block	180 x 500	9
2000/2001	Lowana	F1	Chickpea (Sona)	Spring	block	180 x 500	9
2000/2001	Lowana	F1	Pigeon pea (Quest)	Summer 1	block	150 x 500	7.5
2000/2001	Lowana	F1	Pigeon pea (Quest)	Summer 2	block	150 x 500	7.5
2000/2001	Lowana	F1	Pigeon pea (Quest)	Summer 3	block	150 x 500	7.5
2000/2001	Lowana	F1	Pigeon pea (Quest)	Summer 4	block	150 x 500	7.5
2000/2001	Yarral	F9	Pigeon pea (Quest)	Summer	block	300 x 1190	35.7
2001/2002	ACRI	A2	Chickpea (Amethyst)	Spring	6 patches	12 x 12	0.086
2001/2002	ACRI	A2	Chickpea (Amethyst)	Spring	2 strips	12 x 180	0.432
2001/2002	ACRI	A2	Chickpea (Amethyst)	Spring	block	80 x 180	1.44
2001/2002	ACRI	A2	Pigeon pea (Quest)	Summer	6 patches	12 x 12	0.086
2001/2002	ACRI	A2	Pigeon pea (Quest)	Summer	2 strips	12 x 180	0.432
2001/2002	ACRI	A2	Pigeon pea (Quest)	Summer	block	80 x 180	1.44
2001/2002	ACRI	Leitch 1	Chickpea (Amethyst)	Spring	block	24 x 500	1.2
2001/2002	ACRI	Leitch 1	Chickpea (Sona)	Spring	block	24 x 500	1.2
2001/2002	ACRI	Leitch 1	Pigeon pea (Quest)	Summer	block	24 x 500	2.4
2001/2002	Lowana	F2	Chickpea (Sona)	Spring	block	144 x 583	8.4
2001/2002	Lowana	F2	Chickpea (Amethyst)	Spring	block	144 x 583	8.4
2001/2002	Lowana	F2	Pigeon pea (Quest)	Summer 1	block	144 x 562	8.1
2001/2002	Lowana	F2	Pigeon pea (Quest)	Summer 2	block	160 x 508	8.14
2001/2002	Lowana	F2	Pigeon pea (Quest)	Summer 3	block	144 x 583	8.4
2001/2002	Lowana	F2	Mung bean	Summer	block	352 x 580	20.4

(e) Sampling emerging Helicoverpa moths

In four fields ‘emergence tents’ were installed in chickpea trap crop fields to quantify the number of moths emerging from pupae in the soil subject to different cultivation treatments (Photo 5). The tents covered an area of soil 2m wide x 6 metres long (6 square metres). A collecting jar with a funnel set in the entrance was placed in the top-most section of the tent, and served to collect emerging *Helicoverpa* moths. The tents were installed in October or November following the maturation of the chickpea trap crop. They were checked every 7 to 10 days to monitor the number of *H.armigera* and *H.punctigera* moths emerging from the different cultivation treatments.

(f) *Comparing different trap crop layout configurations*

During each of the three cotton seasons encompassed by this project, the sites at ACRI (Fields A1 and A2) were used to compare the effectiveness of patches, strips and blocks of trap crop relative to cotton and relative to each other (Photos 6 to 12). Each season the experiments were conducted on spring chickpea trap crops, followed by summer pigeon pea trap crops. Each season the following layouts of trap crops were deployed: 6 patches, (12 x 12 metres), 2 strips (12 metres x 180 metres) and one block (80 x 180 metres). In each case these layouts were embedded within a background of unsprayed conventional cotton. Replicated counts of *Helicoverpa* egg and larvae density were made in each patch, strip and block at 7 to 14 day intervals, using the methods described in (c) above.

(g) *Night observations*

Night-time counts of *Helicoverpa* moth activity levels were conducted at irregular intervals in each trap crop and its associated cotton. Counts were made by observing the number of moths flying between goal posts per 5-minute interval using night vision goggles supplemented by infra-red illumination (Photos 13 and 14). Counts were made from the level of the crop canopy. Most night observation sessions were carried out between 8pm and 1am. On two occasions observations were undertaken at intervals throughout the night from dusk to the following dawn. The morning after each night-observation session, visual counts of egg densities were carried out in the cotton in the vicinity of the observed area. Daytime counts of moth densities were also made at some sites by 'flushing' moths from the canopy of the cotton or trap crop using a 1m beat stick and counting the number of moths flushed from cover per 100 metres or crop row.

During each night observation session portable light traps were used to quantify the proportion of *Helicoverpa* moths active relative to other similar sized moths and other night flying insects, and to determine the sex-ratio of *Helicoverpa* captured. The light traps used a 100W blacklight fluorescent tube and they were placed on the ground within the crop 200 metres away from the observation area. The light traps were vertically oriented and were shielded by a steel cone so as to only intercept insects flying over them, and not to attract insects from further a field along a horizontal plane.

(h) *The timing of oviposition*

A field and laboratory experiment was undertaken to determine the times of night over which female *Helicoverpa* moths lay their eggs. In the field experiment, individual plants within a pigeon pea trap crop were covered by mesh bags to exclude access by egg-laying moths (Photo 15). At set intervals through the night, sets of plants were temporarily uncovered to expose them to egg laying moths for 1 hour periods.

In the laboratory experiment, 12 pairs of male and female moths were housed in plastic containers containing paper towel and honey solution, and placed in a controlled temperature cabinet. The light/dark regime was set to 14 L:10 D, and was reversed so that the moths experienced darkness during normal working hours. Each pair was given 3 days to acclimatise to the conditions and to allow the exclusion of any infertile pairs. Once each pair of moths had completed the acclimatisation period and were known to produce fertile eggs, counts of the number of eggs laid were made at set intervals after the onset of darkness inside the controlled temperature cabinet.

(i) *The distribution of *Helicoverpa* within a block of trap crop*

In a one-off experiment the spatial distribution of *Helicoverpa* larvae within a 5 Hectare block of pigeon pea trap crop was quantified by counting the number of larvae present per metre of row at 480 sites spread uniformly throughout the crop. Sampling sites were marked

out with a measuring tape, in rows 10 metres apart and at 10 metre intervals along the length of each row. 10 observers used beat sheets to sample 1 metre of pigeon pea at each sampling point. All *Helicoverpa* larvae were collected and placed into 70% ethanol for later analysis at the University of Queensland to detect DNA microsatellite markers. Prior to collecting the samples, a comparison was made between visual counting, beat sheets and a sweep net to determine the most efficient method. The beat sheet method was adopted because it detected substantially more *Helicoverpa* larvae in pigeon pea, and was also faster than the other two methods.

