Chapter Six

Insecticide Use in Soybean and Predator Abundance.

Introduction

The use of synthetic insecticides is currently the primary control method for *Helicoverpa* spp. in grain crops. Whilst the problems associated with widespread insecticide use are well known, this practice looks set to continue for some time into the future. This fact alone may cause the reader to dismiss predators as an effective component of IPM. However, the development of selective biopesticides, such as Bt and NPV (e.g. Gemstar®), provides opportunities for the use of predators as well as other beneficials. Spray thresholds (Mensah 1999) and the introduction of unsprayed refuge areas support a less pessimistic view of predator incorporation into management systems (Shaw & Watson 2001). Furthermore, a growing number of investigations into the responses of predators to insecticides may provide new methods for minimising the negative effects of spraying on beneficials (Grundy *et al.* 2000, Ma *et al.* 2000, Scholz 2000). Based on our current minimal knowledge of the impact of insecticides on predators it would be presumptuous to dismiss the use of predators in an IPM program at this stage.

Investigations into the impacts of insecticides on beneficials usually take the form of laboratory based exposure studies or field based sampling of abundance. Croft (1990) reviews the majority of studies in this area. Less published information exists for Australian agroecosystems and this has been reviewed by Johnson *et al.* (2000).

Various pesticides have been tested in the laboratory against first-instsr *Pristhesancus plagipennis* Walker nymphs (Wade 1999). Initial toxicity as well as development rates were assessed for each of eleven chemicals. Nymphs were found to be moderately tolerant to pesticides, and developmental time was not significantly affected. The impact of insecticides on *P. plagipennis* was further investigated by Grundy *et al.* (2000).

Lytton-Hitchins (1998) examined springtails, soil-dwelling beetles, ants, and earwigs in Narrabri cotton fields under different management regimes. Insecticide usage influenced species diversity and abundance of these soil-dwelling arthropods. In a separate study in cotton at Narrabri, only two of the 13 foliar insecticides tested had a low impact on predacious ants (Lytton-Hitchins & Wilson 1999). Scholz (2000) examined predators on sweet corn crops sprayed with conventional and selective insecticides. Deltamethrin and methomyl were extremely disruptive, reducing predator numbers to virtually zero. Wilson *et al.* (1998) examined the role of predators in *Tetranychus urticae* Koch population dynamics in cotton.

In crops that were treated with thiodicarb, dimethoate or methomyl outbreaks of *T. urticae* developed earlier and reached greater densities. This was attributed to the lower densities of predators in these plots.

Results of both laboratory and field studies have lead to extension materials which provide the grower with a general idea of the impact of major pesticide groups on different predator groups (Wilson *et al.* 1999, 2002). Whilst such tables are valuable, more detailed information is needed in order to effectively integrate predators into IPM programs. Furthermore, most of the extension material available is based on research in cotton, and may not be transferable to other crops.

<u>Spiders and insecticides</u>

In most insecticide studies mentioned above spiders were lumped together and assessed as one group (if at all). Studies have shown that spider species react differently to insecticide exposure (Mansour & Nentwig 1988). Stark *et al.* (1995) has reviewed most of the overseas laboratory and field-based research I refer to in the following paragraphs. We are only just beginning to understand the many factors that determine a particular species susceptibility to different insecticides.

Samu *et al.* (1992) argued that web-building spiders might be more susceptible to insecticides than hunting spiders. The authors examined uptake of insecticides by orb webs of *Araneus diadematus* Clerck. The webs were especially efficient at collecting small droplets and they concluded that spiders that consume their web might be exposed to accumulated insecticide. However, Pekar (1999) found that hunting spiders were more susceptible to insecticides tested than web-building spiders. Foraging mode and time (diurnal or nocturnal) appear to be factors that affect sensitivity to insecticides. Laboratory tests by Mansour and Nentwig (1988) and Mansour *et al.* (1992) support this conclusion.

Only a few laboratory studies have documented the sublethal effect of insecticides on spiders. Toft and Jensen (1998) found that when wolf spiders, *Pardosa amentata* (Clerck), were given high doses of two insecticides the surviving spiders suffered paralysis for one to two days. After this time, no further effects on growth rate and predation rate were observed. This study showed some evidence of enhanced performance (in terms of feeding activity) by the spiders treated with the insecticide.

Field studies on insecticide effects on spiders have shown differential toxicity to groups of spiders or spider species. In the Linyphiidae toxicity to a deltamethrin spray in wheat varied from 89 percent mortality to six percent mortality for different species (Thomas *et al.* 1990). Bostanian *et al.* (1984) found hunting spiders to be more sensitive to insecticides than web-building species in Quebec apple orchards. The more mobile hunting spiders may have been deterred from the pesticide-treated trees because of the presence of the noxious insecticide or the lack of suitable prey. In another study of the ground-dwelling spider community of apple orchards in Hungary no significant differences were found between conventional and IPM plots (Bogya & Marko 1999). Greater spider densities were recorded in tree rows where weed coverage was higher. These results may have been due to the use of pesticide treatments directed at the tree canopy. The ground-dwelling spiders appear to be unaffected by these sprays. Wisniewska and Prokopy (1997) found that insecticides, even if applied only early in the season, have a marked season-long negative effect on spider populations in commercial apple orchards.

These field studies highlight that different spider species react differently to insecticides and these responses are affected by crop type. If spiders are to attain their maximal numbers, and so contribute significantly to pest control, their response to other components of the IPM program (such as insecticide use) must be better understood. This study aims to determine what impact an insecticide spray has on the whole predator community, individual predator groups and Araneae families in a soybean field. Samples were collected before and a number of days after spraying to determine the time taken for predator populations to recover. It was anticipated that lucerne fields on two sides of the soybean would provide a source of arthropods to recolonise the field after spraying. To investigate this the spatial patterns in arthropod abundance at each time point were analysed.

Materials and methods

Soybeans (Cawana variety) were sown in the last week of December 2000 and harvested in the first week of May 2001 in Horti field (3.2 ha) (fig. 1). Rows were spaced 75cm apart, inter-row cultivated once to control weeds and irrigated when necessary. No insecticides were sprayed on soybeans or adjacent lucerne and surrounding fields with the exception of the treatment spray.

The field was divided into 10 sub-plots measuring 80 metres by 40 metres (fig. 1). A five metre grassy road, which was mowed prior to the treatment spray, separated the plots. In each of these plots five vacuum samples of two metres of soybean row were collected at each sampling date. The vacuum sampler was a converted Echo PB2105 leaf blower with black pipe (diameter 12 cm) inserted over the exhaust fan into which a collection bag was attached by an elastic band. The collection bag (20cm diameter opening, 40cm length) was made out of a fine mesh (0.5mm) material. The soybean was sampled by slowly moving the vacuum nozzle through the foliage and up and down the plant stems. The collection bags were removed from the nozzle while the vacuum was still running and sealed. The bags were kept chilled until they were returned to the laboratory and placed in a freezer overnight to kill the arthropods.

Samples were collected along a transect running through the centre of the plot at 10, 20, 40, 60, and 70 metres. Sampling commenced at 9:00am in the morning and was finished by 12:00 noon. Foliage-dwelling arthropods were sampled six days prior to treatment spray and then, one day, three days, six days, ten days and twenty days after the spray.

Five of the 10 plots were sprayed with a synthetic pyrethroid (Deltamethrin), Decis Options™ (supplied by Aventis Crop Science Pty. Ltd.). A synthetic pyrethroid (Deltamethrin) was chosen for this study because it is considered to be highly toxic to most predator groups in cotton (Wilson *et al.* 1999, 2002). This chemical is commonly used to control *N. viridula* and other pod-sucking bugs as well as *Helicoverpa* spp. in grain crops (Lucy & Mills 2000). The treatment plots were sprayed with a standard boom sprayer at one litre per hectare, which is double the recommended rate. To minimise spray drift into the control blocks spraying was conducted in the evening, and a five metre buffer zone around the edges of the blocks was left unsprayed.

Due to the large number of samples collected during this experiment a rapid sorting protocol was employed. This involved emptying the vacuum sampler bags into a white tray and counting all arthropods visible to the naked eye. The arthropods were identified to species where possible, and spiders to family level. Smaller arthropods, such as some parasitoids (e.g. *Trichogramma* wasps) and juveniles of some insects, were overlooked using this protocol.

Counts of spider webs present in both control and treated plots were conducted at three, six, 10 and 20 days after spraying to quantify the effect of the insecticide on web-building activity. Early in the morning (approximately 6:00am) each plot was searched for 10 minutes by walking at a constant pace between the soybean rows. The number of webs encountered was recorded and specimens of the common spiders collected and stored in 70 percent ethanol for later identification. Care was taken not to destroy the webs (by walking through them) after they had been recorded.

Lycosidae pitfall trap data

Data on Lycosidae abundance collected as part of a mark-recapture experiment (see Chapter five) was used in the analysis. Pitfall traps placed within each plot (n = 16 in control plots, n = 20 in the sprayed plots) was checked over two to three days throughout the season and the numbers of Lycosidae spiders trapped recorded. Spiders caught in three sampling dates prior to spraying and three sampling dates after spraying was totalled and used in the analysis.

