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Research Article

Lure–and–kill as reduced-risk strategy for managing *Helicoverpa* spp. on conventional cotton crops within transgenic cotton fields

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ABSTRACT: Lure–and–kill strategy was evaluated for the management of eggs, larvae and adults of *Helicoverpa* spp. on conventional cotton crops located adjacent to transgenic (Bollgard II) cotton crops in a commercial cotton field in Australia. In this study, a newly developed *Helicoverpa* moth attractant called Magnet®, (AgBiotech Pty Ltd, Australia) containing thiodicarb (Larvin® 375) insecticide, was applied strategically as attracticide to BollgardII® (transgenic (Bt)) cotton crops surrounded by conventional cotton crops. The study showed that the application of the attracticide onto BollgardII® cotton crops indirectly reduced *Helicoverpa* spp. adult populations on adjacent conventional cotton crops by 91.5 per cent compared to 40 per cent on conventional cotton crops located near an "untreated" BollgardII® cotton crops. Similarly, the number of *Helicoverpa* spp. eggs and larvae on the conventional cotton crops located near the "treated" BollgardII® crops was significantly lower than the conventional crops near the "untreated" Bollgard II® crops. In terms of gross margin, there was a saving of $11.40 per ha for *Helicoverpa* spp. control on conventional cotton located adjacent to the BollgardII® cotton crops treated with the attracticide compared to conventional cotton crops adjacent to the "untreated" BollgardII® crops. The predominant natural enemies identified from the study plots were predatory beetles, bugs, lacewings and spiders. The results showed that the number of predators per metre recorded on Bollgard II® cotton crops treated with and without Magnet® mixed with insecticides and the adjacent conventional cotton crops were not significantly different (P>0.05). In conclusion, the use of the attracticide formulation in a "lure–and–kill strategy on transgenic (Bt) cotton crops could conserve predatory insects and reduce *Helicoverpa* spp. infestation and the overall cost of pest control on adjacent conventional cotton crops.

KEY WORDS: *Helicoverpa armigera*, *Helicoverpa punctigera*, BollgardII®, Magnet®, moth attractant, integrated pest management, Lure – and – kill)

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INTRODUCTION

Helicoverpa armigera (Hubner) and *H. punctigera* (Wallengren) attack conventional cotton in Australia and are considered the major pest species (Fitt, 1989; Fitt, 1994). Both species are polyphagous, highly mobile and feed preferentially on young growing tips or reproductive structures of the cotton plants causing significant plant damage and yield loss (Fitt, 1989, 1994). The control of these pests on conventional cotton relies on synthetic insecticide use. Over-reliance on the synthetic insecticides, together with associated problems of insecticide resistance, disruption of beneficial insects and environmental pollution has cast doubt on the long term classical insecticide approach. For this reason cotton growers have adopted integrated pest management programmes based on selective pesticides that enhance the natural enemies of *Helicoverpa* spp. and other secondary pests, but insecticide resistance remains a constant problem (Mensah, 2002; Mensah and Wilson, 1999). As a result, cotton growers are seeking alternative tactics for pest management of *Helicoverpa* spp. and other secondary pests that are compatible with IPM (Wilson *et al.*, 2005).

Lure–and-kill strategy has been used for many years in pest management in agricultural crops (El-Sayed *et al.*, 2009; Welham and Liburd, 2006). The technique involves the use of a semiochemical lure containing a toxicant (usually insecticide) to attract or lure the pest to another crop where the insect is killed after ingesting the semio-chemical lure. Many studies have used "lure–and–kill" strategies successfully against pest insects such as cotton bollworm and native budworm (Pyke *et al.*, 1987), tephritids, house flies, tsetse flies (Jones, 1998), fruit flies (Cunningham and Steiner, 1972), pink bollworm (Haynes and Baker, 1986), coddling moth (Charmilot *et al.*, 2000), and light brown apple moth (Suckling and Brockerhoff, 1999). The attractants can be pheromones or other semiochemicals (De Souza *et al.*, 1992) and are formulated with a mortality agent that can be a toxin, a sterilant (Langley *et al.*, 1990) or a pathogen (Pell *et al.*, 1993).

Previous attract and kill formulations used against lepidopteran pests were based on pyrethroid insecticides (Haynes and Baker, 1986; Miller *et al.*, 1990; Downham *et al.*, 1995) because they exhibit a rapid knockdown effect (Suckling and Brockerhoff, 1999). For example, the attract and kill formulation (Sirene® CM) included a liquid containing pheromone, pyrethroid and a UV-absorber that was used against codling moth to reduce fruit damage in orchards in Switzerland (Charmilot and Hofer, 1997; Hofer, 1997). The response of *H. armigera* males to Sirene® CM in commercial cotton crops in Australia was studied but the contact rate of *H. armigera* males to the formulation was found low to be effective and the study concluded that Sirene® CM might be ineffective in suppressing *H. armigera* infestations on cotton farms (Britton *et al.*, 2002).

However, recently a moth attractant marketed in Australia by AgBiotech Pty Ltd as Magnet® consisting of a volatile blend and feeding stimulants that mimic the type of signals that lepidopteran adults look for when seeking nectar has the potential to attract lepidopteran pests in a wide range of crops (Del Socorro *et al.*, 2003; Grundy *et al.*, 2006). The Magnet® formulation was successfully used to concentrate *Helicoverpa* spp. moths on cotton crops in Australia (Grundy *et al.*, 2006). In Australia, 85% of cotton crops are Bollgard II® (transgenic Bt) and only 15% of the growers grow conventional cotton crops because of the difficulty in managing *Helicoverpa* spp. on the conventional crops with synthetic insecticides.

The strategy of applying Magnet® (moth attractant) containing a toxicant onto BollgardII® cotton surrounded by conventional cotton can lure *Helicoverpa* spp. moths from the environment onto the BollgardII® cotton crops where they are killed. If per chance the moths attracted to the Bollgard II crops happened to lay their eggs before ingesting the attracticide and die, the larvae that hatched from the eggs may be killed by ingesting the Bollgard II® cotton crops. By doing this, *Helicoverpa* spp. moth populations on the surrounding conventional cotton crops may be reduced and could offer cost-effective control on the conventional crop.

The objective of the study was to apply Magnet® (moth attractant) containing a toxicant (i.e., attracticide) to a centrally located BollgardII® (Bt) cotton crop surrounded by conventional cotton crops to determine the effect on *Helicoverpa* spp. adults, eggs and larval populations on the surrounding conventional cotton crops and the cost effectiveness of the lure–and-kill strategy in *Helicoverpa* spp. management.

MATERIALS AND METHODS

Attracticide formulation

The Magnet® product used in this study consisted of a blend of plant synthetic plant volatiles (3.1%), feeding stimulant (20% sucrose), toxicant (0.5% thiodicarb (Larvin® 375) insecticide) and 0.1% blue food dye to mark moths that had fed on the material (Del Socorro *et al.*, 2003; Del Socorro *et al.*, 2004). The mixture was applied at 500 ml per 100 metre of cotton row in 50 cm bands with 72 metre spacing between each band. Magnet® is licensed for commercial use by the Australian Pesticides and Veterinary Medicines Authority (APVMA).

Layout of the experiment

The experiment was conducted on irrigated conventional and BollgardII® cotton fields at ‘Carbucky’ near Goondiwindi (28° 30’S, 150° 21’E) in Queensland in Australia during the 2004-05 and 2005-06 cotton growing seasons. The 2004-2005 season cotton was planted on 7 October 2004 and in 2005-06 season planted on 10 October 2005. In each season, 120 ha of transgenic (BollgardII®) cotton, on a commercial cotton farm, was treated with Magnet® using spacing given above. Six conventional cotton fields (each measuring approximately 30 ha) and located at 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 km away from, and perpendicular to the “treated” BollgardII® cotton fields were selected to assess *Helicoverpa* spp. population. The “treated” BollgardII® and the conventional cotton fields were replicated four times. Each replicate was separated by a buffer of 4 ha cotton. At a second location, an untreated BollgardII® cotton field and six conventional cotton fields of similar sizes and layout but located at least 6 km away from the “treated” BollgardII® cotton field, were selected as the control (untreated) and are subsequently referred to as “untreated”.