(j) *The timing of Helicoverpa pupal diapause relative to trap crop phenology*

The HEAPS model was used to predict the timing of spring emergence of *H.armigera* moths from their over-wintering diapause. Graphs and tables of emergence times were used to formulate recommendations for the planting and flowering times of spring trap crops. The HEAPS model was also used to predict the timing of autumn diapause induction, relative to the time of flowering of late-summer trap crops.

The APSIM model was used to predict the probable flowering times of chickpea trap crops at a range of locations and under full and half moisture profiles.

(k) *A modelling evaluation of the total area of trap crops required for effective operation.*

A spreadsheet model was devised to compute the likely proportion of *Helicoverpa* eggs within a discrete region expected to be laid onto trap crops. The model was used to generate the predicted proportions of total eggs that will be laid onto trap crops for 5 different total areas of trap crops: 1%, 2%, 5%, 10% and 20% of the total crop area. The model generates predictions for a range of levels of trap crop attractiveness relative to cotton. Specifically, the levels of trap crop attractiveness considered were within the ranges 1 to 10, and 10 to 100 times as attractive as cotton. For example, a value of 1 indicates the trap crop is identical in attractiveness to cotton, and that it would receive the same number of eggs per unit area. A value of 10 indicates that female moths find the trap crop 10 times more attractive than cotton, and therefore would tend to lay 10 times as many eggs onto the trap crop. However the model assumes that the moths disperse homogeneously throughout the area, and that the incidence of encountering the trap crop is directly proportional to the total area of trap crop within the region. The model assumes that only trap crops and cotton provide hosts for *Helicoverpa* in the region. The scale of the model's predictions are undefined.

The equations used by the model are as follows:

$$E = N/(N+1)*100$$

Where...

E = % eggs laid on trap crops

N = Number of eggs laid into a trap crop per 1 egg in cotton

A = Attractiveness of the trap crop relative to cotton

T = Total area of Trap crop within the region

And where N is computed as follows:

$$N = (A*(T/100))/(1*((100-T)/100))$$

4. Results

The effectiveness of trap crops.

All the trap crops examined in the course of the project successfully attracted *Helicoverpa* eggs, and the results for each type of crop were generally consistent across the different field sites and across the three cotton seasons 1999/00, 2000/01 and 2001/02. The trap crops were most attractive whilst they were flowering, or, in the case of pigeon pea, in the 2 days immediately prior to flowering. The different types and seasonal timing of trap crops varied in their effectiveness at diverting eggs away from cotton.

(i) *Spring flowering trap crops*

Spring flowering chickpea proved to be extremely attractive to *Helicoverpa*, with densities of up to 25 eggs and/or larvae per row metre commonly occurring. Figure 1 illustrates a typical example of *Helicoverpa* densities in a chickpea trap crop monitored over a range of sampling dates. Chickpea trap crops attracted eggs of both *H.armigera* and *H.punctigera*, although because the flowering period corresponds with the influx of immigrating *H.punctigera* at the start of each season, this species tended to predominate in chickpea trap crops. In all cases the density of *Helicoverpa* was substantially higher in chickpea trap crops than densities on nearby newly emerged cotton crops (Figure 1).

During October and November spring trap crops of chickpea are usually the most attractive crop host for *Helicoverpa* available within the landscape, and they are likely to make a significant impact by diverting eggs of the first generation of *H.punctigera* and *H.armigera* away from cotton. By acting as a population sink early in the season, and suppressing population size, spring trap crops are likely to make an impact on the subsequent dynamics of these pests for the next generation and possibly longer. By attracting the eggs of *H.armigera* moths that have emerged from over-wintering diapause, spring chickpea trap crops are also likely to play an important role in reducing the incidence and severity of resistance to insecticides and transgenic cotton. Moths emerging from diapause are the survivors of the last generation at the end of the previous cotton season. Individuals from this generation are likely to be resistant to many insecticides, and in fact this population of emerging moths are the sole carriers of resistance from one season to the next.

Spring chickpea trap crops required careful monitoring to ensure that they did not become nurseries generating *Helicoverpa* moths. Apart from occasional NPV infection or parasitism by Tachinid flies, *Helicoverpa* larvae generally had very high survival rates to the pupal stage in chickpea trap crops. Appendix 5: "Spring trap crop management guidelines" addresses this and other management issues.

(ii) *Mid-summer trap crops*

The *Helicoverpa* population data collected in this project consistently showed a high degree of variation in the apparent attractiveness of summer flowering trap crops relative to the egg densities recorded in nearby cotton. For example, although the 'Quest' pigeon pea cultivar is indeterminate and continues producing flowers throughout the season, it does not maintain a constant level of attractiveness. In most of the pigeon pea trap crops examined in the course of this project, the highest densities of white eggs were recorded during the 2 days immediately prior to the bulk of the field commencing flowering (Photo 16). Figure 2 shows the rises and falls in egg densities in three staggered plantings of pigeon pea at Lowana. Block 1 was planted first, then block 2 was planted 3 weeks later, and block 3 was planted 3 weeks after block 2. While the cotton maintained relatively constant egg densities (see Photo 17). As each planting of pigeon pea became highly attractive, there was also an increase in

egg densities in the other adjacent blocks of pigeon pea as well, even though they had become less attractive and had previously shown declining egg densities. In contrast, Figure 3 presents data from a single block of pigeon pea trap crop at *Myambala* that consistently had a lower proportion of plants infested by *Helicoverpa* than the adjacent cotton. Eggs from both species of *Helicoverpa* were detected in pigeon pea trap crops at all sites.

The strips of sunflower trap crops at ACRI consistently had similar egg densities to the adjacent cotton. This is despite the substantial difference in height between the crop canopies (see Photo 12). Crop canopy height has been identified as an important component of host attractiveness by other research (Dr R.Sequeira pers. com). The single crop of mungbean at Lowana monitored during 2000/01 failed to attract *Helicoverpa* eggs on most sampling dates, and always hosted less *Helicoverpa* larvae than nearby cotton. However from M.Dillon's personal experience mungbeans at other locations in previous seasons have been known to support extremely high populations of up to 70 larvae per square metre. Eggs from both species of *Helicoverpa* were collected from the sunflower and mungbean trap crops.

NPV infection rates were relatively high in pigeon pea crops (see Photo 18). Predatory insects and spiders, and parasitic wasps were also common in the unsprayed pigeon pea and sunflower trap crops.