Plant damage

Damage to the soybean plants was assessed before spraying and 20 days after spraying. An assessment of leaf area loss and pod damage was made in each of the plots. At each of the five transect locations 10 leaves were randomly selected and leaf area loss estimated as a percentage. This gave an average leaf area loss per plot derived from 50 leaves. At each point 10 soybean seedpods were collected, and the number of seeds with suspected insect damage recorded as a percentage. This gave average pod damage per plot derived from 50 pods.

Data analysis

Arthropods were grouped into pests, predators and Araneae for data analysis. The data was transformed prior to analysis for normality. For Predators and Araneae the data was square root transformed and pest data was transformed by the natural logarithm. A repeated measures ANOVA was used to test if there was any significant difference between the arthropod abundance in the treated and control plots at all sampling dates. Plot number and sampling location (transect location) within each plot were also included in the model. The test was performed in the statistical program S-Plus. Spatial patterns in the recolinisation of the sprayed and control plots at each sampling date were mapped using the GIS package, ArcView. This program interpolates between sampling points to produce a contour map. The final set of points on the edge of the soybean field (plots one, two nine and 10) are only half complete (see fig. 5 and 6) because there was not another set of sampling points beside them.

The effect of insecticide on the main groups of pests and predators was compared using an impact rating. Total arthropod numbers collected in all five treatment plots and all five control plots (total per 50m vacuum sample) were used in the analysis. The impact rating was calculated using the following formula:

Impact rating = (control after spray, day 1 – control before spray, day 0) – (treatment after spray, day 1 – treatment before spray, day 0)

This allowed the abundance of arthropods in each plot prior to spraying to be taken into consideration.

A mortality estimate, which took into account control mortality based on Abbott's formula, was also employed (Fleming & Retnakaran 1985, Abbott 1925). The average arthropods collected per two metre vacuum sample over all five control plots and all five sprayed plots was used in the analysis. Abbott's formula expressed as a percentage is:

$$\text{Corrected \% population reduction} = \left[1 - \frac{\text{After spray Treatment plots}}{\text{Before spray Treatment plot}} * \frac{\text{Before spray Control plots}}{\text{After spray Control plots}}\right] * 100$$

A third impact rating (treatment mortality) was calculated for those arthropod groups in which there was an increase in the numbers in the control plots after spraying. The change in control plots was treated as zero and percentage mortality was calculated only from figures recorded in treated plots. Mean values were again used in this analysis.

The impact of the insecticide spray on different predator groups, spider families and pest groups was graphically displayed using bar charts of the change in abundance before and after spraying in the control and the sprayed plots. Total number of each arthropod group caught after spraying was subtracted from total number caught before spraying. Therefore negative bars indicated that abundance of a particular predator group decreased after spraying with insecticide.

Total numbers of spider webs built at three, six, 10 and 20 days after spraying was recorded for each plot. A repeated measures ANOVA was used to compare the spider webs recorded in the control and the sprayed plots at each sampling date. The analysis was performed on data transformed by the natural logarithim for normality.

The difference between the numbers of Lycosidae spiders caught in pitfall traps prior to spraying and after spraying in the treated plots was assessed using a nonparametric one-way ANOVA (Kruskal-Wallis rank sum test). The same test was repeated for the control plots. The same method was used to assess plant damage (leaf area loss and pod damage) before and after spraying with insecticide. Plant damage increased in all plots from pre-spray check to post-spray check that was conducted 20 days after spraying. This was expected because leaf area loss is a cumulative measure of plant damage. A Kruskal-Wallis rank sum test was used to compare mean leaf area loss in sprayed and control plots before spraying. A separate test was then performed on mean leaf area loss in the sprayed and control plots after spraying. This method was repeated for the pod damage estimates. All statistical analysis was performed in the program S-Plus.

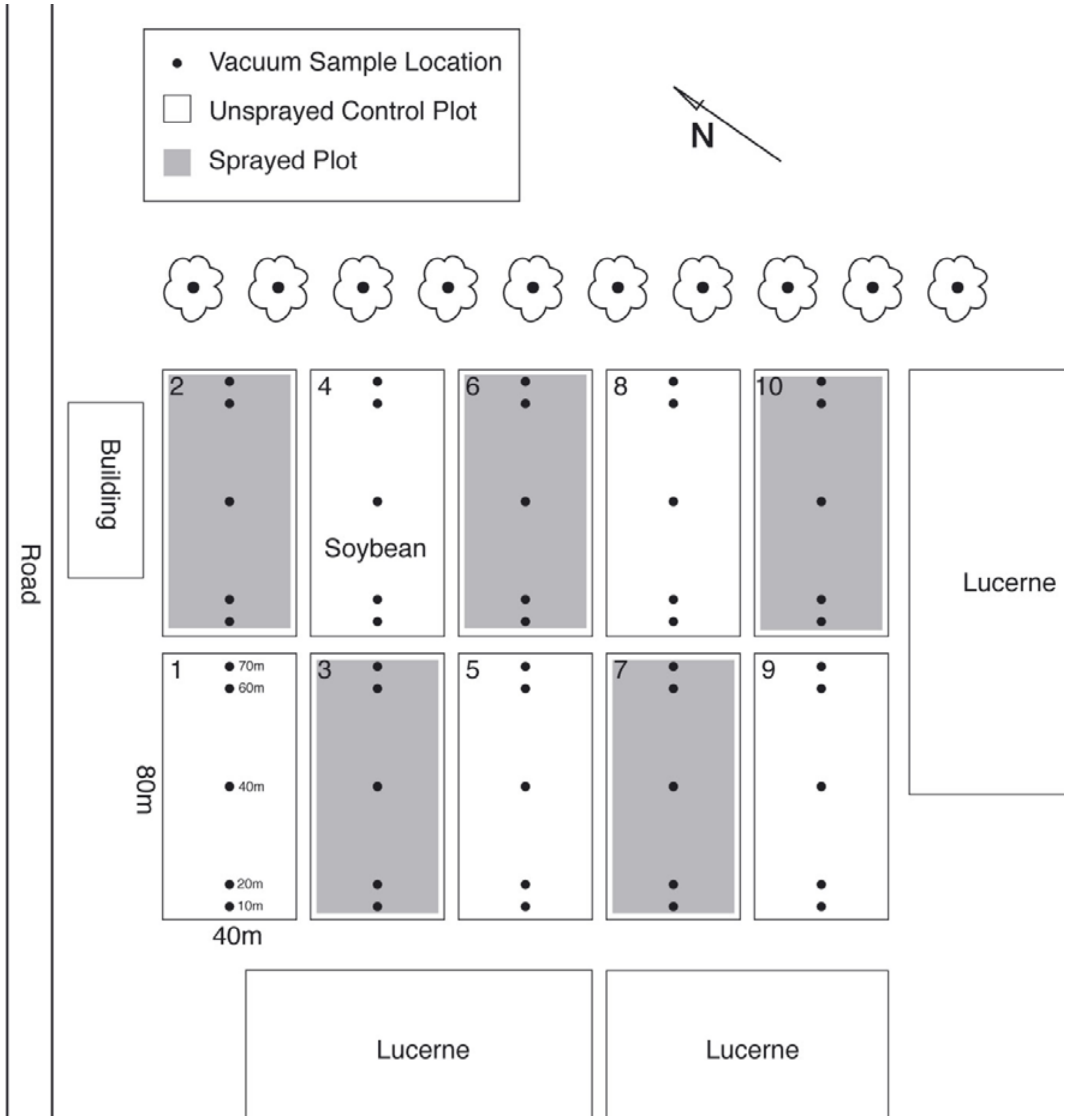


Figure 1. The Horti field site (2001/02). Shows location of treatment (sprayed) and control plots for insecticide exclusion experiment, and location of five sampling points in each plot. At each sampling point a vacuum sample from a 2m row of soybean plants was collected before spraying (day 0) and 1, 3, 6, 10 and 20 days after spraying. In each of the sprayed plots an unsprayed buffer zone of 5m was left around the edge of the plots.

Results

Arthropod population response to insecticide spray

The insecticide spray reduced populations of predators (fig. 2), Araneae (fig. 3) and pests (fig. 4) in soybean. There was a significant effect of insecticide treatment on the numbers of predators ($F_{1,8}$ = 45.96, P < 0.01), Araneae ($F_{1,7}$ = 30.16, P < 0.01), and pests ($F_{1,8}$ = 71.43, P < 0.01). In the treated plots numbers of predators, Araneae and pests were reduced from pre-treatment levels one day after spraying. In control plots, predators and Araneae numbers decreased one day after spraying, but pests increased one day after spraying, from a mean of 13.7 (± 1.4 standard error) before spray to 21.8 (± 3.2) after spray. Predator and Araneae numbers did not return to pre-treatment levels even 20 days after spraying in treated plots. Control plots showed a gradual decrease in predator numbers with time. A similar trend was observed for pest arthropods. There was a significant effect of sampling date and a significant interaction between sampling date and treatment (sprayed or control) for predators (date $F_{5,200}$ = 15.82, P < 0.01, interaction $F_{5,200}$ = 4.29, P < 0.01), and pests (date $F_{5,200}$ = 19.24, P < 0.01, interaction $F_{5,200}$ = 15.37, P < 0.01). There was a significant effect of sampling date on Araneae abundance ($F_{5,199}$ = 2.35, P = 0.042) but no interaction effect between sampling date and treatment ($F_{5,199}$ = 1.25, P = 0.28).