Application of the treatments

The Magnet® was applied using a motor bike fitted with a third wheel that allowed it to function in a cotton crop row at a speed of 15-20 km/hr. In 2004-05 season, three applications were made on 26 November, 15 December 2004 and 7 January 2005. In 2005-06 season Magnet® was applied on 8 December 2005 and 12 January 2006. In both 2004-05 and 2005-06 seasons, the application dates coincided with the pre- and peak squaring periods of the cotton plants when *Helicoverpa* spp. moths were abundant in the study area. The decision to apply Magnet® was based on consultant and grower observations of moth activity on the farm.

Sampling

Flush counts of *Helicoverpa* spp. adult moths, eggs and larvae were taken on four metre (rows) wide by 10 m long in each replicated plot (i.e., “treated” and “untreated” BollgardII® and conventional cotton fields). Adult *Helicoverpa* spp. moths were then flushed from the “treated” and “untreated (control)” BollgardII® and conventional cotton blocks by walking 50 m into the field and throwing one handful of dry gravely soil across each plot and counting the number of *Helicoverpa* moths that were disturbed and emerged from the canopy (Del Socorro *et al.*, 2003; Del Socorro and Gregg, 2004). The number of moths per ha was estimated from these counts (Del Socorro *et al.*, 2003; Del Socorro and Gregg, 2004). In 2004-05, *Helicoverpa* spp. moth counts were taken on 25 November, 14 December, 6 and 13 January (i.e., 24 hours prior to application of the Magnet® formulation). In 2005-06, the counts were taken on 7 December 2005, 11 and 17 January 2006.

Visual counts of *Helicoverpa* spp. eggs and larvae and also natural enemies of *Helicoverpa* spp., mainly predatory insects on whole cotton plants in each of the "treated" and "untreated (control)" fields were made twice a week commencing 24 h after each treatment in four randomly selected 1m lengths of row of each treatment replicate, i.e. a total of 4m per row of cotton in each treatment. Counts were separated into *Helicoverpa* spp. eggs and larvae. Data were expressed as numbers per metre for each treatment.

Dead moth counts

Dead moths were assessed 3 days after each Magnet® spray in the "treated" and "untreated" BollgardII® and conventional cotton crops by walking 50 m into the crop in the furrows beside the rows where the Magnet® formulation was applied (in the case of "treated" BollgardII® crop) and at 72 m spacing in the "treated" conventional and the "untreated" BollgardII® and conventional cotton crops. A metre stick was placed in the furrow and all dead moths in the one metre length of furrow were counted. This was repeated in each of the 4 plots in the treated and control plots.

Cost effectiveness of the attract and kill strategy

Foliar application and costs of chemical products applied to the conventional cotton crops near both the "treated" and "untreated" Bollgard II® crops were recorded. The decision to apply pesticides to control *Helicoverpa* spp. on each treatment was based on a predator-to-*Helicoverpa* spp. eggs and larvae (pest) ratio of 0.5 (Mensah, 1999, 2000, 2002). The grower did all pesticide management or agronomic inputs. At the end of the season, the benefit (in terms of pest control) to the grower of the "treated" and "untreated (control)" conventional cotton crops was calculated on the quantity of insecticides sprayed, cost of insecticides and insecticide application costs.

Analysis of data

All data was analysed using repeated measures ANOVA (Graphpad Instat Software, Inc., Version 2.03, San Diego, CA, USA). Treatment and sample dates were the independent variables. Tukey-Kramer multiple comparisons test was used to separate the means. In the analysis of dead moths, all data collected 3 days after treatment was transformed by (X + 0.5) before analysis. Arithmetic, rather than transformed means are given in the results.

RESULTS AND DISCUSSION

Flush counts of adult moths

The number of *Helicoverpa* spp. moths per ha recorded on the "treated" and "untreated" BollgardII® and conventional cotton crops in 2004-05 season is given in Fig. 1. The higher decline in moth numbers occurred on the "treated" BollgardII® and conventional cotton crops indicating moths attracted to the "treated" BollgardII® field were killed by the Magnet® formulation thereby significantly reducing moth numbers ($P<0.01$) on the adjacent conventional cotton crops and to a lesser extent on the "untreated" fields. This was supported by the higher number of dead moths recorded in the "treated" BollgardII® and conventional cotton crops (2.75 ± 0.48 and 0.25 ± 0.15 per metre, respectively) compared with 0.01 ± 0.01 per metre recorded on the "untreated" BollgardII® and conventional cotton crops (Table 1). Overall, the highest number of moths per ha per sample date was recorded on the "treated" BollgardII® crop (1456.3 ± 443.71), followed by the "untreated" conventional crops (599.50 ± 96.01) and "untreated" BollgardII® crop (550.75 ± 80.19) (Figure 1). The "treated" conventional cotton crop located 0.5 km away recorded the lowest number of moths per ha per sample date (488.25 ± 178.59) (Figure 1). This was not significantly different ($P>0.05$) from the conventional crop located 1.0 km away but was significantly different ($P<0.01$) from the "treated" conventional crops located 1.5 to 3.0 km away. No significant difference ($P>0.05$) was detected between the number of moths recorded on the "untreated" BollgardII® and conventional cotton crops (Figure 1). The estimated number of moths per ha recorded on the "treated" BollgardII® and conventional cotton crops during 2005-06 season is given in Figure 2. No significant difference ($P>0.05$) was detected between the number of moths per ha recorded on the "treated" Bollgard® and conventional cotton crops (Figure 2) despite the high number of dead moths (5.12 ± 0.88 per metre) recorded in the treated BollgardII® crop (Table 1).

Dead moth counts

In 2004-05 and 2005-06, the number of dead moths per metre recorded in the "treated" BollgardII® crops was significantly higher ($P<0.0001$) than those recorded in the "treated" conventional cotton crops and the control plots (Table 2). The "treated" conventional cotton crops located 0.5 to 1.0km away from the "treated"

Table 1. Counts of dead *Helicoverpa* spp. adults per metre row sample strips in the Magnet® plus insecticide – treated and untreated BollgardII® cotton and conventional cotton fields, Carbucky near Goondiwindi, 2004-06 (n = 4 m)

Treatments	*Helicoverpa* spp. density (Dead moths/m) 3 DAT		
	2004-05 season		2005-06 season
	[1]Treated	[2]Control	[1]Treated only
BollgardII® cotton field treated or untreated with Magnet® plus insecticides	2.75 ± 0.48a	0.01 ± 0.01c	5.12 ± 0.88a
Conventional cotton field located 0.5 km away from BollgardII® field	0.25 ± 0.15b	0.01 ± 0.01c	0.50 ± 0.20b
Conventional cotton located 1.0 km away from BollgardII® field	0.08 ± 0.01c	0c	0.13 ± 0.13c
Conventional cotton located 1.5 km away from BollgardII® field	0c	0c	0c
Conventional cotton located 2.0 km away from BollgardII® field	0c	0.01 ± 0.01 c	0c
Conventional cotton located 2.5 km away from BollgardII® field	0c	0c	0c
Conventional cotton located 3.0 km away from BollgardII® field	0c	0c	

Means within columns followed by the same letter are not significantly different ($P > 0.05$), Tukey-Kramer multiple comparison test (DAT = days after treatment); [1]BollgardII® cotton crops treated with Magnet® mixed with insecticide (thiodicarb) and conventional cotton crops located 0.5-3.0 km from treated Bollgard® crops; [2]BollgardII® cotton crops untreated with Magnet® mixed with insecticides conventional cotton crops located 0.5-3.0 km from untreated BollgardII® crops.