(iii) *Late-summer trap crops*

Sorghum trap crops timed to flower at the end of the cropping season as the cotton crops were cutting out consistently attracted very high *H.armigera* egg densities, and they sometimes hosted extreme populations of *H.armigera* larvae (Photos 19 to 22). *H.punctigera* were never recorded from sorghum trap crops. Figure 4 presents data from a late season trap crop composed of two separate sowings of sorghum. Block 1 was planted 2 weeks before block 2. The maximum density of *Helicoverpa* eggs and larvae recorded was 256 per metre on 4 April 2001 in block 2. These trap crops were slashed when the larvae within each of them reached medium size, and the stubble was subsequently cultivated. Sampling in the soil below these crops did not detect any pupae.

Such late summer trap crops act as a population sink at the end of the season. As such they are likely to play a valuable role in providing a host for last-generation *H.armigera* to lay their eggs on – eggs that may otherwise be placed elsewhere in the landscape and eventually produce over-wintering diapausing pupae.

The effectiveness of cultivation to suppress moth emergence.

The results from the 'emergence tent' trials are presented in Table 2. Areas of soil in 4 different chickpea trap crop fields that were not cultivated after the crop had finished produced up to 0.42 *Helicoverpa* moths per square metre, equivalent to over 4166 moths per hectare. In the portions of fields that were cultivated once with a disc plough, the density per metre was reduced at least 10-fold to between 0.01 and 0.04 moths, or between 139 and 417 moths per hectare. A double cultivation was evaluated in one chickpea field. The 36 square metres within the emergence tents that had been cultivated twice with a disc plough at different angles did not produce any live moths at all. Overall, the data clearly show that cultivating the soil once trap crops are no longer attractive is a very effective method of killing any surviving pupae, and that ideally two passes should be made to increase the efficacy of the cultivation.

Table 2. The number of moths caught in emergence tents placed over different cultivation treatments following chickpea trap crops.

Auscott F6, F9, and F10	Uncultivated	1 x Cultivation	
No. of tents	6	12	
Square metres	36	72	
Total <i>Helicoverpa</i> moths	15	1	
Moth density/m	0.42	0.01	
Moths/Ha	4167	139	
Lowana Field 4	Uncultivated	1 x Cultivation	2 x Cultivation
No. of tents	6	4	6
Square metres	36	24	36
Total <i>Helicoverpa</i> moths	15	1	0
Moth density/m	0.42	0.04	0.00
Moths/Ha	4167	417	0

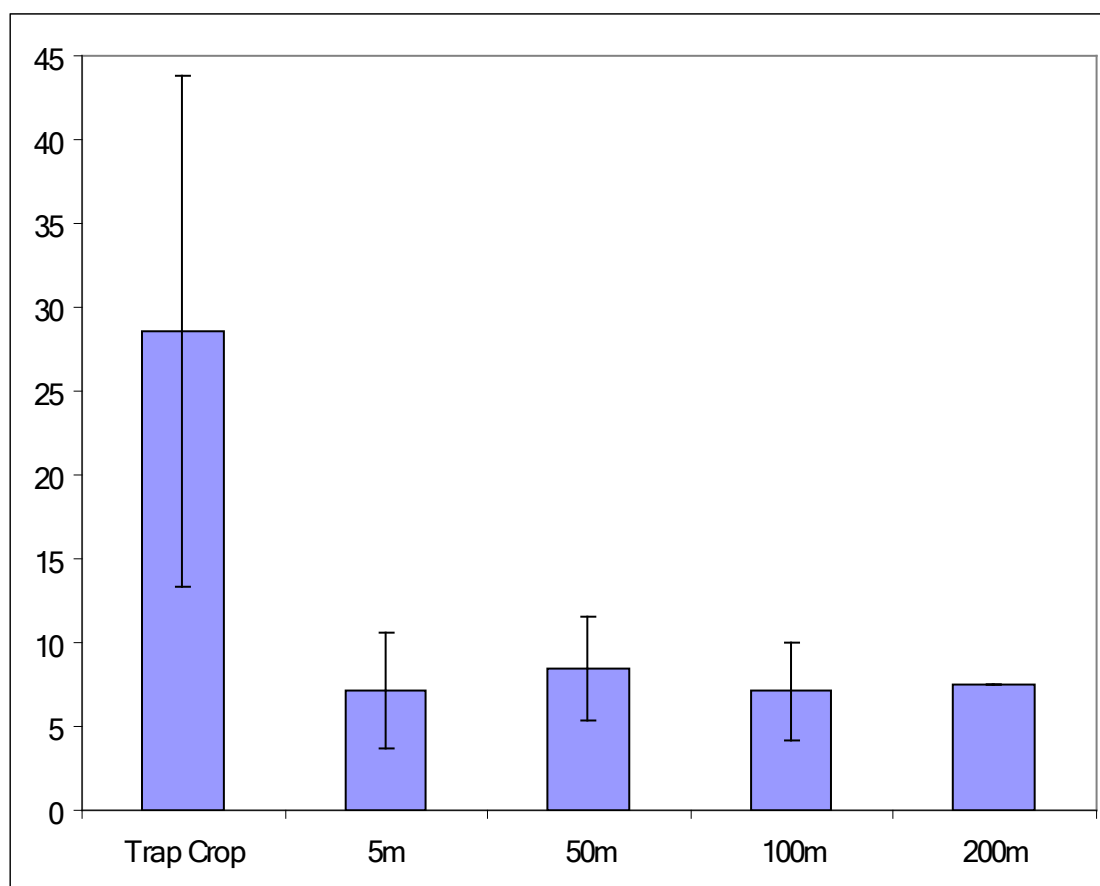


Figure 5. ACRI Pigeonpea egg density per metre in unsprayed cotton at a range of distances away from the trap crop.

The impact of trap crops on egg densities in surrounding cotton.

On five occasions during the project replicated samples were taken at a range of distances away from trap crops into the surrounding cotton. Overall there was no evidence to suggest that there was any type of gradient in egg density as the distance away from a trap crop increases. Figure 5 presents data summarised over a whole season for *Helicoverpa* egg densities in a pigeon pea trap crop and in surrounding cotton at distances of 5, 50, 100 and 200 metres away from the trap crop. In this case the pigeon pea attracted significantly more *Helicoverpa* eggs than the cotton, however there are no differences in the density of eggs in the cotton relative to the distance away from the trap crop. Figure 3 presents data from *Myambala* in which the pigeon pea trap crop generally has a lower proportion of plants infested by *Helicoverpa* than the surrounding cotton at 5, 50, 100 and 200 metres away on 5 separate dates. The sampling dates span the period in which the pigeon pea trap crop commenced flowering and should have become an attractive host. The data show no consistent trend of either increasing or decreasing proportions of plants infested with *Helicoverpa* in relation to the distance from the trap crop.