There were no clear spatial patterns in recolonisation of sprayed plots by pests (fig. 5) or predators (fig. 6). It was anticipated that the sprayed plots adjacent to the lucerne fields would be first to regain arthropods due to movement from lucerne into soybean. However, the maps shows no such trend. This conclusion is supported by the ANOVA that showed no significant effect of sampling site within plots on predator ($F_{4,32}$ = 0.56, P = 0.69), Araneae ($F_{4,31}$ = 1.50, P = 0.23) and pest ($F_{4,32}$ = 1.07, P = 0.39) abundance. Plot two, which was furthest plot away from the lucerne (see fig. 1), showed the first signs of increased pest and predator numbers at three days post spraying. For the pest group this was primarily due to the collection of a group of *N. viridula* immatures (29 in two metre vacuum sample) newly hatched from an egg raft. Predator and pest numbers in sprayed plots did not return to pre-spray levels even 20 days after spraying.

Arthropod groups affected by insecticide

The predator population collected in the soybean using a vacuum sampler prior to spraying was mainly composed of Coleoptera (41%, mainly Coccinellidae adults 20% and larvae 20%) and Araneae (34%) (table 1). For the Araneae the most abundant were Oxyopidae (33%)

(table 2). Pests consisted mainly of jassids (70%) and Lepidopteran larvae (20%) such as the cluster caterpillar, loopers and *Helicoverpa* spp. (table 3). *Helicoverpa* spp. pests had not reached the spray threshold of two larvae per square metre, and pod sucking bugs were present but in low numbers.

An impact rating was used to standardise the mortality due to insecticide sprays by including mortality (and population growth) recorded in control plots (table 4). Pest arthropods (from 14 for pest Coleoptera to 392 for pest Hemiptera) had a higher impact rating than the predatory arthropods (from four for Neuroptera to 34 for predatory Hemiptera). This is supported by Abbott's corrected mortality estimate that was higher for pest arthropods (predators 78%, pests 84%). Pest arthropod numbers increased in control plots after the insecticide spray, which may bias Abbott's mortality estimate. Of the predatory groups the Hemiptera had the highest impact rating (34, fig. 7). This was not due to excessive mortality in treated plots but an increase in control plots. Araneae and Formicidae had the next highest impact rating (19 and 18 respectively). This was due to high mortality levels in treated plots. The population of predatory Coleoptera decreased in both treated and control plots. Neuroptera and Syrphidae where largely unaffected by the spray, but their overall numbers were low throughout the experiment. If we use the corrected mortality estimates, Neuroptera (100%) and predatory Coleoptera (94%) had the greatest percentage mortality due to insecticide spray (table 4). Of the Araneae collected Araneidae and Oxyopidae had the highest impact rating (Table 4, fig. 7). This was due to a combination of high mortality in treated plots and an increase in control plots. Clubionidae had a low impact rating because large mortality was observed in both the treated and control plots.

Of the pest groups present the Hemiptera (mostly jassids) had the greatest impact rating (table 4, fig. 8). An increase was recorded in control plots and a similar decrease was recorded in treated plots. This suggests that Hemiptera moved from treated plots to the control plots, rather than population increase. Abbott's corrected mortality estimates showed that Lepidoptera (32%) and pest Coleoptera (100%) had the highest mortality due to the insecticide.

<u>Web-building Araneae</u>

During arthropod collection before and one day after spraying it was observed that there were more webs being built in control plots than treated plots (fig. 9). This observation was quantified by counting webs found during a 10 minute search of each plot. There were three dominant Araneidae species recorded in the soybean crop *Neoscona theisii* (Walckenaer), *Austracantha minax* (Thorell), *Larinia phthisica* (L. Koch) all of which built vertical orb-webs. A single Tetragnathidae species *Leucauge* sp. was present and built a horizontal orb web. There was a significant decrease in the number of webs being built in treated plots at all sampling dates (treatment $F_{1,8}$ = 64.92, P < 0.01, sampling date $F_{3,24}$ = 30.50, P < 0.01). Despite being unable to compare with pre-treatment figures insecticide appears to have significantly decreased the number of webs being built in sprayed plots. The greatest difference between webs recorded in sprayed plots (16.2 ± 0.86) and control plots (44.4 ± 3.91) was recorded at six days after spraying. On this particular morning the temperature had remained high thoughout the previous night. No condensation (dew) was found on the plants, and spiders where still very active into the morning. The weather conditions may have encouraged more spiders to build webs and remain in them for longer. Web density in treated plots remained low even at 20 days after spraying.

<u>Lycosidae pitfall trap data</u>

There was a reduction in numbers of Lycosidae captured in both control and treated areas after spraying (fig. 10). The reduction in treated plots was proportionally greater. There was no significant difference found between mean spiders captured in control plots before and after spraying (H_{16} = 1.10, P = 0.29). Comparison of mean spiders captured in sprayed plots before and after spraying was also not statistically significantly different (H_{20} = 2.94, P = 0.09). Mortality due to the insecticide spray was 75 percent after correction for control mortality using Abbott’s formula.

<u>Plant damage</u>

Damage to plants throughout the season was very low. Leaf area loss never reached more than 10 percent (fig. 11) and pod damage was never higher than 12 percent, regardless of treatment or plot location (fig. 12). Before spraying with insecticide mean leaf area loss in control plots (mean 2.95 ± 0.27 standard error) was slightly lower than in sprayed plots (3.32 ± 0.45). However, this difference was not significant (H_{24} = 0.32, P = 0.57). After spraying mean leaf area loss in control plots (6.28 ± 0.44) was slightly higher than in sprayed plots (5.14 ± 0.45) and this difference was significant (H_{24} = 4.05, P = 0.04). Before spraying with insecticide mean pod damage in control plots (1.52 ± 0.67) was lower than in sprayed plots (2.77 ± 0.92). This difference was not significant (H_{24} = 0.74, P = 0.39). After spraying the mean pod damage in the control plots (3.18 ± 0.76) was higher than in the sprayed plots (1.80 ± 0.57) but this difference was not significant (H_{24} = 1.72, P = 0.19).

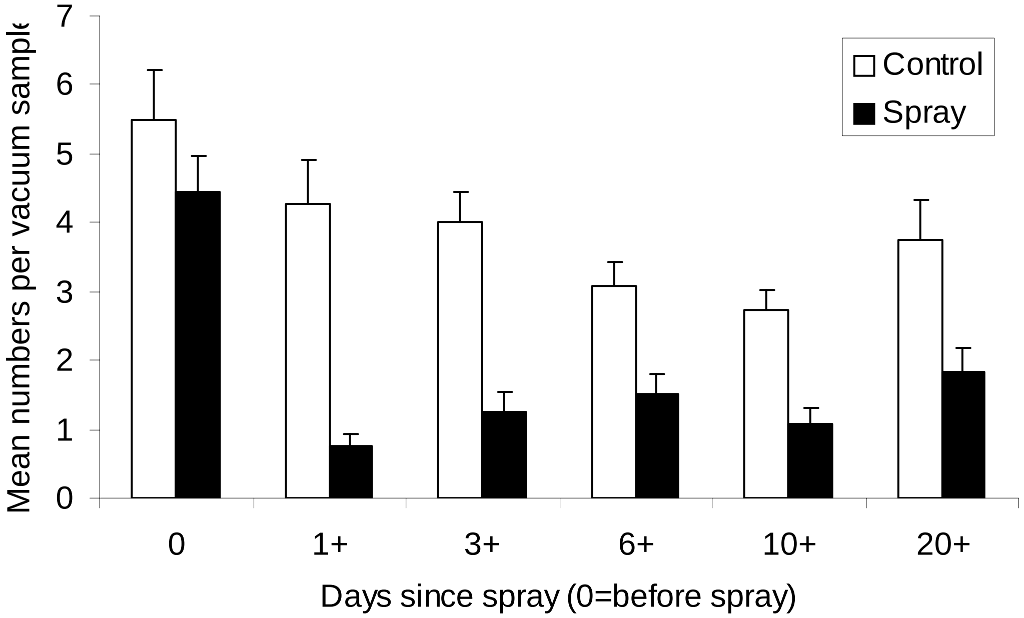


Figure 2. Arthropod predators caught in vacuum samples from soybean before (time 0) and 1, 3, 6, 10, and 20 days after spraying with an insecticide. Five two metre vacuum samples were collected per plot and there was five control plots and five sprayed plots. Bars indicate standard error.