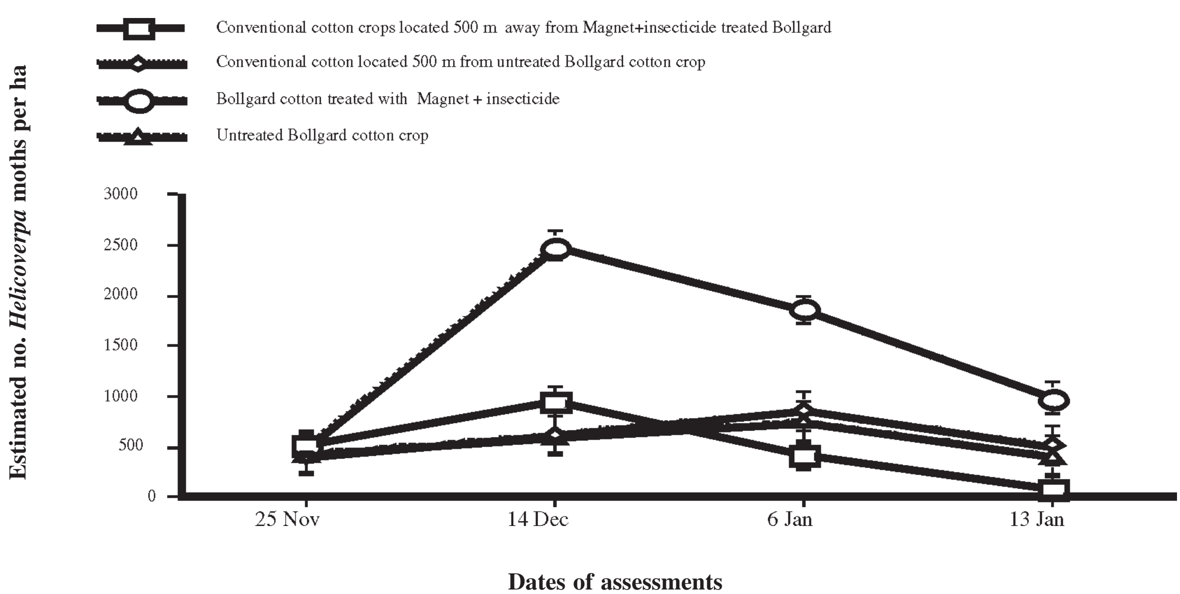

Fig. 1. Number of *Helicoverpa* spp. on conventional cotton crops located 500 m from Bollgard® cotton crops treated with Magnet® mixed with insecticide at Carbucky near Goondiwindi in 2004-05 (Treatments were applied on 25 November 2004, 15 December 2004 and 7 January 2005)

BollgardII® cotton crop had significantly (P<0.05) more dead moths per metre than the "treated" conventional cotton crops located 1.5 to 3 km away from the "treated" BollgardII® crop (Table 1). No dead moths were found in the "treated" conventional cotton crops located 1.5 to 3 km away from the "treated" BollgardII® crop (Table 1). In contrast, we found 0.01 moths per metre in the conventional cotton crop located 2 km away from the "untreated (control)" BollgardII® field (Table 1). All dead moths counted were blue from the Magnet® dye indicating they had fed on the Magnet® formulation.

Eggs and larval counts in "treated" and "untreated" BollgardII®

The number of eggs laid on the "treated" BollgardII® cotton crop was significantly higher (P<0.005) than the "untreated (control)" Bollgard® (Fig. 3). The number of eggs per metre on the "treated" BollgardII® cotton crop ranged from 5 to 30 per metre compared with 0 to 10 per metre on the untreated BollgardII® crop (Fig. 3).

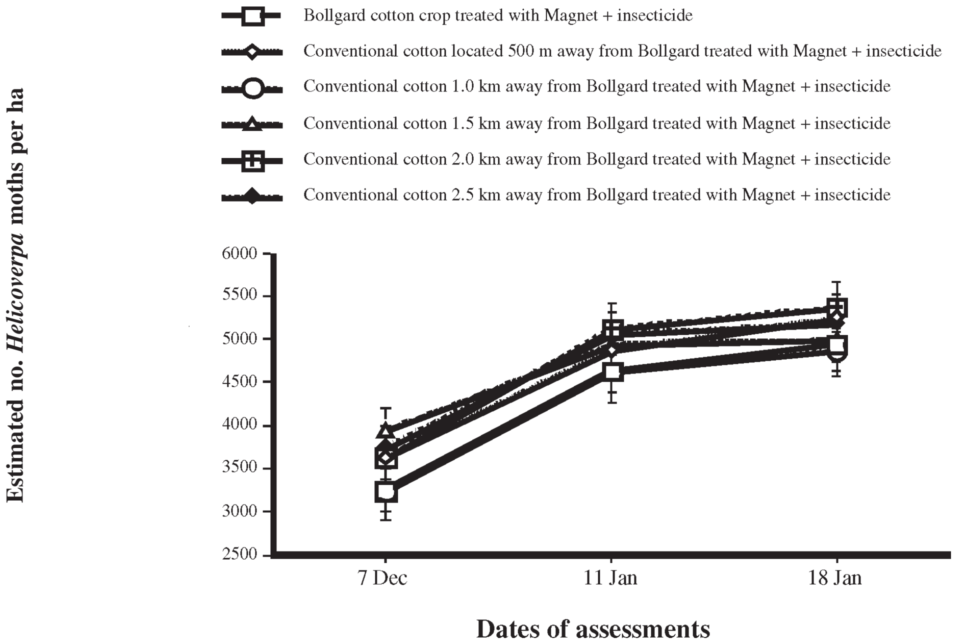

Fig. 2. Number of *Helicoverpa* spp. on conventional cotton crops located 0.5 – 2.5 km away from Bollgard® cotton crops treated with Magnet® mixed with insecticide at Carbucky near Goondiwindi in 2005-06 (Treatments were applied on 8 December 2005 and 12 January 2006)

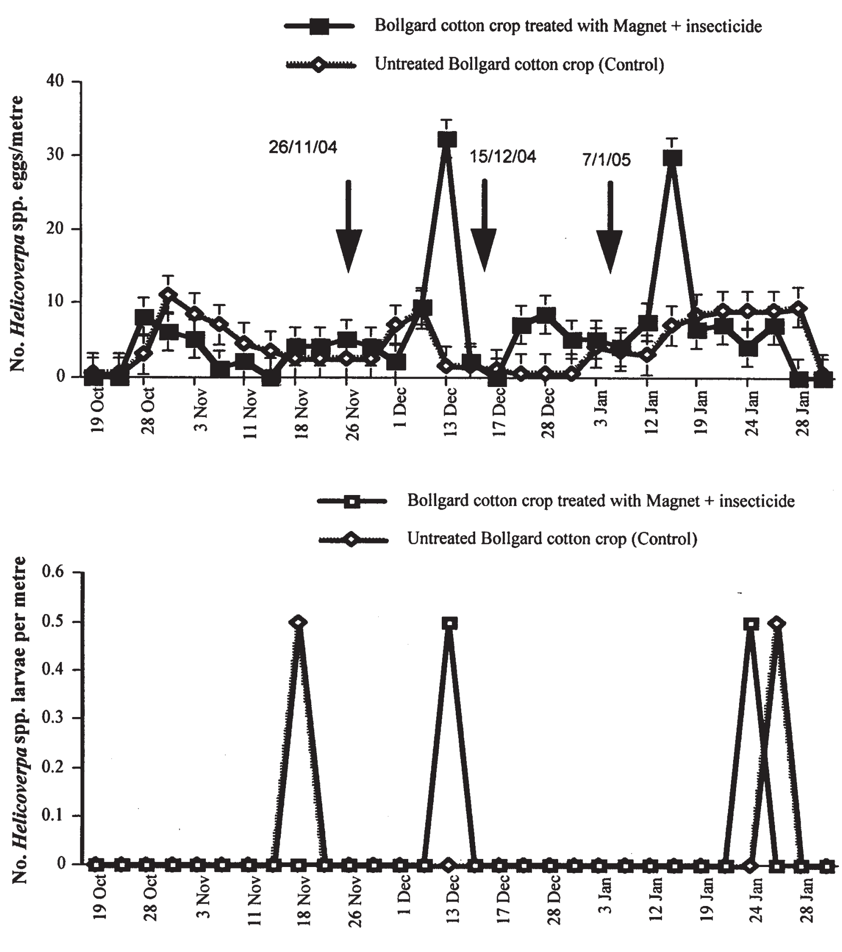

Fig. 3. Effect of application of Magnet® mixed with insecticide on BollgardII® cotton crops on oviposition and larval survival of *Helicoverpa* spp. at Carbucky near Goondiwindi in 2004-05