The relative effectiveness of patch, strip and block trap crops.

Our results consistently showed that solid blocks of trap crops are much more effective at attracting *Helicoverpa* eggs than strips or patches. Furthermore as the area of blocks of trap crop increased, they tended to host relatively higher densities of *Helicoverpa*. Figures 6 and 7 are presented as typical examples of the differences in *Helicoverpa* densities that were found in the different layouts. Figure 6 presents data from pigeon pea trap crops at ACRI. The patch and strip configuration attracted few eggs – and significantly lower densities than the surrounding cotton. However the block of pigeon pea attracted significantly more eggs than the nearby cotton. Figure 7 presents data on the density of *H.armigera* pupae under cotton, and under patches, strips and a block of an adjacent sorghum trap crop at ACRI. The block of sorghum hosted significantly more pupae than the strips or patches. However the cotton crop also had a similar density of pupae to the sorghum block.

There are a number of possible reasons that may contribute to this result. For example, because *Helicoverpa* moths fly at approximately 5 metres per second, it is likely that they may over-shoot narrow strips or small patches of suitable hosts – particularly if they are flying down-wind with wind assistance. Fast flying moths may either pass over without detecting the trap crop, or even if they do detect it, they may not be able to easily find it again in an area dominated by cotton. Another feature of narrow strips or small patches of trap crop is that they have a relatively high perimeter to area ratio. As a trap crop increases in size, the length of perimeter per unit of internal area declines. This means that for moths that are randomly flying within a trap crop, the probability of encountering the boundary and leaving the trap crop increases as the crop reduces in size in one or more dimensions. A long thin strip of trap crop will have a greater length or perimeter than a more square shaped trap crop of the same area.

Nocturnal observations of Helicoverpa moth activity.

Results from the nocturnal observations indicate that *Helicoverpa* moths fly freely over trap crops and cotton and do not appear to restrict their movements to specific types of hosts. Figures 8 and 9 present typical data of *Helicoverpa* moth activity levels as measured by the number of moths passing through goal posts set within the trap crop and also within the adjacent cotton. The observations presented in Figure 8 show moth counts in the trap crop and in the adjacent cotton at 4 different distances from the trap crop. Figure 9 presents observations in the cotton, and at also 3 different distances within the adjacent trap crop. There is no consistent pattern of moth activity in relation to the type of crop or distance from the trap crop. Figure 8 also illustrates the range of moth activity levels recorded during the project, from zero to over 25 moths per minute flying through the goal posts. A consistent observation was that moth activity levels were highest at dusk and immediately after sunset. Figures 9a, 9b, 9c and 9d present moth activity levels in a pigeon pea trap crop and adjacent cotton at Yarral in a sequence over the course of an entire night. The data clearly show high activity levels early in the evening that steadily decline during the night through to dawn. Figure 10 summarises the whole night counts presented in figure 9, and shows the overall average moth activity level at each observation station. There are no significant differences between the cotton site and the three pigeon pea sites.

There were no consistent correlations between nocturnal *Helicoverpa* moth activity levels and *Helicoverpa* egg densities counted the following morning over the three seasons spanned by the project. A possible explanation for this result may be that moths are engaging in a range of behaviours apart from oviposition, including dispersing, feeding, searching for mates or seeking shelter. There were also no consistent correlations between nocturnal *Helicoverpa* moth activity levels over trap crops or cotton and the subsequent daytime flush counts of *Helicoverpa* moths sheltering in these crops the following morning. This is illustrated by comparing the flush counts shown in Figure 11 with the nocturnal moth activity counts for the previous nights presented in Figure 8 in a pigeon pea trap crop at Myambala, and in the adjacent cotton at 5, 50, 100, and 200 metres from the trap crop over 4 sampling dates.

Light trap catches indicated that there were distinct patterns of nocturnal activity by night flying insects in general, and by female and male *Helicoverpa* moths in particular. Figure 12 shows the number of night flying insects relative to *Helicoverpa* moths captured by a light trap that was checked at hourly intervals. The other night flying insects captured were predominantly crickets, beetles and other types of moths. Similar to *Helicoverpa*, other insects were most active around dusk and in the period following sunset. Figure 13 shows the relative proportion of *Helicoverpa* moths to these other insects during each time period. Figures 12 and 13 show that from around midnight onwards *Helicoverpa* moths became the most abundant night flying insects captured by the light trap, and the proportion of *Helicoverpa* moths relative to other insects continued to increase over the second half of the night.

Light trap data clearly show a marked difference in activity levels between male and female *Helicoverpa* moths. Figure 14 shows the rate of moths captured during each time interval through the night. Female moth activity levels are initially high but fall to a low level from before midnight through to dawn. In contrast male moth activity levels remain relatively constant throughout the night. Figure 15 shows the relative proportion of each sex. It shows a strong contrast as the night progresses, with proportionally more female moths initially, but then steadily decline relative to the proportion of males through the remainder of the night.

The timing of Helicoverpa egg laying activity.

The field plant exclusion experiments (photo 15) designed to quantify the nocturnal timing of *Helicoverpa* egg laying did not produce any consistent data due to insufficient and irregular egg pressure. However the laboratory experiments were successful, and the results of two of these trials are presented in Figures 16a and 16b. Pilot experiments had indicated that the captive moths were potentially disturbed by the hourly interruptions to count eggs. For this reason two experiments were conducted. In trial 1 (Figure 16a), the eggs were checked at hourly intervals for the first 4 hours of darkness, and then were left undisturbed for the remainder of each night. In trial 2 (Figure 16b) this was reversed, and the moths were left undisturbed for the first 4 hours, and were then checked at hourly intervals to count eggs laid. Combining the results of the two experiments suggests that in these laboratory experiments, female *Helicoverpa* moths laid eggs throughout the night at a relatively uniform rate. There were no hourly periods that received significantly more or less eggs than other periods.

The spatial distribution of Helicoverpa larvae within a trap crop.