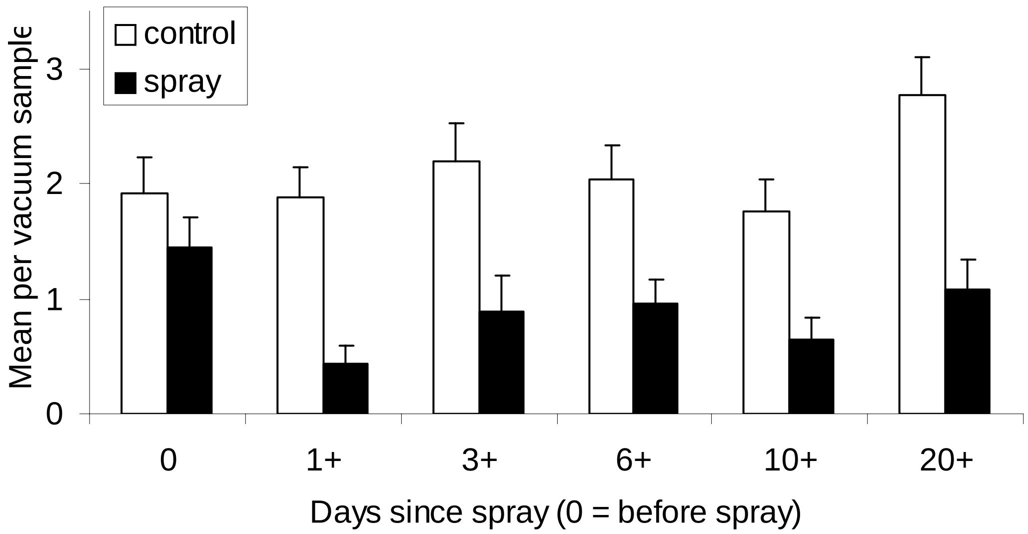


Figure 3. Araneae caught in vacuum samples from soybean before (time 0) and 1, 3, 6, 10, and 20 days after spraying with an insecticide. Five two metre vacuum samples were collected per plot and there was five control plots and five sprayed plots. Bars indicate standard error.

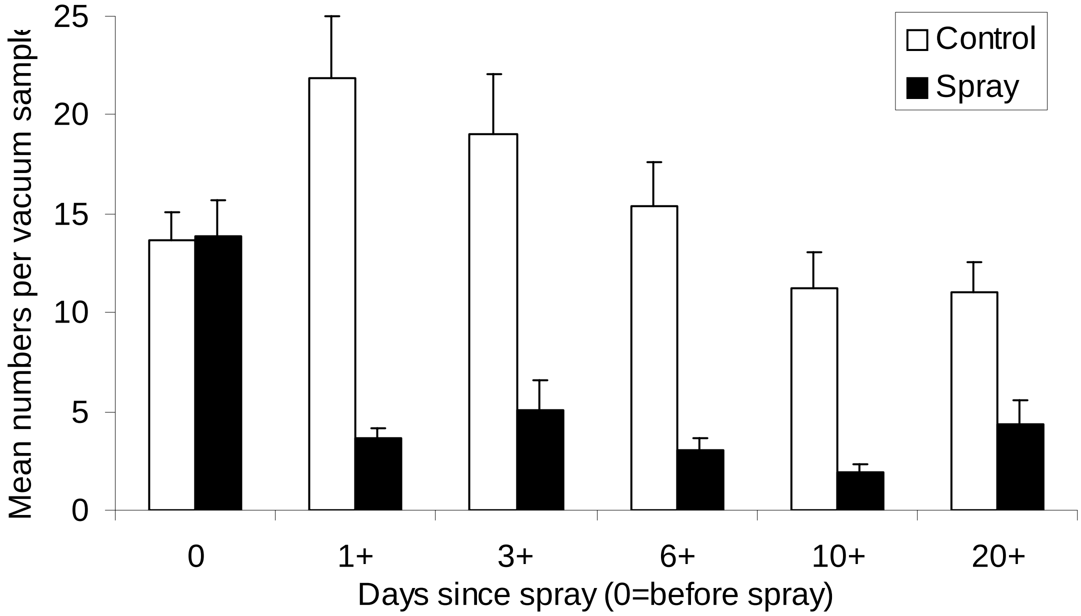
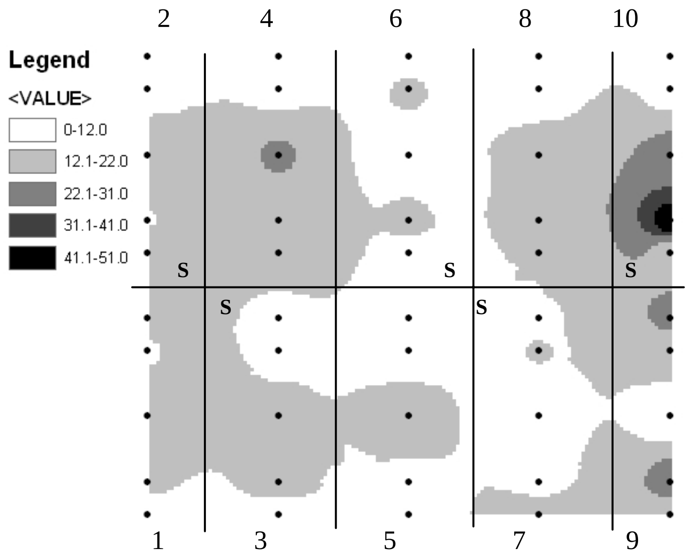
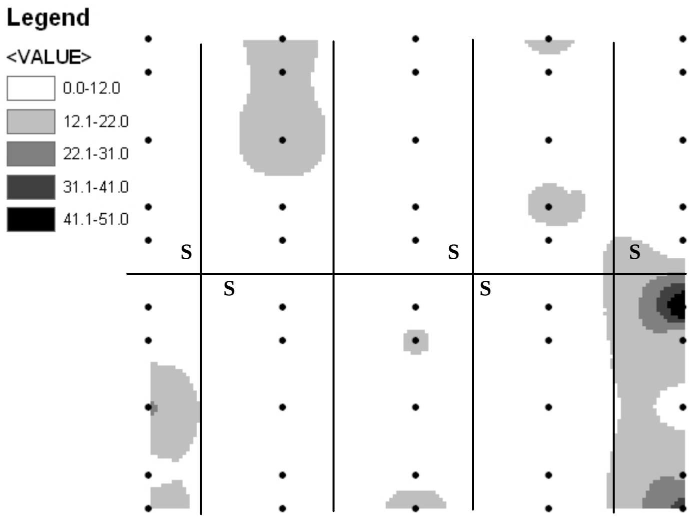


Figure 4. Arthropod pests caught in vacuum samples from soybean before (time 0) and 1, 3, 6, 10, and 20 days after spraying with an insecticide. Five two metre vacuum samples were collected per plot and there was five control plots and five sprayed plots. Bars indicate standard error.

Pests at time 0.



Pests time 1.



Pests time 3.

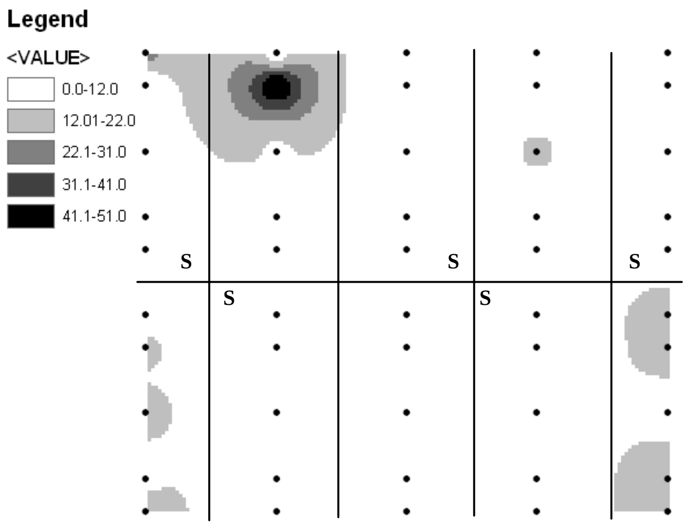
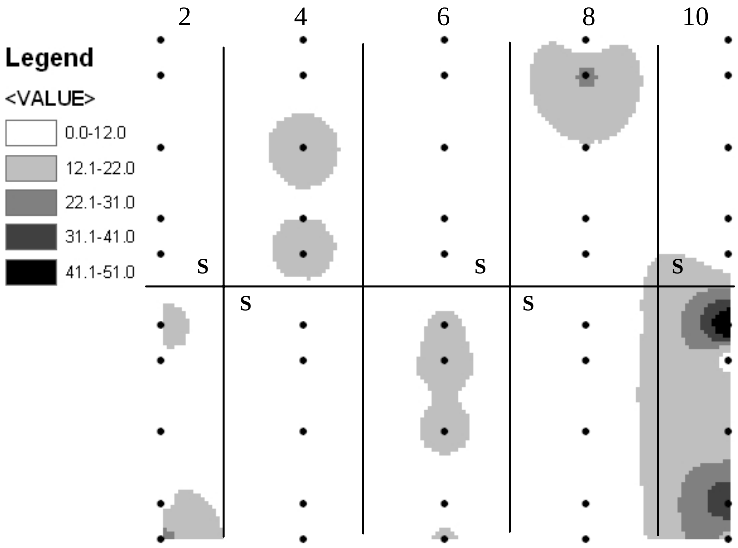
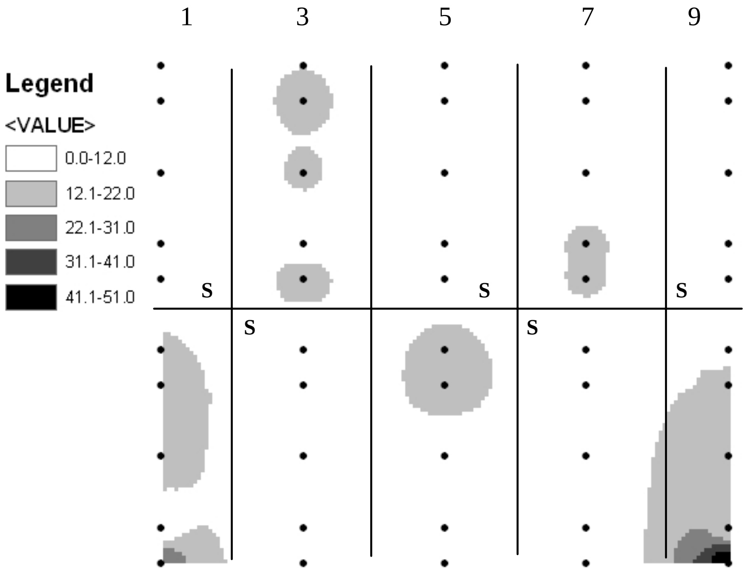


Figure 5. Spatial patterns in pest arthropod abundance within a soybean field before (time 0) and 1, 3, 6, 10 and 20 days post spraying with an insecticide. Plot numbers are shown on the top graph and an **S** indicates the plot was sprayed with insecticide.