Although the high number of eggs recorded on the "treated" BollgardII® crop was the highest among the treatments, the number of larvae per metre was not significantly different (P>0.05) between the "treated" and "untreated (control)" indicating that any eggs that may have hatched on the treated BollgardII® crop were killed by the BollgardII® toxin. In 2005-06, no significant difference (P>0.05) was detected in the number of eggs and larvae on the "treated" and "untreated" BollgardII® and conventional cotton crops at the time the trial was terminated. An explanation forthis was that high number of residual moths in the environment resulted in a high egg lay on both treated and control plots.

Control of Helicoverpa *spp. on "treated" and "untreated" conventional cotton crops and cost effectiveness of the attract and kill strategy.*

Assessment of Helicoverpa *spp. egg and larvae on "treated" and "untreated" conventional cotton crops*

Prior to the first treatment application, the same number of *Helicoverpa* spp. eggs and larvae per metre were recorded on "treated" and "untreated" conventional cotton crops located 0.5 and 1.0 km away from the treated and untreated BollgardII® cotton crops during the 2004-05 season (Figure 4 and 5). However, after the application of Magnet® formulation onto the BollgardII® cotton crop, the number of eggs and larvae per metre on the "treated" conventional cotton crops located 0.5 km away from the "treated" BollgardII® crop were significantly lower (P<0.005) than the "untreated" conventional cotton crops located same distance from the "untreated" BollgardII® crop (Figure 4 and 5). The number of eggs and larvae per metre on the "treated" conventional cotton crops located 0.5 km

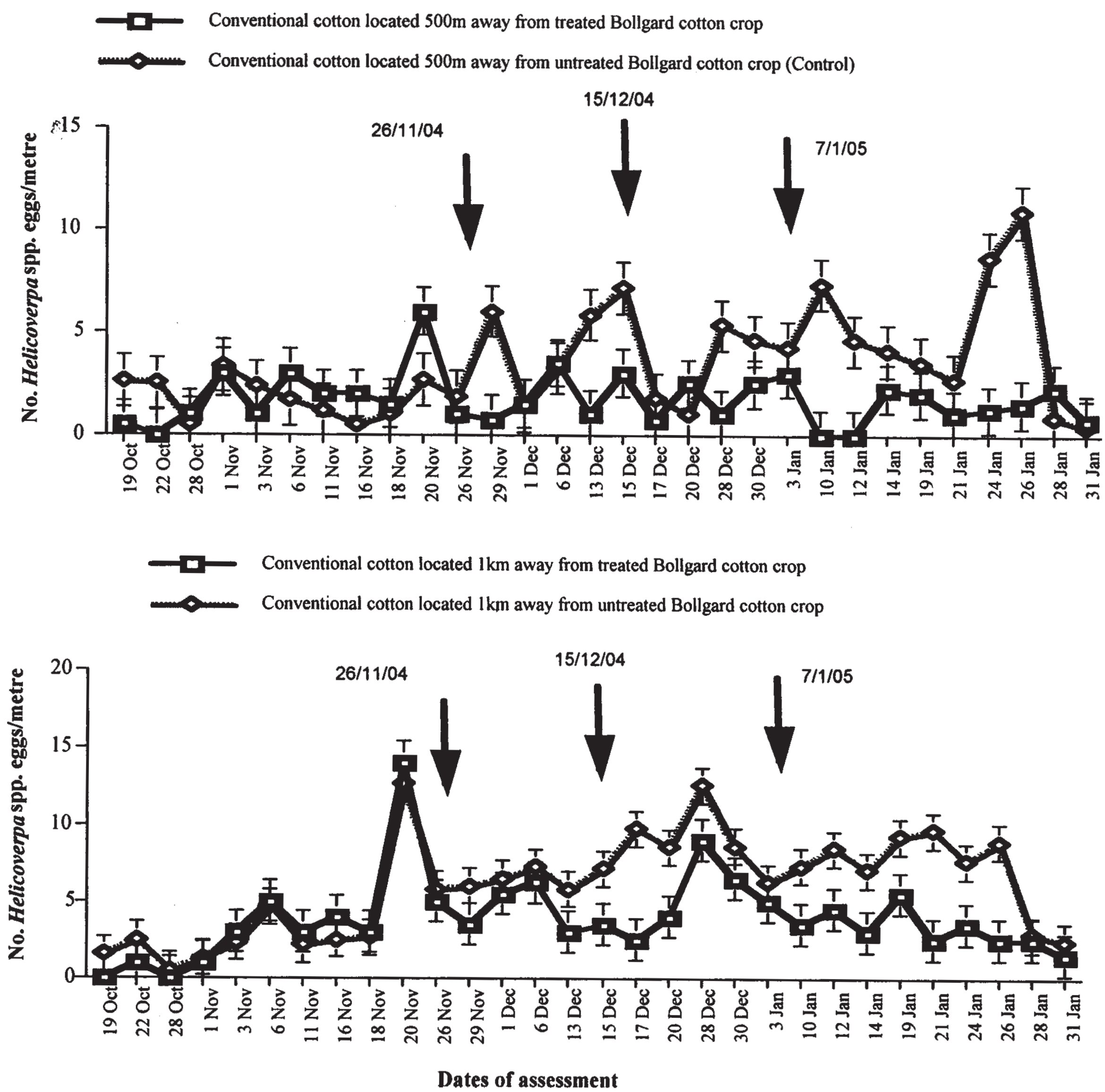

Fig. 4. Effect of application of Magnet® mixed with insecticide (thiodicarb) on numbers of *Helicoverpa* spp. eggs per metre on conventional cotton crops located 0.5 and 1 km away from "treated" and "untreated" Bollgard® (transgenic) cotton crops at Carbucky in Goondiwindi in 2004-05