Figure 17 provides a shaded representation of the density of *Helicoverpa* larvae recorded by 480 beat sheet samples in the 5 Ha block of pigeon pea at Lowana. In all 2177 larvae were collected. The larvae were not distributed uniformly within the crop. There was a strong trend of higher densities in the southern end of the trap crop. However no measurable agronomic or physical reasons for this difference were readily evident, and the increase in density did not appear to be related to the edge of the trap crop per se. The average density around the sample points closest to the edge was 2.94 larvae/m compared with the average density of the central sample points of 2.72 larvae/m. The pigeon pea trap crop was surrounded by cotton on all sides. Collections of larvae were not completed in adjacent cotton on this date, and the distribution of *Helicoverpa* larvae in the surrounding cotton crops is unknown.

The timing of Helicoverpa pupal diapause relative to trap crop phenology.

HEAPS model predictions of the timing of the cumulative spring emergence of *H.armigera* moths from their over-wintering diapause were used in the Spring Trap Crop Management Guidelines (Appendix 5). Predictions were also produced on request for other cotton researchers and Industry Development Officers. Figure 18 is an example of the model output predicting the timing of emergence over 12 years at Griffith in southern NSW based on historical weather data. This type of information is useful for fine-tuning the planned flowering dates of spring trap crops to maximise their effectiveness at capturing the first generation of *H.armigera*. Similarly, Figure 19 provides examples of HEAPS predictions of autumn diapause induction at Griffith. The information is important for farmers planning to destroy and cultivate late summer trap crops (and cotton and other crop residues) at the end of the season.

The APSIM model predictions of the probable flowering times of chickpea trap crops at a range of locations and under full and half moisture profiles were incorporated into the Spring Trap Crop Management Guidelines (Appendix 5). An example of the detailed output of the model results for Boggabri in the upper Namoi is presented in Table 3a and 3b.

Table 3a. APSIM Predicted flowering dates based on long term temperatures for Sorghum (early maturing) sown at Boggabri, NSW on full moisture profile.

Sowing Date	80% probability for start of flowering	Average date for start of flowering	20% probability for start of flowering
2-Oct	17-Dec	22-Dec	26-Dec
9-Oct	22-Dec	27-Dec	2-Jan
16-Oct	27-Dec	2-Jan	6-Jan
23-Oct	1-Jan	6-Jan	11-Jan
30-Oct	7-Jan	12-Jan	17-Jan
6-Nov	13-Jan	18-Jan	23-Jan
13-Nov	19-Jan	24-Jan	29-Jan
20-Nov	25-Jan	30-Jan	3-Feb
27-Nov	31-Jan	5-Feb	10-Feb
4-Dec	7-Feb	12-Feb	16-Feb
11-Dec	13-Feb	18-Feb	22-Feb
18-Dec	20-Feb	24-Feb	1-Mar
25-Dec	27-Feb	3-Mar	8-Mar
1-Jan	7-Mar	10-Mar	14-Mar

Table 3b. APSIM Predicted flowering dates based on long term temperatures for Sorghum (early maturing) sown at Boggabri, NSW on half moisture profile.

Sowing Date	80% probability for start of flowering	Average date for start of flowering	20% probability for start of flowering
2-Oct	22-Dec	3-Jan	10-Jan
9-Oct	27-Dec	7-Jan	14-Jan
16-Oct	2-Jan	12-Jan	19-Jan
23-Oct	6-Jan	16-Jan	24-Jan
30-Oct	12-Jan	22-Jan	31-Jan
6-Nov	17-Jan	26-Jan	3-Feb
13-Nov	23-Jan	31-Jan	7-Feb
20-Nov	28-Jan	5-Feb	12-Feb
27-Nov	31-Jan	5-Feb	10-Feb
4-Dec	10-Feb	20-Feb	25-Feb
11-Dec	16-Feb	25-Feb	4-Mar
18-Dec	23-Feb	5-Mar	10-Mar
25-Dec	2-Mar	11-Mar	17-Mar
1-Jan	8-Mar	18-Mar	23-Mar

The proportion of cropping area of trap crops required for effective operation.

Most trap cropping programs within the Australian cotton industry have been implemented on the basis of planting about 1% of the cropping area on a farm or within an Areawide management group to trap crops. During early spring and late summer when trap crops are not competing with cotton as hosts for *Helicoverpa* eggs, a 1% area may well provide a very effective population sink. However for trap crops designed to divert eggs away from cotton there is no scientific data available to determine the optimal proportional area of trap crops. There is also a lack of specific data quantifying the relative attractiveness of different types of host crops to *Helicoverpa* under commercial farming conditions. However some estimates can be made of the likely effectiveness of different proportional areas of trap crop using a range of assumptions about relative attractiveness and moth dispersal behaviour. Spreadsheet model predictions of the likely proportion of *Helicoverpa* eggs within a discrete region that can be expected to be laid onto trap crops are presented in Figures 20 and 21. For 5 different trap crop areas (1%, 2%, 5%, 10% and 20%), the predicted proportion of total *Helicoverpa* eggs that will be laid onto trap crops within the landscape is predicted for a range of trap crop attractiveness relative to cotton. The attractiveness scale can be interpreted as the number of eggs that would be laid onto the trap crop, for every 1 egg laid onto cotton if moths had a clear choice.

The results in Figure 20 clearly show that for a trap crop competing against cotton, either the trap crop must be highly attractive (tens of times more attractive than cotton), or there must be a substantial area of trap crop in the landscape for an appreciable proportion of eggs to be diverted away from cotton. Figure 21 presents the same data, but at a finer scale, with relative attractiveness ranging from 1 to 10. It is likely that most trap crops used for *Helicoverpa* would have levels of attractiveness in this range. The results suggest that for trap crops that compete against cotton, if the total area set aside for trap crops is less than 2%, then the proportion of *Helicoverpa* eggs that could be expected to be laid onto trap crops is about 10% or less. It must be emphasised that these are theoretical predictions, and do not consider potential aspects of *Helicoverpa* behaviour that may influence how and where they lay their eggs. For example, the work of Dr Paul Cunningham and Prof. Myron Zalucki suggests that moths may 'learn' to lay eggs on the host that they encounter most and are familiar with.