Pests time 6.



Pests time 10.



Pests time 20.

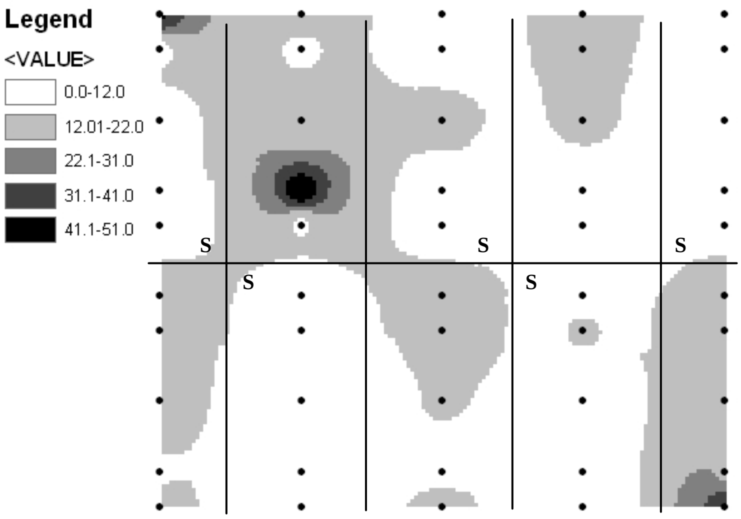
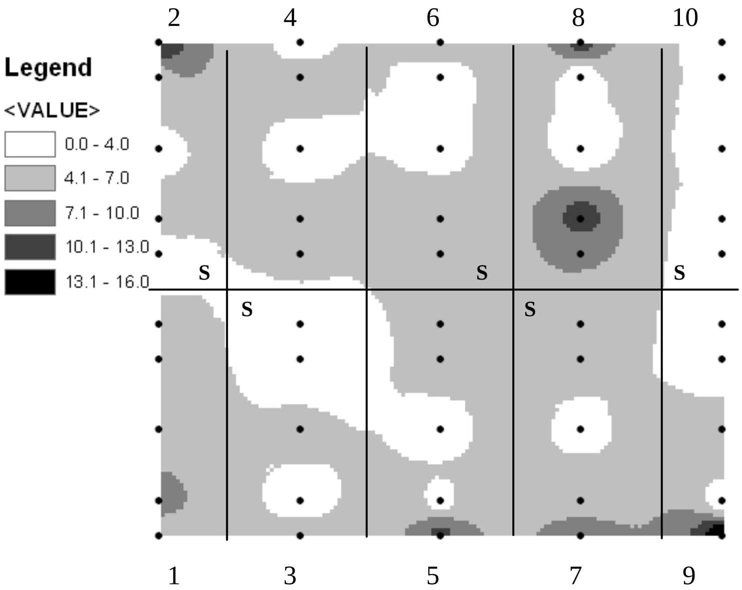
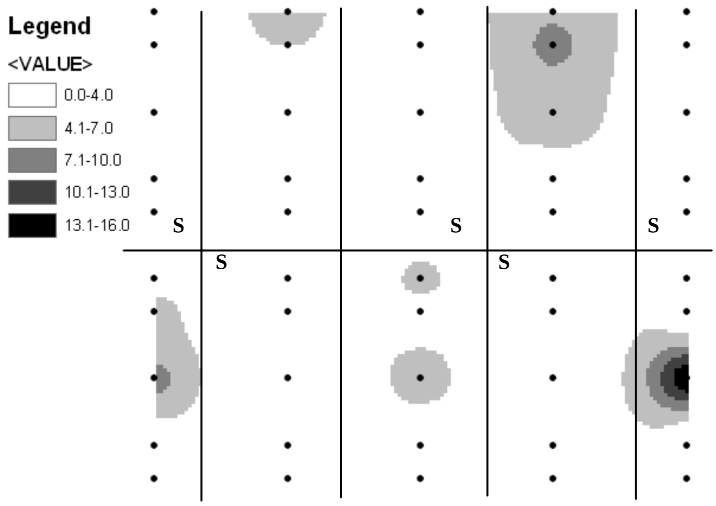


Figure 5. continued….

Predators time 0.



Predators time 1.



Predators time 3.

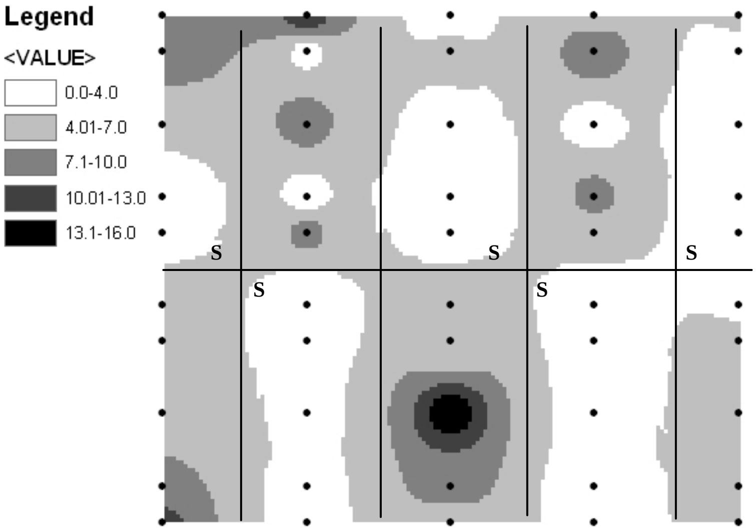
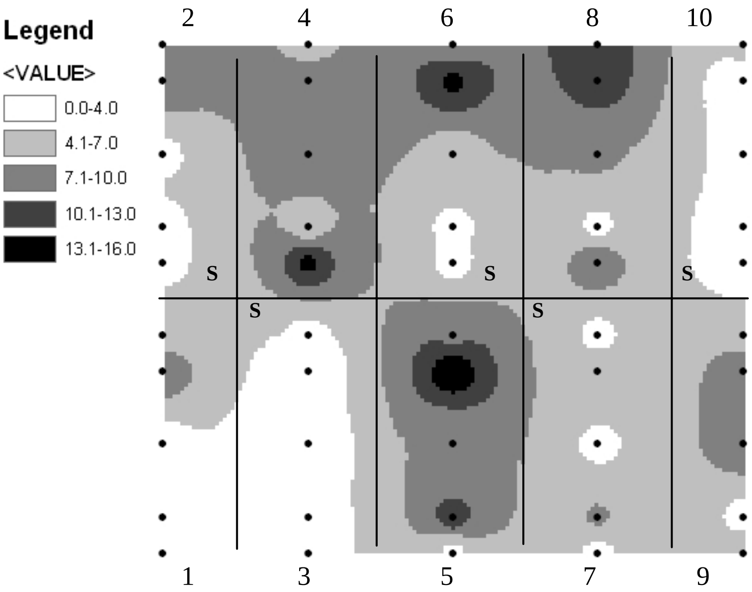
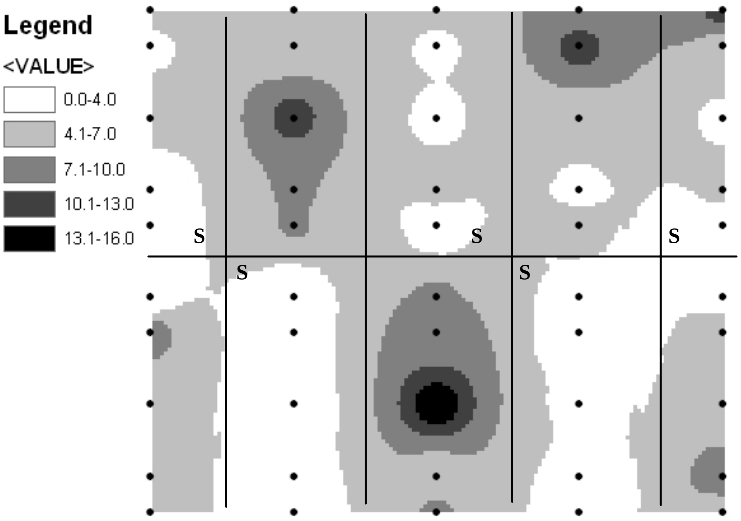


Figure 6. Spatial patterns in predator abundance within a soybean field before (time 0) and 1, 3, 6, 10 and 20 days post spraying with an insecticide. Plot numbers are shown on the top graph and an **S** indicates the plot was sprayed with insecticide.

Predators time 6.



Predators time 10.



Predators time 20.