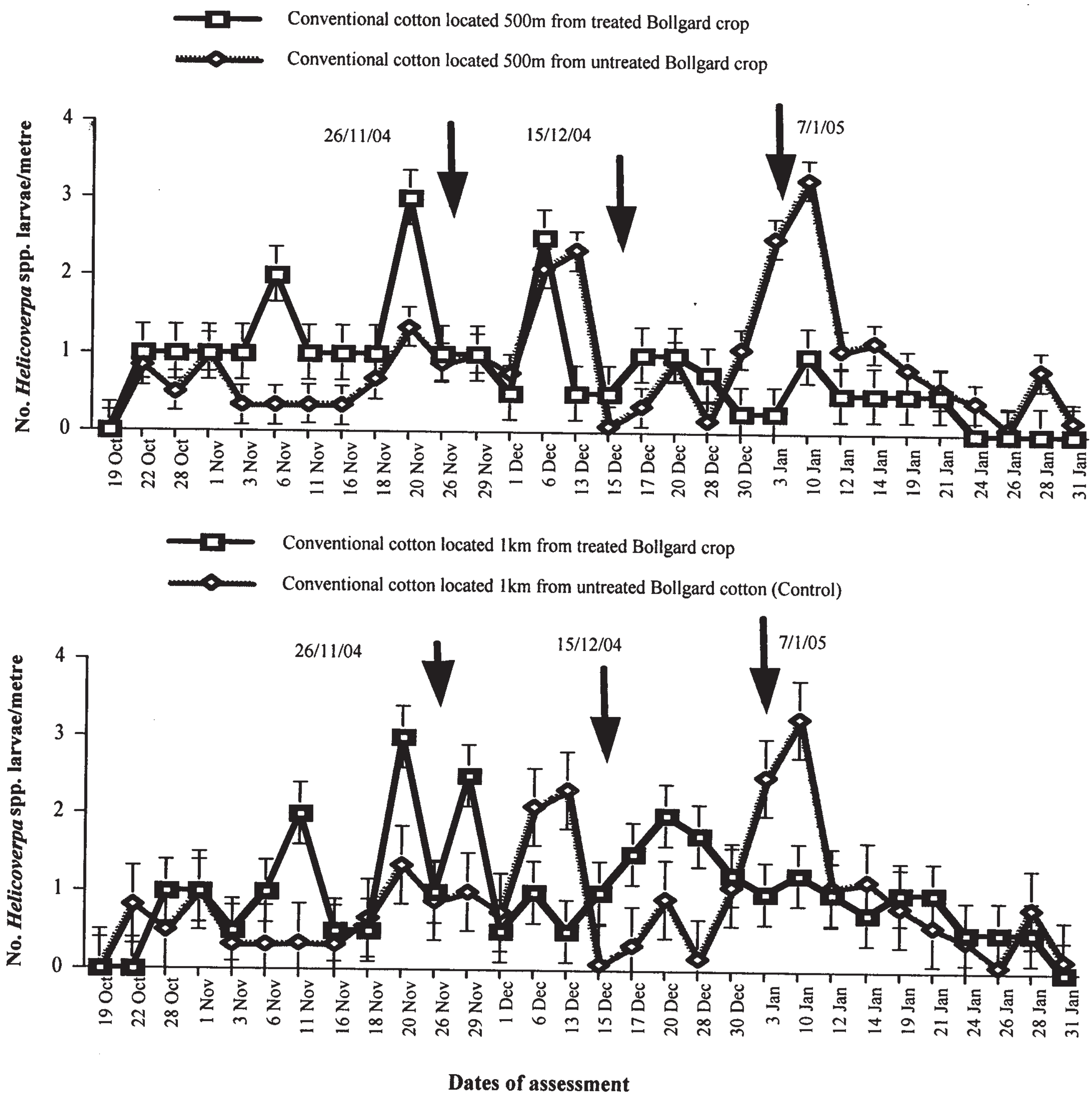

Fig. 5. Effect of application of Magnet® mixed with insecticide (thiodicarb) on numbers of *Helicoverpa* spp. larvae per metre on conventional cotton crops located 0.5 and 1 km away from "treated" and "untreated" BollgardII® (transgenic) cotton crops at Carbucky in Goondiwindi in 2004-05

away was significantly lower (P<0.001) than the "treated" conventional cotton crops located 1.0 and 1.5 km away (Figure 6). In contrast, no significant difference (P>0.05) was detected in the number of eggs and larvae per metre on the "treated" BollgardII® and conventional cotton crops located 0.50 and 1.0 km away (Figure 7). In addition, no significant difference (P>0.05) was detected in the "untreated" conventional cotton crops located 0.5 and 1 km away from the "untreated" BollgardII® cotton crops.

Control of Helicoverpa spp. on "treated" and "untreated" conventional cotton crops

The overall number of larvae per metre recorded in 2004-05 season on the "treated" conventional cotton crops was significantly lower (P<0.05) than the "untreated" conventional cotton crops (see Figure 4 and 5). Control of *Helicoverpa* spp. larvae on the "treated" conventional cotton crops commenced on 7 November 2004 whereas the "untreated" conventional crops commenced on 1 December

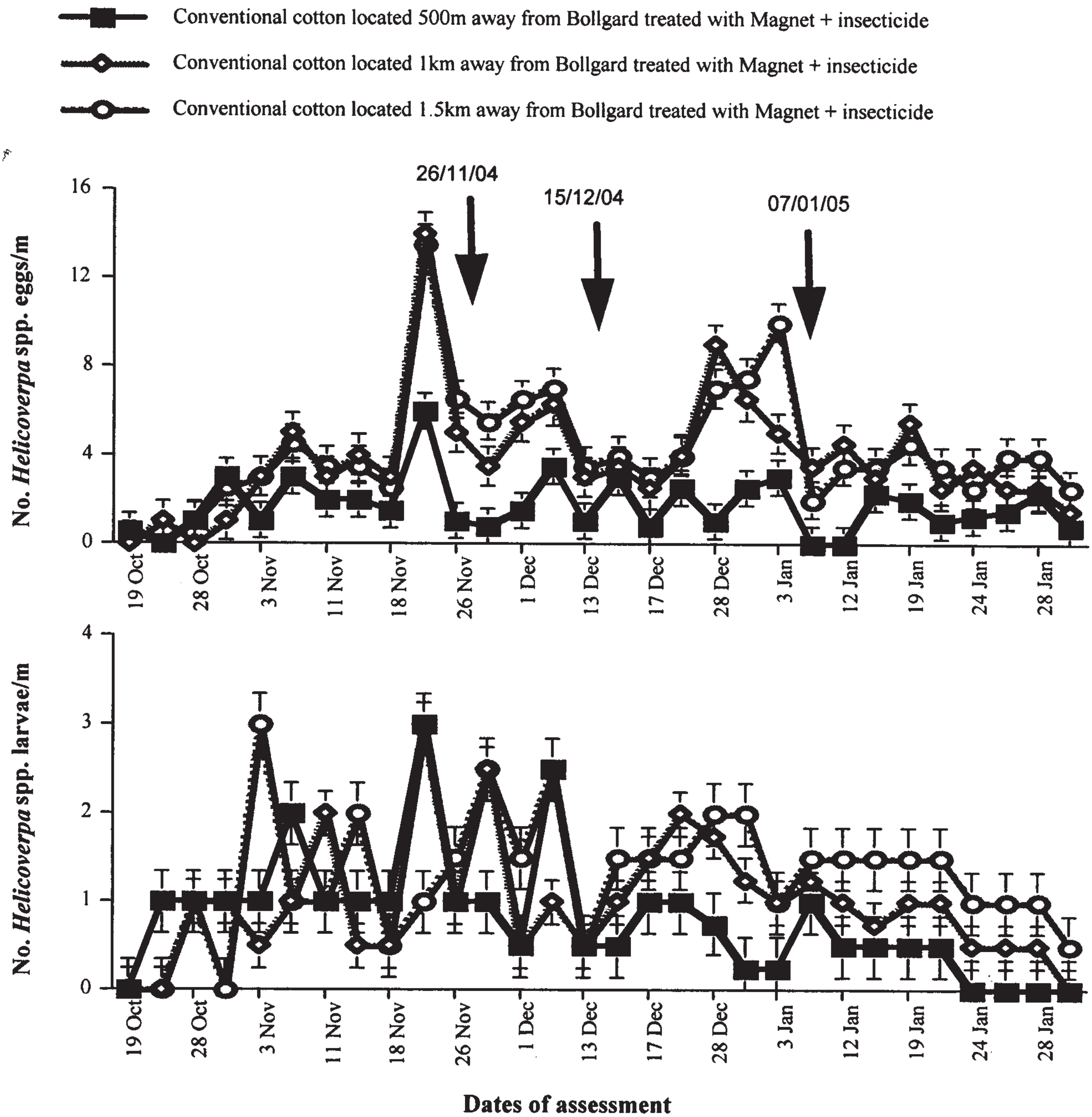

Fig. 6. Comparison of numbers of *Helicoverpa* spp. eggs and larvae per metre on conventional cotton crops located 0.5, 1.0 and 1.5 km away from Bollgard® (transgenic) cotton crops treated with Magnet® mixed with insecticide (thiodicarb) at Carbucky in Goondiwindi in 2004-05