5. Conclusions and ‘take home messages’

- Spring trap crops are effective at diverting eggs away from young cotton.
- Spring trap crops can attract very high densities of eggs, and therefore provide a significant population sink for the first generations of *Helicoverpa* emerging from diapausing pupae or arriving as immigrants.
- A brochure “Spring Trap Crop Management Guidelines” produced in collaboration with DPI researchers provides an overview of the benefits of spring trap crops and recommendations for agronomic management.
- In-season trap crops of Pigeonpea are only highly attractive for short periods (~7 days) immediately prior to, and during, initial flowering. Results were variable, but in general flowering pigeon pea subsequently attracted similar densities of eggs as those present in nearby cotton.
- A staggered planting of three blocks of pigeon pea that commenced flowering at three week intervals resulted in a relatively continuous high level of attractiveness relative to cotton.
- Sorghum trap crops are highly attractive as the flower first emerges from the boot for a period of 7 to 10 days.
- Late season trap crops of sorghum (especially staggered plantings) are highly attractive relative to mature cotton at that time, and can attract extremely high densities of eggs.
- Late season trap crops of sorghum have the potential to provide a significant population sink for the last generation of *Helicoverpa*. They attract eggs that would otherwise be laid elsewhere on the landscape and hatch into individuals that would later become diapausing pupae.
- Trap crops in a block configuration are superior to strips or patches, and some data suggests that strips are superior to small patches per unit area.
- As the size of an individual block of trap crop increases, the egg densities per unit area that it attracts also increases. The reasons for this are unknown. It may be that the perimeter to area ratio falls as trap crop size increases, or it may be attributable to aspects of moth behaviour.
- No evidence of egg density gradients were detected in cotton surrounding trap crops.
- Spreadsheet modelling studies suggest that for trap crops to effectively compete directly against cotton, they must either be highly attractive (in the order of 10 or more times more attractive than cotton) and/or the proportional area of the landscape planted to trap crops must be relatively high. For example, if a trap crop is 10 times more attractive than cotton, and represents 2% of the cropping area, it is predicted that about 15% of all *Helicoverpa* eggs will be laid onto the trap crop, and 85% will still be laid onto cotton. Note that these results are not applicable in early spring or late summer when trap crops may not be ‘competing’ with cotton.
- Trap crops are compatible with and complimentary to INGARD® refuges. This was a confusing issue for many cotton growers and consultants. A cotton grower article was published outlining how trap crops and refuges work (Appendix 9).

6. Economic, Environmental and Social outputs of this research

This research is relevant to the sustainability and profitability of the cotton industry because it examined aspects related to the deployment and impact of trap crops for attracting *Helicoverpa* eggs. Results indicate that spring trap crops (especially chickpea) can be very successful, and have the potential to substantially impact on the first spring generation - thereby suppressing subsequent populations, and possibly allowing a significant proportion of the regional population to be controlled with 'soft' chemicals and/or mechanical means. Such a suppression of a regional pest population has the potential to reduce overall chemical use and to help conserve susceptible genes in the pest population. The efficacy and potential benefits of in-season summer trap crops were more variable, and sometimes eggs were only diverted away from cotton for only short periods during initial flowering. Late season trap crops were very effective at attracting high densities of *Helicoverpa*. These represent the last generation of predominantly *H.armigera* – the survivors and progeny of survivors of the whole seasons insecticide regime. These individuals are likely to carry resistance genes, and late season trap crops provide an effective and sustainable means of cultural control.

A direct outcome of this work has been Mr Dillon's significant contribution to the "Spring trap crop guidelines" brochure published in August 2000. The project has addressed the people and communities outcome by providing advisory support to new and existing areawide management groups that are deploying trap crops and/or implementing other IPM practices in the Macquarie, Namoi, Gwydir and Macintyre valleys. The research completed during this project underpins progress towards an increased adoption of IPM approaches, and a reduction in cotton growers' dependence on chemical insecticides.

7. Summary

a) Technical Advances

The major technical result to arise from this work has been the clear demonstration that *Helicoverpa* populations can be manipulated to lay their eggs onto trap crops within the landscape. This is particularly so during spring and late summer when cotton is either not present or not attractive as an oviposition host.

The project also clearly demonstrated that the spatial configuration of individual trap crops influences their attractiveness. Larger trap crops attract proportionally more eggs, and blocks attract more eggs than strips or patches. These findings have been incorporated into the Ingard® resistance management strategy by stipulating the minimum dimensions of refuges.

b) Other Information Developed

A number of methods for studying *Helicoverpa* behaviour and ecology were developed in the course of this research. In particular, the use of night vision goggles, infra-red spotlights and goal posts has been a novel approach that allows comparison and quantification of moth activity levels within specific crops.

c) Changes to the Intellectual Property Register

None required. There were no commercially significant innovations achieved during this project.

8. **Future plans:**

a) Further Development of Project Technology

The utilisation of trap crops within areawide management groups continues to be evaluated as one component of M.Dillon's current CRDC project CSE103C "The impact of area wide management on beneficial arthropod and *Helicoverpa* populations".

Methods for quantifying moth flight behaviour and activity levels over crops continue to be refined.

b) Presentation and Dissemination of Project Outcomes

Project results have been extensively presented to growers, consultants and scientists. See section 9 below for a complete listing. Future planned scientific manuscripts are also listed in section 9(f) below.

c) Future Research

The recent registration of the "Magnet" *Helicoverpa* attractant, the ongoing research and development into *Helicoverpa* repellents and trap-based suppression systems by commercial companies, and advances in scientific understanding of *Helicoverpa* chemosensory ecology and host preference and learning behaviour all have substantial implications for trap crop research. Such technologies that manipulate, or 'push' and 'pull', populations of *Helicoverpa* around the agricultural landscape are likely to be fertile areas for future research that may lead to sustainable management systems for this major pest.

9. **Publications Arising and Planned**

a) Industry Talks, Education, Training and Media

Research findings have been presented at field days, farm walks and shed meetings at Narrabri, Pilliga, Wee Waa, Boggabri, Moree, Warren, Tandou, Walgett, Bourke, Boggabilla, Goondiwindi, and Dalby.

Over the course of the project advice on deploying and managing spring and summer trap crops has been given to cotton Industry Development Officers, Areawide Management groups, and numerous individual cotton growers.

Each year since 1999 a lecture on "Trap Cropping" has been presented to UNE Cotton Production Course residential students visiting ACRI, Narrabri.

Mr Dillon presented reviews of the trap crop project at the Toowoomba Grains IPM workshop (June 2001), and at the Total Ag 'IPM Day' (November 2001). Mr Dillon gave two presentations to the Lower Namoi Pilot IPM Short course.

A research overview seminar was presented at a Certification & Up-skilling Workshop for Cotton Consultants of Australia Inc., Wee Waa, NSW. 12 September 2002.

M.Dillon was filmed for two “Web on Wednesday” online video interviews broadcast on the CSD website: ‘Late season trap crops and compatibility with Ingard® refuges’ (8 November 2001); and, ‘Heliothis predictions’ (9 October 2002).