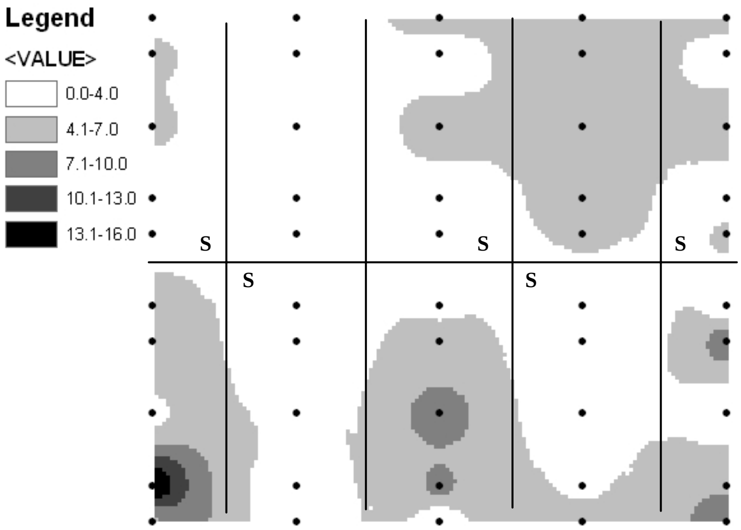


Figure 6. continued….

Table 1. Composition of arthropod predators caught in vacuum samples from soybean prior to spraying with an insecticide. Total is calculated from control and treated plots.

	Total (all plots)	%
Predatory Coleoptera	103	40.6
Araneae	87	34.3
Formicidae	37	14.6
Predatory Hemiptera	19	7.5
Neuroptera	5	1.9
Syrphidae	3	1.2

Table 2. Composition of Araneae caught in vacuum samples from soybean prior to spraying with an insecticide. Total is calculated from control and treated plots. Unidentified spiders were removed from the analysis.

	Total (all plots)	%
Oxyopidae	21	33.3
Araneidae	15	23.8
Clubionidae	14	22.2
Tetragnathidae	7	11.1
Thomisidae	3	4.8
Theridiidae	2	3.2
Salticidae	1	1.6

Table 3. Composition of arthropod pests caught in vacuum samples from soybean prior to spraying with an insecticide. Total is calculated from control and treated plots.

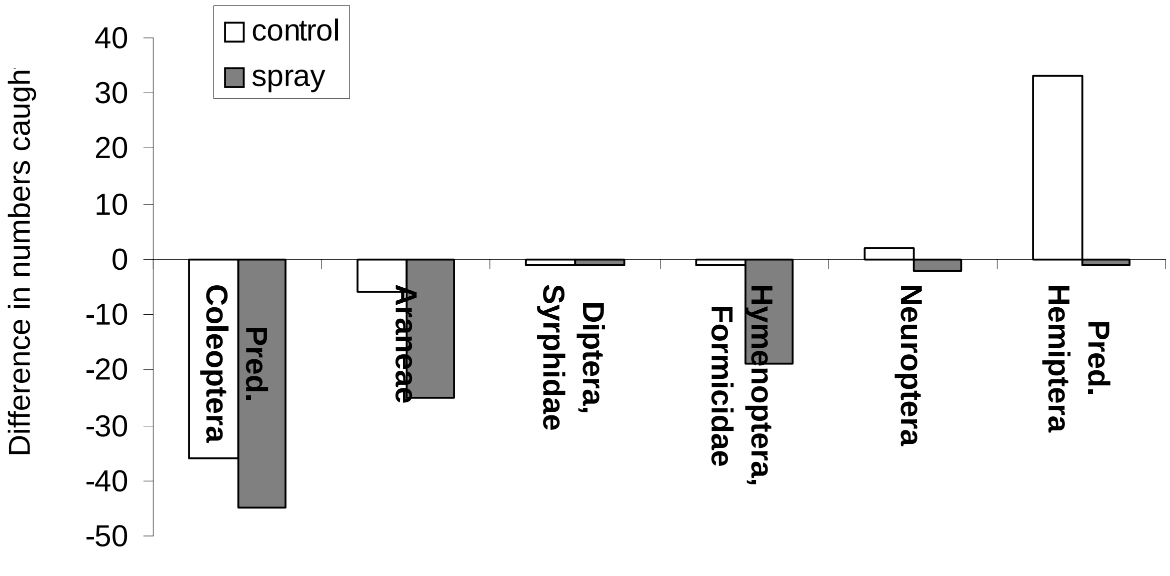
	Total (all plots)	%
Jassids	440	69.9
Other Lepidoptera	126	20.0
Other Hemiptera	46	7.3
Pest Coleoptera	7	1.1
Helicoverpa spp.	6	1.0
Black field cricket	4	0.6

Table 4. Two methods for assessment of the impact of an insecticide on arthropod groups. Data was collected from vacuum samples in soybean before spraying and one day after spraying with insecticide. See methods for explanations of how each rating system is calculated.

Arthropods	Impact rating	Abbott's formula (% mortality)	Treatment mortality
Total Pests	455	84%	74%
Pest Hemiptera	392	12%	78%
Lepidoptera	49	32%	55%
Pest Coleoptera	14	100%#	
Orthoptera, Gryllidae	0	0%#	
Total Predators	101	78%	
Predatory Hemiptera	34	80%	11%
Hymenoptera, Formicidae	18	85%	
Predatory Coleoptera	10	94%	
Neuroptera	4	100%#	
Diptera, Syrhidae	0	0%#	
Araneae	19	65%	
Araneidae	9		
Oxyopidae	8		
Unknown Araneae	5		
Tetragnathidae4			
Theridiidae	2		
Pisauridae	2		
Salticidae	1		
Thomisidae	1		
Clubionidae	1		

#Indicates very low numbers in both treatment and control plots

A. Predators



B. Araneae

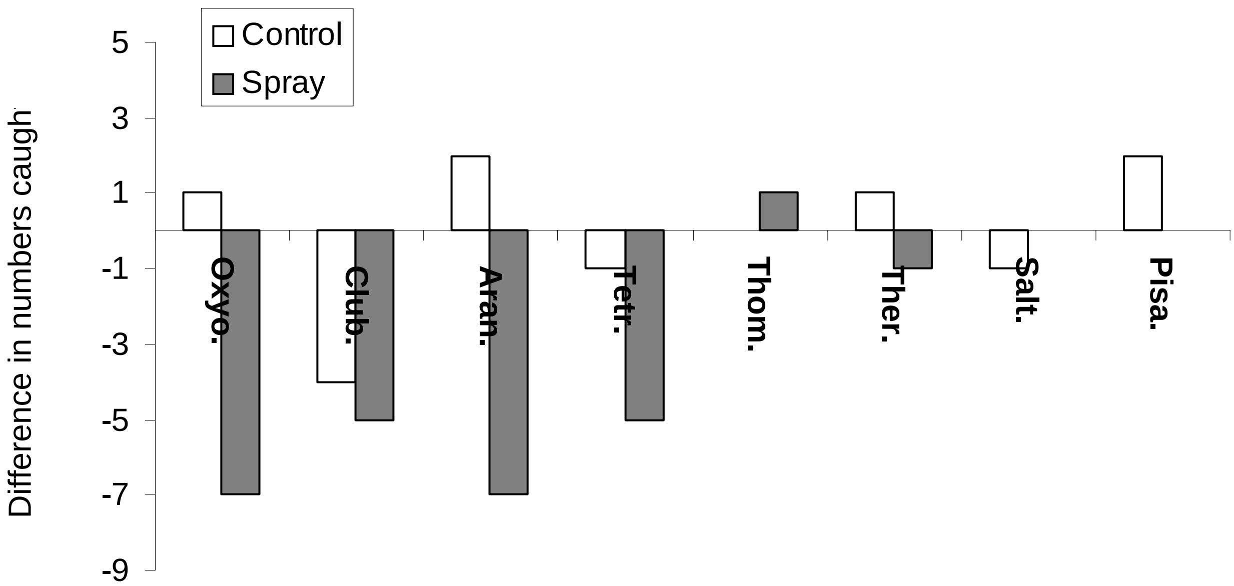


Figure 7. Difference in **A.** arthropod predators and **B.** Araneae caught in a soybean field before, and one day after spraying with insecticide. Each bar represents the total numbers caught after spraying minus the total numbers caught before spraying. Negative values indicate a population decrease after spraying. Unidentified spiders were not included in B.