2004. An explanation for this was some moths attracted to the Magnet® formulation on the "treated" Bollgard® crops might have initially landed on the adjacent conventional crops and lay some eggs before moving on to the Magnet® source on the BollgardII® crops. In all, we applied seven pesticide sprays to manage *Helicoverpa* spp. on the "treated" and nine on the "untreated" conventional cotton crops in the 2004-05 season. There was no insecticide savings on the "treated" conventional cotton crops relative to the "untreated" conventional cotton crops in 2005-06 season. In 2004-05 season, the total cost of pesticides applied to the conventional cotton crops adjacent to the Bollgard II® crops that received attracticide sprays was $606.70 and that without the attracticide spray was $618.10. Thus the benefit to the grower in terms of pest control was $11.40 per hectare on the "treated" over the "untreated" conventional crops in 2004-05 season. In 2005-06 season, no benefit was achieved by the grower in terms of pest control when the attracticide (Magnet® formulation) was applied to the BollgardII® cotton crops.

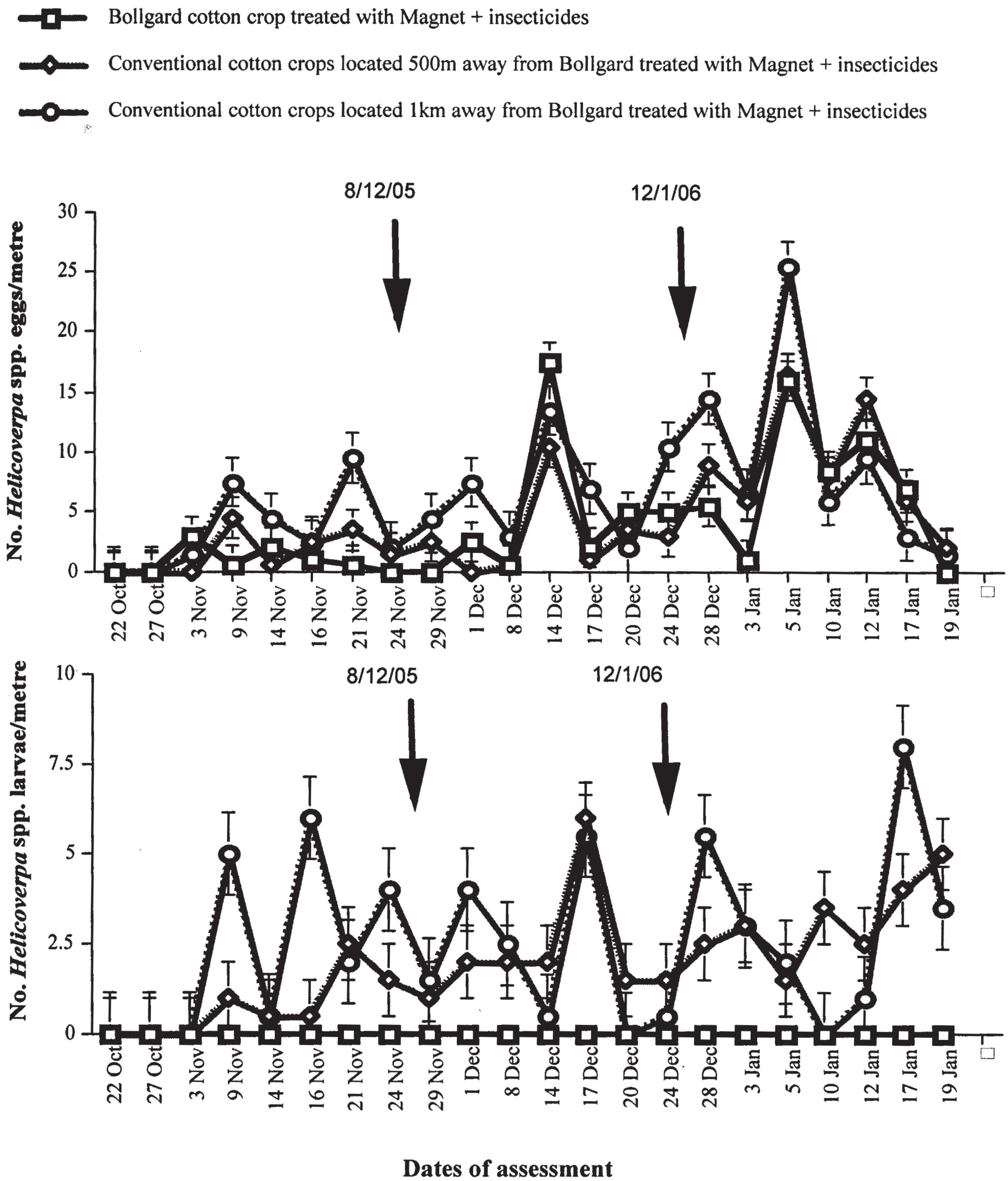

Fig. 7. Comparison of numbers of *Helicoverpa* spp. eggs and larvae per metre on conventional cotton crops located 0.5, 1.0 and 1.5 km away from Bollgard® (transgenic) cotton crops treated with Magnet® mixed with insecticide (thiodicarb) at Carbucky in Goondiwindi in 2004-05

This was due to unusually high *Helicoverpa* spp. pressure which resulted in high egg lay irrespective of higher numbers of moths killed using the lure and kill strategy on the Bollgard II crops.

Assessment of predatory insects on "treated" and "untreated" conventional cotton crops

The predominant predatory insects identified from the study plots were predatory beetles, bugs, lacewings and spiders (Table 2). These predators were found at the study site in all plots during each sampling date. The results showed that the number of predators per metre recorded on Bollgard II® cotton crops treated with and without Magnet® mixed with insecticides and the adjacent conventional cotton crops were not significantly different (P>0.05) (Table 3 and Figure 8).

Table 2. Predators of cotton pests sampled and identified from study plots from 2004-2005

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

Table 3. Counts of predatory insects per metre in the Magnet® plus insecticide–treated and untreated BollgardII® cotton fields and conventional cotton fields, Carbucky near Goondiwindi, 2004-05

Treatments	**Predators per metre**	
	2004-05 season	
	[1]Treated	[2]Control
BollgardII® cotton field treated or untreated with Magnet® plus insecticides	4.79 ± 0.72a	4.28 ± 0.75a
Conventional cotton field located 0.5 km away from BollgardII® field	4.83 ± 0.66a	3.59 ± 0.48a
Conventional cotton located 1.0 km away from BollgardII® field	3.62 ± 0.64a	3.75 ± 0.69a
Conventional cotton located 1.5 km away from BollgardII® field	3.31± 0.41 a	3.70 ± 0.88a
Conventional cotton located 2.0 km away from BollgardII® field	3.66 ± 0.53a	4.12 ± 0.78a
Conventional cotton located 2.5 km away from BollgardII® field	3.00 ± 0.37a	3.55 ± 0.67a
Conventional cotton located 3.0 km away from BollgardII® field	4.35 ± 0.61a	4.09 ± 0.91a

Means within columns followed by the same letter are not significantly different (P>0.05), Tukey-Kramer multiple comparison test; [1] BollgardII® cotton crops treated with Magnet® mixed with insecticide (thiodicarb) and conventional cotton crops located 0.5-3.0 km from treated BollgardII® crops; [2]BollgardII® cotton crops untreated with Magnet® mixed with insecticides conventional cotton crops located 0.5-3.0 km from untreated BollgardII® crops