M.Dillon was interviewed for three articles published in ‘The Land’ national newspaper: ‘Heliothis weapon in chickpeas’ (15 July 1999). ‘Trap crops value unknown’ (22 February 2001). ‘Trap crops for heliothis’ (19 September 2002).

b) Industry Guidelines

Dillon ML. 1999. *Helicoverpa armigera* diapause induction and emergence tables. Support Document 2 in Mensah R and Wilson L. (Editors). "*Integrated Pest Management Guidelines for Australian Cotton*", Australian Cotton Cooperative Research Centre, Narrabri. 1999. [Appendix 1]

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Mensah R, Dillon ML, Khan M, Tann C and Wilson L. 1999. Cotton Insect Pests and their weed hosts. Support Document 4 in Mensah R and Wilson L. "*Integrated Pest Management Guidelines for Australian Cotton*", Australian Cotton Cooperative Research Centre, Narrabri. 1999. [Appendix 3]

Dillon ML. 1999. Guide to planting dates and flowering dates for chickpea trap crops. Support Document 6 in Mensah R and Wilson L. "*Integrated Pest Management Guidelines for Australian Cotton*", Australian Cotton Cooperative Research Centre, Narrabri. 1999. [Appendix 4]

Ferguson J, Miles M, Murray DAH, Dillon ML, Kauter G, and Lloyd R. 2000. *Spring Trap Crop Management Guidelines*. Australian Cotton Cooperative Research Centre, Cotton Research and Development Corporation and Grains Research and Development Corporation.

[Appendix 5]

Wilson, L.J., Mensah R., Dillon M., Wade M., Scholz B., Murray D.A., Heimoana V., and Lloyd R. (2002) Impact of insecticides and miticides on predators in cotton: October 2002 update. Support Document 1 in: Mensah, R. and Wilson, L.J. (Editors): *Integrated Pest Management Guidelines for Australian Cotton*. Australian Cotton Cooperative Research Centre, Narrabri, NSW. <http://cotton.pi.csiro.au/Publicat/Pest/> [Appendix 6]

Hickman M, Larsen D and Dillon ML. 2002. Guidelines for assessing pupae risk for dryland cotton growers. Cotton Information Sheet July 2002. Australian Cotton Cooperative Research Centre, Narrabri. [Appendix 7]

c) Conference and Seminar Presentations

Dillon ML. 1999. Trap Cropping for *Heliothis*. Paper presented to the CSD/CSIRO Cotton Research Review, 11-12 May 1999 Narrabri.

Dillon ML 1999. Trap cropping attractiveness and performance. Invited presentation. Proceedings of the Cotton Production Seminar (Cotton Consultants Australia Inc.), Goondiwindi 26-27 August 1999. [Appendix 8]

Dillon, ML.. 2000. Trap crops for *Helicoverpa* in Australian cotton systems. Oral Presentation at the Australian Entomology Conference, Darwin, June 2000.

Fitt, GP., and Dillon, ML. 2000. Cropping patterns: A landscape perspective of cultural control. Oral Presentation for the International Congress of Entomology, Iguazu Falls, Brazil. in the Agricultural Entomology symposia: "New wine from old skins: A landscape view of cultural control".

Dillon, ML., Fitt, GP. 2000. *Heliothis* local movement and resistance management for transgenic cotton. Oral Presentation for the International Congress of Entomology, Iguazu Falls, Brazil. Presented in the symposia: "Forecasting and managing migratory insect pests and natural enemies".

Dillon ML. 2001. Areawide Management in Northern NSW. Paper presented to the CSD/CSIRO Cotton Research Review, June 2001 Narrabri.

Dillon M. 2003. IPM on an Areawide Scale in the Macintyre Valley. Proceedings of the Cotton Production Seminar (Cotton Consultants Australia Inc.), Narrabri 26-27 August 2003.

Dillon ML. 2003. Understanding the components of successful areawide management. Presentation to Cotton CRC Annual Review, Armidale, 23-24 July 2003.

Dillon ML. 2003. Research Overview presented at "DPI Farming Systems IPM Meeting" Toowoomba, 25/26 June 2003.

M.L. Dillon. 2003. Trap crops for managing *Helicoverpa* (Lepidoptera: Noctuidae) in Australian cotton farming systems. Oral presentation at the World Cotton Research Conference-3, Cape Town, South Africa (March 2003).

M.L. Dillon. 2004. Invited Presentation (2004, Forthcoming) Trap crops for managing *Helicoverpa armigera* in Australian cotton. Paper presentation in Cotton Pest Management Symposium, XXII International Congress of Entomology, Brisbane, Queensland, Australia.

d) Industry Publications

Fitt, GP., Dillon ML and Tann, C. 2000. Entomological Research Update: Cotton Season 1999-2000. Pages 84-85 in Cotton Seed Distributors 2000 Variety Trial Results & Grower Information. CSD, Wee Waa.

Dillon M. and Hoque Z. 2000. An analysis of pest pressure within an areawide management group. Pages 75-83 in Proceedings of the 10th Australian Cotton Conference, Brisbane, Qld. 16-18 August 2000.

Dillon ML. 2001. INGARD® Refuges v Trap Crops: Are they compatible? *The Australian Cottongrower* 22(6): 10-12. [Appendix 9]

Dillon ML, Tann, C. and Baker G. 2001. Entomological Research Update: Cotton Season 2000-2001. Pages 90-91 in Cotton Seed Distributers 2001 Variety Trial Results & Grower Information. CSD, Wee Waa.

Dillon ML and MacKinnon L. 2002. Using light traps to suppress *Helicoverpa*. *The Australian Cottongrower* 23(2): 32-36.

Tann C., Dillon ML and Baker, G. 2002. Entomological Research Update: *Helicoverpa* Cotton Season 2001-2002. Pages 102-103 in Cotton Seed Distributers 2002 Variety Trial Results & Grower Information. CSD, Wee Waa.

e) Scientific Manuscripts

M.A.Merritt, K.S.Wilkinson, K.D.Scott, M.Dillon, L.J.Scott, C.L.Lange, M.K.Schutze, J.K.Kent, D.J.Merritt And G.C.Graham. (2004, submitted.) Gene flow in two consecutive collections of the Lepidopteran pest, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) from the Narrabri region, New South Wales. Australian Journal of Agricultural Research.