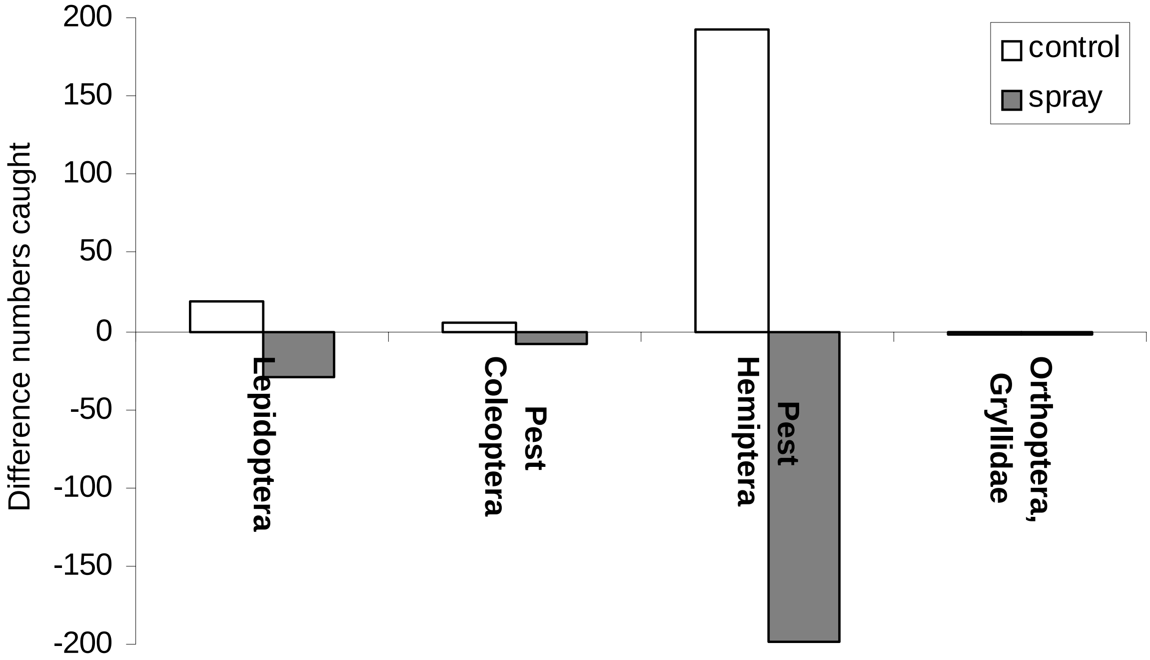


Figure 8. Difference in arthropod pests caught in a soybean field before, and one day after spraying with insecticide. Each bar represents the total numbers caught after spraying minus the total numbers caught before spraying. Negative values indicate a population decrease as a result of spraying.

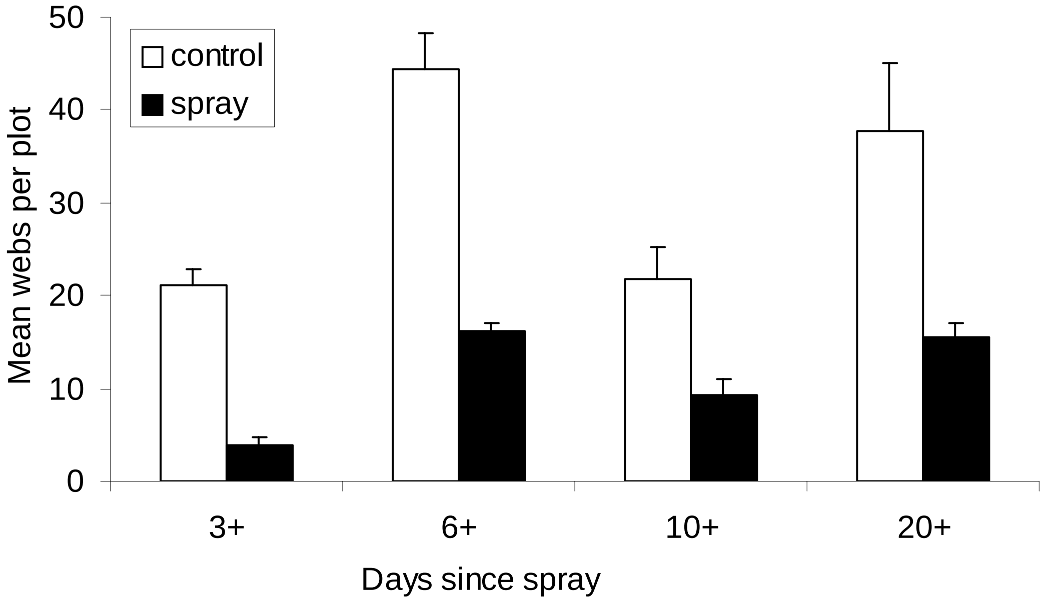


Figure 9. Numbers of spider webs built in soybean field at 3, 6, 10 and 20 days after spraying with insecticide. There was five control plots and five sprayed plots and a 10 minute search for spider webs was conducted in each plot at each sampling day. Bars represent standard error.

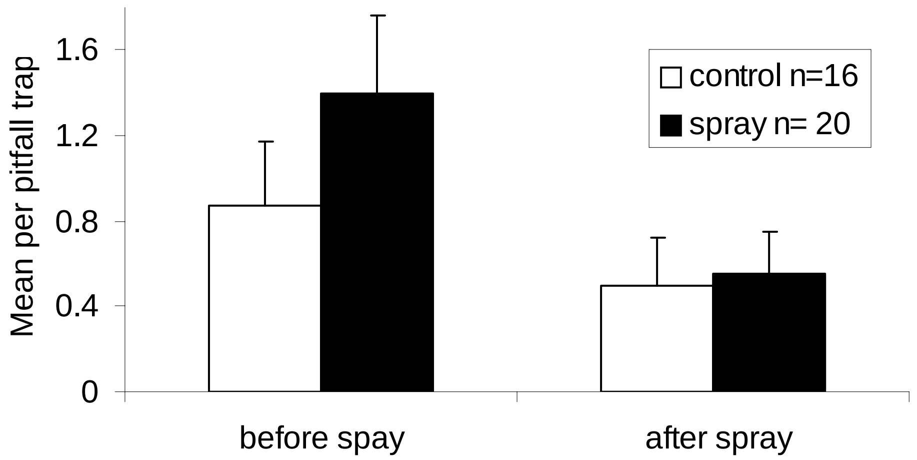


Figure 10. Lycosidae spiders caught in pitfall traps in soybean before and after spraying with an insecticide. Data from three collection dates prior to, and three after spraying was used. Bars indicate standard error.

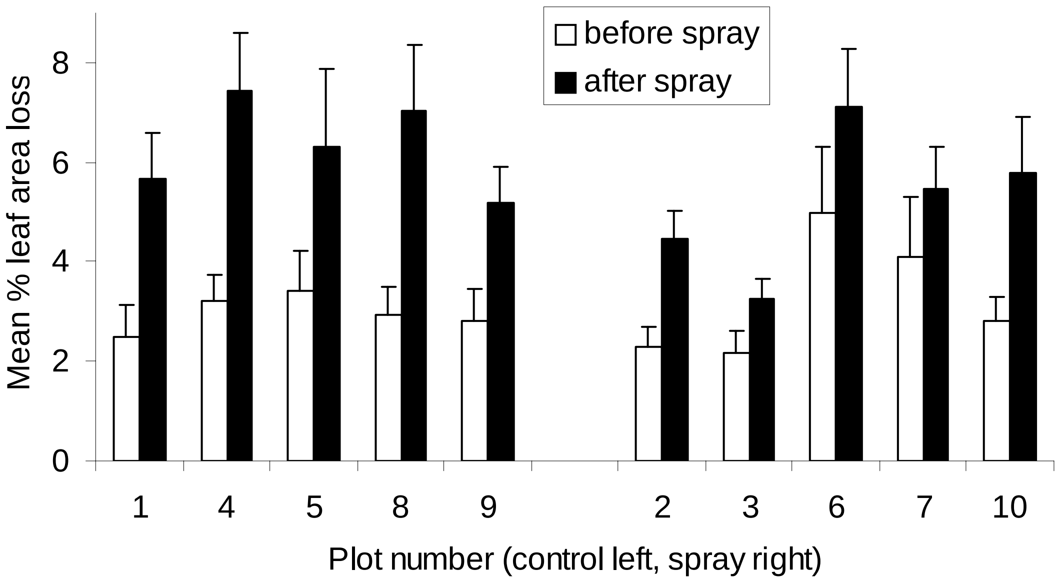


Figure 11. Damage to soybean leaves from polyphagous arthropods before spraying with insecticide and twenty days after. Bars represent standard error.

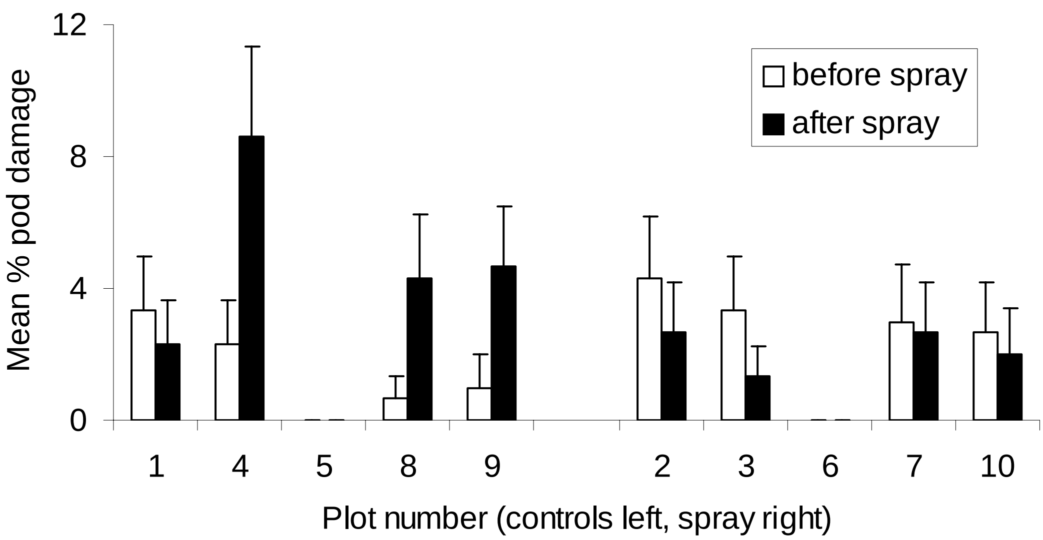


Figure 12. Damage to soybean pods from polyphagous arthropods before spraying with insecticide and twenty days after. Bars represent standard error.