The results of the study showed that application of the Magnet® formulation containing an insecticide (attracticide) to BollgardII® cotton fields surrounded by conventional cotton fields lured and killed *Helicoverpa* spp. (moths) resulting in a reduction of *Helicoverpa* spp. population on the surrounding conventional cotton fields located 0.5 to 1 km away. In this study, the first treatment application of the attracticide onto the Bollgard II® cotton crops did not reduce the moth numbers on the adjacent conventional cotton crops but rather increased the moth numbers by 86 per cent. The reason for the increase in moth population could be that the odour emitted from the Magnet® formulation dissipated before residual moths could reach the treated zone. These moths might have stayed in the conventional cotton crop that was closest to the "treated" BollgardII® crops increasing the moth population in the crops. However, after the second and third application of the attracticide, the number of moths on the conventional cotton crops adjacent to the treated Bollgard II® cotton crops declined significantly from a peak of 950 to 85 moths per ha whereas the number of moths per hectare on the untreated Bollgard II® crop was 510 per ha. This may indicate an increased build up of the attracticide residue on the treated Bollgard II® cotton leaves resulting in increased persistence of the product odour forcing any

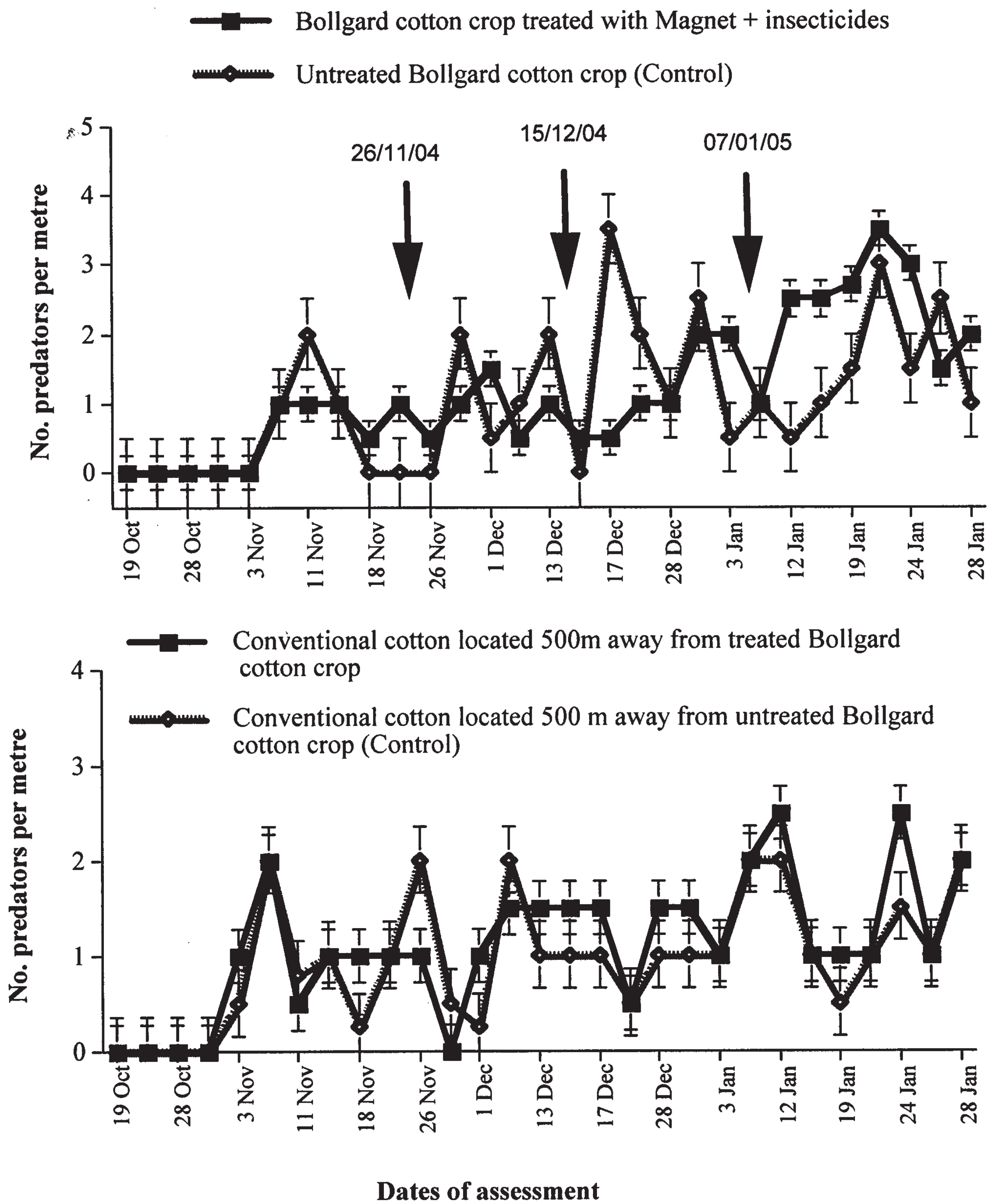

Fig. 8. Counts of predatory insects per metre in the Magnet® plus insecticide – treated and untreated BollgardII® cotton fields and conventional cotton fields located 0.5 km away in Carbucky near Goondiwindi, 2004-05

residual moths that might have remained in the conventional cotton crop to move into the treated zone in the BollgardII® field to feed and die. The plant volatiles in the attracticide formulation mimic the type of signal moths respond when they seek nectar. The odour emitted by Magnet® dissipates with time.

The study also showed that despite the high initial increase in moth numbers on the conventional cotton crop that was closest to the "treated" BollgardII® crop after the first attracticide application, it did not translate into higher number of *Helicoverpa* spp. eggs and larvae in the plot. Rather, the number of eggs and larvae were significantly lower in the "treated" conventional cotton crops compared to the "untreated" conventional cotton crops. In terms of *Helicoverpa* spp. management, the conventional cotton crops located adjacent to the "treated" BollgardII® cotton crops received 7 pesticide sprays compared to 9 on the conventional crops near the "untreated" BollgardII® crops. This resulted in a pest control saving of $11.40 per ha in the "treated" over the "untreated" conventional cotton crops.

The study also showed no significant differences in the number of predatory insects recorded in Magnet® plus insecticide treated and untreated BollgardII® and adjacent conventional cotton crops indicating that the attracticide had no negative effect on predatory insects. The "treated" BollgardII® crop had 3 to 5 times more *Helicoverpa* spp. eggs per metre than the "untreated" BollgardII® cotton crop. The higher number of eggs recorded on the "treated" BollgardII® cotton crop could mean that the *Helicoverpa* spp. moths that were lured to the attracticide formulation on the BollgardII® crop, might have laid on the crop before ingesting the formulation and dying. This is in contrast to studies by Del Socorro *et al*. (2003) and Del Socorro and Gregg (2004) who reported lower egg lay of moths on cotton crops treated with Magnet attractant. Despite the high number of eggs laid on the "treated" BollgardII® cotton crop, the number of larvae per metre was not significantly different from the "untreated" BollgardII® cotton crop (control) indicating that the Bt toxin in the BollgardII® cotton crop might have killed any larvae that hatched from the eggs. Thus, the use of the "lure and kill" strategy on the BollgardII® cotton crop may not in any way put undue resistance development pressure on the BollgardII® technology.

One may speculate as to why we did not apply the Magnet® formulation to a refuge or conventional crop rather than the BollgardII® crop. The explanation given is that applying the formulation to the BollgardII® cotton crops ensures that if *Helicoverpa* spp. females lured to the treated zone laid eggs on the crop before ingesting the attracticide and die any larvae hatching out of the eggs may be killed by the toxin transgenic crop. In this way, *Helicoverpa* population is not being built up in the attracticide treated zone to spread to the surrounding cotton crops. *Helicoverpa* spp. population build up would occur if the attracticide is applied to refuge or conventional cotton crops resulting in additional pest control costs on the conventional cotton crops.