Heuke L and Dillon ML. (In preparation) Growing pigeon pea as a refuge and trap crop for cotton. [Appendix 10]

Duffield SJ and Dillon, ML. (In preparation). The emergence and control of overwintering *Helicoverpa armigera* in southern NSW. [Appendix 11]

f) Planned Scientific Manuscripts

“Trap crops for *Helicoverpa* spp. in Australian cotton production”.

- This paper will present an overview of trap cropping as an IPM tool for managing *Helicoverpa* spp in Australian cotton production systems. It will review farm level and AWM group case studies of the deployment of trap crops. A synopsis of this paper has been accepted for presentation as an invited talk at the forthcoming XXII International Congress of Entomology in Brisbane, 15-21 August 2004. The full paper will be submitted for internal review in July 2004 and will be targeted at the international journal “Environmental Entomology”.

“Trap crop algebra: the theoretical effectiveness of trap cropping strategies deployed against *Helicoverpa* moths”.

- This paper will present the results of modelling studies on the effectiveness of a range of trap crop deployment strategies against *Helicoverpa*. Sensitivity analysis will be used to examine how a range of likely moth flight and oviposition behaviours interact with the spatial layout, size, floral timing and attractiveness of trap crops. The paper will be submitted for internal review in August 2004 and will be targeted at the Australian Journal of Entomology.

“Estimating *Helicoverpa* moth densities over cotton crops using night-time goal post counts”.

- This paper will present results of modelling studies of moth flight behaviour validated against visual observations of nocturnal and diurnal moth counts and white egg densities. . The paper will be submitted for internal review in September 2004 and will be targeted at the Australian Journal of Entomology.

“Optimal flight strategies for moths in relation to wind speed, wind direction and the distribution of host patches in agro-ecosystems”.

- This paper will present a theoretical analysis demonstrating that the optimal flight strategy for a moth seeking suitable host patches in a diverse landscape is to fly directly downwind. Such behaviour maximises groundspeed per unit of expended energy, thereby increasing the probability of encountering suitable host patches per unit time with minimum effort. The paper will discuss the implications of agricultural landscapes that are restricted to fertile ‘valleys’ and how this may explain some of the differences in observed dispersal between *H.armigera* which has evolved in close association with human agriculture, and *H.punctigera* an endemic Australian moth adapted to utilising ephemeral host patches in a large scale arid landscape. The paper will be submitted for internal review in October 2004 and will be targeted at an international entomological journal.

10. Impact of project Results and Conclusions for the Cotton Industry

The findings of this project confirm that spring and late summer trap crops can play a very valuable role in providing a significant population sink for *Helicoverpa*. In doing so, trap crops help to suppress the overall population, and possibly subsequent populations, of both species of *Helicoverpa* within a region. Such suppression must lead to reduced egg pressure on cotton crops, and this potentially reduces the frequency and/or severity of chemical insecticides that farmers may otherwise have had to apply to protect their crop. By reducing farmers’ dependence on chemical insecticides, trap crops help to slow the evolution of resistance, and they help to reduce potential adverse environmental effects of disruptive sprays.

The project findings suggest that mid-summer trap crops like pigeon pea are not always highly attractive, and may not necessarily divert eggs away from cotton. The demonstration of a significant influence of individual trap crop spatial configuration on the number of eggs attracted, and the apparent lack of evidence of gradients in *Helicoverpa* egg density in proximity to cotton crops suggests that there are aspects of moth egg laying behaviour that we do not yet fully understand or know about. The theoretical evaluation of the proportion of the cropping area that should be sown to trap crops demonstrated that if trap crops have to compete against cotton they need to be either highly attractive and/or planted in proportionally large areas.

Some of the information on the effectiveness at attracting eggs of individual trap crop size and layout configurations has been utilised in the INGARD® Resistance Management Strategy. In particular, the minimum requirements for the size and shape of INGARD® refuges takes into account the finding that patches and strips are inferior to blocks.

11. Acknowledgements

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Part 4 – Final Report Executive Summary

Trap crops act as diversionary hosts for key pests, attracting and concentrating the pests and their eggs into a relatively small area where the population can be controlled, often by mechanical means. Within the Australian cotton industry trap crops are planted by individual farmers, and/or by members of Areawide management groups as a means of diverting *Helicoverpa armigera* and *H.punctigera* eggs away from cotton and also to suppress the overall population of *Helicoverpa* within a locality.

This project set out to quantify the effectiveness of the main types of trap crops deployed by cotton farmers, and to measure their impact on egg densities in surrounding cotton. Another aim was to quantify the night-time activity levels and egg laying behaviour of *Helicoverpa* moths within trap crops and in associated cotton crops.

In the course of the project over 50 trap crops were monitored and sampled. The main trap crops studied were chickpeas, pigeon peas, sorghum, and sunflower. The findings of this project confirmed that spring and late summer trap crops can play a very valuable role by attracting very high densities of *Helicoverpa* eggs and therefore in creating a significant population sink. In doing so, trap crops help to suppress the overall population, and possibly subsequent populations, of both species of *Helicoverpa* within a region. Such suppression must lead to reduced egg pressure on cotton crops, and this potentially reduces the frequency and/or severity of chemical insecticides that farmers may otherwise have had to apply to protect their crop. By reducing farmers' dependence on chemical insecticides, trap crops help to slow the evolution of resistance, and they help to reduce potential adverse environmental effects of disruptive sprays.

The project findings suggest that mid-summer trap crops like pigeon pea are not always highly attractive, and may not necessarily divert eggs away from cotton. The failure to detect any evidence of gradients in *Helicoverpa* egg density in proximity to cotton crops, and the significant influence of individual trap crop spatial configuration on the number of eggs attracted suggests that there are aspects of moth egg laying behaviour that we do not yet fully understand or know about. The theoretical evaluation of the proportion of the cropping area that should be sown to trap crops demonstrated that if trap crops have to compete against cotton they need to be either highly attractive and/or planted in proportionally large areas.

The project demonstrated that larger individual trap crops attracted proportionally higher densities of eggs than smaller trap crops. Direct comparisons showed that trap crops planted as blocks attracted significantly higher egg densities than strips or patches. Some of the information on the effectiveness at attracting eggs of individual trap crop size and layout configurations has been utilised in the INGARD® Resistance Management Strategy. In particular, the minimum requirements for the size and shape of INGARD® refuges takes into account the finding that patches and strips are inferior to blocks.

During the project M.Dillon made a substantial contribution to the production of the “Spring Trap Crop Management Guidelines” for cotton growers. Project results were also widely disseminated at field days, farm walks, industry seminars and conferences, and in industry related print media.

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