Discussion

Impact on predators

The populations of predators in treated plots were reduced by the application of insecticide (fig. 1). Predator numbers did not return to pre-treatment levels even 20 days after spraying. Control plots also showed a decrease in predator numbers with time. There are a number of possible explanations for this result. Firstly, the predator population may have been entering the decline phase as the plants matured which coincided with spray application. This seems likely given that a similar trend was observed for pest arthropods. Secondly, the spray may have repelled predators into leaving the site all together. Alternatively, the reduction in prey after spraying may have caused some predators to leave the site. Finally, there may have been insecticide drift from the sprayed plots into the control plots. If this occurred you would expect a reduction in both predators and pests in control plots directly after spraying. This trend was only seen in predator samples. Furthermore, significant spray drift is unlikely because spray conditions were good and the unsprayed buffer zones relatively large.

How rapidly predator populations in a treated area recover from an insecticide spray depends on many factors such as distance to unsprayed areas, movement capabilities of individual predator species, residence time of the chemical in the crop and the growth rate of surviving immature stages in the crop. A study by Thomas *et al.* (1990) estimated recovery times for a Linyphiidae spider ranged from 3.7 to 6.5 weeks at 15 and 75m from an unsprayed area. The results presented here show no clear spatial patterns in recolonisation of sprayed plots despite the presence of large areas of unsprayed lucerne adjacent to treated fields (fig. 5 and 6). This results supports conclusions in Chapter four, which found that large-scale movements of predators from lucerne into an adjacent soybean field was limited even when no insecticide sprays were involved. Van den Berg *et al.* (1998) examined spatial patterns in recovery of predators and pests in soybean fields in Indonesia. One field showed some evidence that spiders, beetles, crickets and lepidopterous larvae had moved from an unsprayed control region into the sprayed region after insecticide application. The same trend was not observed in the second field. Van den Berg *et al.* (1998) used large single plots treated with insecticide and used the untreated surrounding area as a control. Smart *et al.* (1989) suggests that the largest practical plot size design (even with reduced replication) is a better method for estimating effects of pesticides on more mobile beneficial species. Such a design may be more useful for detecting spatial recolonization patterns than the replicated block design used in this study.

An impact rating was used to account for mortality (and population growth) in control plots (table 4). Impact ratings should be interpreted with care because a high rating can occur for a number of reasons. For example, the predatory Hemiptera had the highest impact rating (of 34) which suggests that they were heavily impacted by insecticide application. However, the high rating was not due to excessive mortality in treated plots but rather an increase in numbers of Hemiptera in control plots (the same trend was seen for pest Hemiptera). It is difficult to determine if this is due to movement among plots, or natural population increase (births) within plots. Either way the insecticide appears to have a negative effect on predatory Hemiptera. Araneae and Formicidae had the next highest impact rating (19 and 18 respectively). This was due to high mortality levels in treated plots. Predators overall had a very high impact rating (101) as well as a high Abbott's corrected mortality estimate (78%). This supports impact tables such as Wilson *et al.* (2002), which suggest that pyrethroid sprays have a very high impact on predators in cotton (i.e. greater than 60% mortality following application).

Impact on Pests

Populations of pests in treated plots were reduced by the application of insecticide (fig. 4 and 8), however an increase was observed in pest arthropods in control plots one day after spraying. This indicates that there may have been movement of pests from treated plots to control plots in response to the insecticide spray. Alternatively, the pest population may have risen due to reproduction and growth in control plots between the initial pre-treatment samples and post-treatment samples.

Impact on Araneae

Spiders made up a large proportion (34%) of the predators present within the soybean field prior to spraying with the insecticide. Spiders suffered 65 percent mortality (Abbott's corrected estimate) after the insecticide spray was applied. Araneidae and Oxyopidae had the highest impact rating (9 and 8 respectively). This was due to a combination of high mortality in treated plots and an increase in control plots. Clubionidae had a low impact rating because a reduction in numbers was recorded in both treated and control plots. The few Clubionidae egg sacs that were observed in the field plots were apparently unaffected by the spray. Eggs, young and the brooding female may have been sheltered from insecticide by the tightly sealed nest. These were a good source of immature spiders immediately after spraying.

There was a considerable decrease in the number of spider webs being built in the treated plots from three days to 20 days after spraying. Despite being unable to compare with pre-treatment figures insecticide appears to have appreciably decreased the number of webs being built in sprayed plots. It is impossible to tell if this is a result of direct mortality of web-building spiders, or if insecticide deterred spiders from building webs in treated plots. Many authors have found that web-site tenacity is influenced by prey availability and non-prey web damage (McNett & Rypstra 1997, Nakata & Ushimaru 1999, Chmiel *et al.* 2000). Non-prey web damage was kept to a minimum when searching through the plots. It is more likely that the spiders died or re-located their webs in response to a low prey capture rate induced by insecticide spray. Web density in treated plots remained low even at 20 days after spraying. This suggests that web-building spiders did not re-colonise these plots after the residual effect of the insecticide had worn off. Again, this is probably due to low prey availability making web catches too low to justify the expenditure of building a web in the same location.

Only vacuum samples from the plant foliage were conducted throughout this experiment. The conclusions drawn must therefore be limited to the foliage-dwelling pests and predators. Nocturnally active and ground-dwelling arthropods would have been missed via this collection protocol. The data from pitfall traps placed out as part of another experiment were used to get some idea of the effect of the insecticide application on ground-dwelling Lycosidae. Numbers of Lycosidae caught in treated plots was reduced after spraying however a reduction in numbers was seen in control plots as well. Whilst the insecticide spray appeared to have some effect on abundance of Lycosidae in sprayed plots the difference before and after spraying was not significant ($P = 0.09$). Feber *et al.* (1998) found more ground-dwelling spiders and a greater number of spider species in organically farmed wheat in comparison to conventional fields. The influence of abundant understorey vegetation and the absence of insecticide sprays could not be separated. The negative effect of insecticides on spider abundance in the field has been demonstrated in a number of studies (Bostanian *et al.* 1984, Stark *et al.* 1995).

Mark-recapture studies have shown that Lycosidae are capable of travelling great distances within soybean fields and between fields (Pearce & Zalucki 2002, see Chapter five). For the purposes of this study the sprayed and unsprayed plots could not be considered independent and there may have been movement of spiders between plots. Further studies to determine the response of ground-dwelling spiders and insect predators to insecticide sprays is warranted.

Plant damage

Plant damage was very low throughout the experiment. Leaf area loss never reached the 30% threshold that is considered to result in yield losses (Colton *et al.* 1995). Leaf area loss increased from before spray count to after spray count. This was expected given that there was at least 20 days between the two counts and leaf area loss is a cumulative measure of damage. More importantly the change leaf area loss in control plots was not different to that in treated plots. A similar trend was seen for pod damage. For edible beans three percent pod damage is tolerated (Lucy & Mills 2000) and in many parts of the field damage was below this level.

In conclusion, despite the insecticide spray reducing pest numbers no gain in terms of an appreciable reduction in plant damage was obtained. The pyrethroid insecticide dramatically reduced most predatory arthropods for up to 20 days after spraying. If the results of this experiment are indicative of what occurs during commercial spraying then even a single insecticide spray may have a dramatic effect for a long period on predator populations within fields. Further studies using insecticide exclusion techniques should include an estimate of predation rate to begin to assess what impact reduction in predator numbers is having on the pest population dynamics.

Chapter summary

- The pyrethroid insecticide caused a significant reduction in the abundance of predators and pests in the treated plots. Arthropod populations did not recover to pre-treatment levels even 20 days after spraying despite the presence of large unsprayed refuge areas (lucerne fields) near the sprayed crop.
- The insecticide had the greatest impact on pest and predatory Hemiptera. This was due to high mortality in the treated plots as well as greater numbers in the control plots after spraying. It is difficult to determine if this is due to movement of arthropods from treated to control plots, or population growth in control plots.
- Impact of insecticide on different predatory groups' varied according to the rating system employed. Confounding results were obtained when increases in population numbers occurred in control plots. For mobile predators movement between plots cannot be ruled out and causes problems for assuming independence of treatment units.
- Insecticide reduced the numbers of spider webs built in treated plots. Spiders may have died or re-located their webs in response to a low prey capture rate induced by the insecticide spray.
- Insecticide reduced numbers of Lycosidae captured in pitfall traps in control and treated plots. However, the reduction in treated plots was proportionally greater. Mortality due to the insecticide spray was 75 percent after correction for control using Abbott's formula. Other ground-dwelling predator groups were not investigated in this experiment. Further studies to determine their responses to insecticides are warranted.
- Damage to plants throughout the season was very low. At 20 days after spraying there was less pod damage in sprayed plots, however this was not significantly different to control plots.
- An assessment of predation rates in control and treated plots using egg cards would have provided useful results but were not possible due to time constraints. Further studies using insecticide exclusion techniques should include an estimate of predation rate to begin to assess what impact the reduction in predator numbers is having on the pest population dynamics.

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