In this study, *Helicoverpa* spp. pressure in the study area during the 2005-06 season was significantly higher than the 2004-05 season. As a result, there was a high population of residual moths in both "treated" and "untreated" BollgardII® and conventional cotton crops in the study area despite high number of dead moths killed on the treated BollgardII® cotton crops. In fact, 3.04 *Helicoverpa* spp. larvae per metre per sample date, which was above the recommended larvae threshold of 2 per metre (Deutscher and Wilson, 1999) were recorded during the mid and late season in both "treated" and "untreated" conventional cotton crops. As a result, there was no pest control savings made on conventional cotton crops by using the lure and kill strategy in 2005-06 season. Therefore, the benefit to be gained in pest management on conventional cotton crops using the "lure and kill" strategy on BollgardII® cotton crops, may vary between seasons based on moth pressure and that the strategy may be used successfully only at low density target population (El-Sayed, 2009).

In general, the "lure and kill" strategy offers a number of advantages over foliar application of conventional insecticides to manage *Helicoverpa* spp. The application of the attracticide formulation used a comparatively small amount of synthetic insecticides compared with foliar application of insecticide when used to manage the same conventional crop. The formulation is targeted specifically and so there is no spray drift and also the quantity of insecticides applied is reduced resulting in minimal contamination of the environment. Furthermore, growers could save approximately $11.40 per hectare on their conventional crops by using the strategy under similar pest pressure conditions.

In conclusion, the study showed that application of a new moth attractant containing toxicant in a "lure and kill" strategy on BollgardII® cotton crops surrounded by conventional cotton conserved predators of *Helicoverpa* spp. and has the potential to supplement IPM program to reduce *Helicoverpa* spp. infestation and quantity of synthetic insecticide use in both conventional and transgenic cotton cropping systems.

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REFERENCES

Britton, D. R., Gregg, P. and Del Socorro, A. 2002. Attract and kill formulations for *Helicoverpa armigera* males (Lepidoptera: Noctuidae), pp. 259–265. *Proceedings 11th Australian Cotton Conference*, Brisbane, Queensland, Australia.

Charmillot, P. J. and Hofer, D. 1997. Control of codling moth, *Cydia pomonella* by attract and kill formulation. Technology Transfer in Mating Disruption. *IOBC WPRS Bulletin*, **20**: 139–140.

Charmilot, P. J., Hofer, D. and Pasquier, D. 2000. Attract and kill: a new method for control of the codling moth (*Cydia pomonella*). *Entomologia Experimentalis et Applicata,* **94**: 211–216.

Cunningham, R. T. and Steiner, L. F. 1972. Field trial of Cue-Lure and naled on saturated fibreboard blocks for control of the melon fly by the male-annihilation technique. *Journal of Economic Entomology,* **65**: 505–507.

Del Socorro, A. and Gregg, P. 2004. Attract-and-kill for *Helicoverpa* moths – a new tool for areawide pest management, pp. 721–728. In: *The 12th Australian Cotton Conference*, Broadbeach, Queensland, Australia.

Del Socorro, A., Gregg, P., Tennant, R. and Moore, C. 2003. Attract and kill heliothis for low pressure season. *Australian Cotton Grower,* **24**: 14–19.

De Souza, K. R. and McVeigh, L. J. 1992. Selection of insecticides for lure and kill studies against *Spodoptera littoralis* (Lepidoptera: Noctuidae). *Journal of Economic Entomology,* **85**: 2100–2106.

Deutscher, S. and Wilson, L. J. 1999. Insect thresholds on cotton (CottonLogic, Australian Cotton CRC, Narrabri, New South Wales, Australia).

Downham, M. C. A., McVeigh, L. J. and Moawad, G. M. 1995: Field investigation of an attracticide control technique using the sex pheromone of the Egyptian cotton leafworm, *Spodoptera littoralis* (Lepidoptera: Noctuidae). *Bulletin of Entomological Research*, **85**: 463–472.

El-Sayed, A. M., Suckling, D. M., Byers, J. A., Jang, E. B. and Wearing, C. H. 2009. Potential of "Lure and Kill" in long-term pest management and eradication of invasive species. *Journal of Economic Entomology*, **102**: 815–835

Fitt, G. P. 1989. The ecology of *Helicoverpa* in relation to agroecosystems. *Annual Review of Entomology,* **34**: 17–52.

Fitt, G. P. 1994. Cotton Pest Management: Part 3. An Australian perspective. *Annual Review of Entomology,* **39**: 543–562.

Grundy, P., Short, S., Hawes, A., Zalucki, M. and Gregg, P. 2006. Moth busting for Bt resistance management. In: *The 13th Australian Cotton Conference*, Broadbeach, Queensland, Australia, [CD ROM]

Haynes, K.F., Li, W. G. and Baker, T. C. 1986. Control of pink bollworm moth (Lepidoptera: Gelechiidae) with insecticides and pheromones (attracticide): Lethal and Sublethal effects. *Journal of Economic Entomology,* **79**: 1466–1471.

Hofer, D. 1997. Attract and kill: another step forward-first sales of Sirene® CM, pp. 8–9. In: Scheurer, R. (Ed.), *Insecticides Newsletter*. Novartis Crop Protection, Basel, Switzerland.

Jones, O. J. 1998. Lure and kill, pp. 280–299. In: Howse, P. E., Stevens, I. D. R. and Jones, O. T. (Eds.). *Insect Pheromones and their use in pest management*. Chapman and Hall, London, UK.

Langley, P. A., Felton, T., Stafford, K. and Oouch, H. 1990. Formulation of pyriproxifen, a juvenile hormone mimic, for tsetse control. *Medical and Veterinary Entomology,* **4**: 127–133.

Mensah, R. K. 2002. Development of an integrated pest management programme for cotton. Part 1: establishing and utilising natural enemies. *International Journal of Pest Management,* **48**: 87–94.

Mensah, R. K. 2000. Conservation and utilization of beneficial insects for pest management programs in cotton systems in Australia. *ICAC Recorder,* **28**: 8–14.

Mensah, R. K. 1999. Habitat diversity: implications for the conservation and use of predatory insects of *Helicoverpa* spp. in cotton systems in Australia. *International Journal of Pest Management*, **45**: 91–100.

Mensah, R. K. and Wilson, L. J. 1999. *Integrated pest management guidelines for Australian cotton.* In: EntoPak. *CRC publications*, Australian Cotton Research Institute, Narrabri, NSW, Australia.

Miller, E. R., Saten, R. T., Nowell, C. and Gourd, J. 1990. Pink bollworm (Lepidoptera:Gelechiidae): point source density and its relationship to efficacy in attracticide formulations of gossyplure. *Journal of Economic Entomology,* **83**: 1321–1325.

Pell, J. K., Macaulay, E. D. M. and Wilding, N. 1993. A pheromone trap for the dispersal of the pathogen *Zoophthora radicans* Brefeld amongst populations of the diamond back moth *Plutella xylostella* L. *Biocontrol Science and Technology,* **3**: 315–320.

Pyke, B., Rice, M., Sabine, G.. and Zalucki, M. 1987. The push-pull strategy-behavioural control of *Heliothis*. *Australian Cotton Grower,* **9**: 7–9.

Suckling, D. M., and Brockerhoff, E. G. 1999. Development of an attracticide against light brown apple moth (Lepidoptera: Tortricidae). *Journal of Economic Entomology,* **92**: 853–859.

Wilson, L. J., Mensah, R. K. and Fitt, G. P. 2005. Implementing integrated pest management in Australian cotton, pp. 97-117. In: Ishaaya, I. (Ed.). *Insect Pest Management: Field and Protected Crops*, Springer-Verlag, Berlin, 344 pp.

Welham, S. W. and Liburd, O. E. 2006. Mating disruption and attract and kill as reduced risk strategies for control of grape root borer in Florida vineyards. *Florida Entomologist,* **89**: 245–250.