Part 1 - Summary Details

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

CRDC Project Number: **CSP165**

Project Title: Aphids - control, ecology and CBT resistance.

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CRDC Program: 3 Crop Protection

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Executive Summary

This project evaluated options for selective control of aphids, studied the field epidemiology of cotton bunchy top disease and determined the suitability of relay crops for aphid pest management. Key conclusions were;

1) Acetamiprid plus pulse provided good control of aphids but flared mites, presumably because it reduced beneficial numbers. This will also be a risk if this product or other neonicotinoids are used against mirids.

2) None of the 'soft' soap or oil options alone provides adequate control of heavy aphid populations. Canopy oil may be effective if applied to lower density aphid populations (e.g. less than 10-15 aphids per leaf) in a regular program.

3) The biopesticides evaluated are unlikely to provide the high level of control provided by acetamiprid plus pulse. However, efficacy should improve as more field adapted strains are selected. Used early, these products may be effective at preventing aphid populations from increasing without flaring mites and with reduced resistance risk.

4) CBT appears to be relatively common in aphid populations. CBT affected plants were often observed in the centre of aphid hotspots – often only one or two infected plants are found. In 2005-06 we found CBT affected plants in aphid hotspots in 6 of 8 sites.

5) The latent period of CBT in cotton plants can be relatively short (about 10 days) but is likely to be influenced by aphid numbers (lower densities could have a longer latent period). This is complex and needs further experimentation to sort out.

6) Yellow dwarf forms of cotton aphid transmit CBT poorly compared to 'normal' sized aphids.

7) The rate of spread of aphid populations while they are in the apterous form (non-winged) is relatively modest e.g. it took about 40-50 days to travel 8m, both across and along rows. Once populations reach densities that produce alates (winged forms) the spread of aphids could be much faster.

8) Spread of CBT was much faster and higher when the infestations in the field were initiated with a CBT affected plant carrying a high aphid population, compared with those initiated by infesting a field plant with CBT infected aphids. This is likely due to movement of CBT infected aphids off the CBT affected plant compared with movement of clean aphids off the aphid infested plant due to the latent period.

9) In terms of risk of CBT outbreaks – generally low densities of aphids colonising plants means transmission efficiency is low and the latent period likely to be longer, which may severely limit the level of infection in field. Exceptions would be in years were season conditions generated high numbers of aphids and of alternative hosts with CBT – which could then colonise cotton crops at higher densities or situations where stubb cotton was abundant in a field and acted as a source of CBT carrying aphids.

10) The effect of CBT on yield is greater the earlier that plants are infected.

11) Lucerne and sorghum are good relay crops for aphid management as they host aphids that don not attack cotton on which beneficials and parasites could build up and move into cotton.

These outcomes significantly advance our understanding of aphid and CBT epidemiology and will be valuable to industry in developing management strategies.

Part 3 – Final Report Guide (due 31 October 2007)

(The points below are to be used as a guideline when completing your final report.)

Background

1. Outline the background to the project.

Over the past five years aphids, particularly cotton aphid (*Aphis gossypii*) have emerged as a greater potential problem. This is due to three main factors (i) the changing pest management system where the use of broad spectrum insecticides early season has declined, thereby also reducing co-incidental control of aphid populations (CBT) disease which has caused concerned growers to use lower thresholds, (ii) the resulting increase in resistance in cotton aphid to organophosphate and carbamate insecticides and (iii) the finding that cotton aphid is a vector for the debilitating Cotton Bunchy Top. Further, greater emphasis on selective control of pests may favour aphids if insecticides are used that don't control aphids but do suppress some of their predators or parasites.

In response to the emerging threat from aphids, CRDC has funded projects to understand their effects on yield (CSP 147C); their ecology and sampling (CSP145C); the impact of beneficial populations (DAQ119C); investigation of insecticides for their control (DAN141C); and resistance management (DAN139C). In addition, a project was initiated to understand the cause of CBT, its epidemiology and to select for resistance to it in cotton (CSP143C). The project proposed here will finalise several important pieces of research from CSP145C and CSP143C.

Despite being hampered by the dry conditions, solid progress has been made in CSP143C and some key outcomes include;

a) Identification of a broad range of hosts for cotton aphid, green peach aphid and cowpea aphid as well as for most other aphid species encountered in the region.
b) Determination of the season pattern of abundance of aphids, and their natural enemies, on crop and weed hosts
b) Determining the within plant, between plant and dispersal patterns of aphids in cotton.
c) Evaluation of several alternative sampling strategies.
c) Demonstrating that farm gardens can be reservoirs for resistant cotton aphid.

However, there is further study required, in particular (i) study of aphid host through winter. This is important as a better knowledge of key winter hosts provides opportunities to reduce abundance, but has been restricted by the dry conditions (ii) data is required on the rate of spread of aphid infestations under both sprayed and unsprayed conditions (iii) there is still a need for selective, cost effective options to control aphids and an emerging possibility is the use of insecticidal soaps.

Similarly, there has been good progress in the Narrabri component if CSP 143C, with a solid understanding developed of transmission of CBT by aphids (see Table 1). CSIRO breeders have also been progressing selecting for resistance in elite cotton varieties. However, future progress in ensuring that CBT resistance becomes widely available depends on access to efficient procedures to screen lines with CBT infected aphids. CBT resistance is significant, not just for its values in years when aphid turn up early, but also because it reduces the desire to use reduced thresholds and hence reduces selection pressure for resistance, as well as costs and environmental contamination.

Table 1. Transmission characteristics of CBT.

Transmission Characteristic	Treatments	Results
Acquisition Time	Aphids allowed to feed on CBT affected plants for varying periods (5 min, 1hr, 6 hrs, 24 hrs, 48 hrs) then transferred to health y plant where symptoms of CBT are monitored	Minimum of 5 minutes
Inoculation Time	CBT affected aphids placed on healthy plants for various lengths of time (5 min, 30 mins, 1 hr, 6 hrs, 24 hrs, 48 hrs) and removed. Development of CBT in plants monitored.	Minimum of 1 hour
Persistence	CBT affected aphids transferred to new plants each day for 7 days	Persistent disease – all days show symptoms.
Aphid Threshold	Various numbers of CBT affected aphids (1, 3, 5, 10, 20) were confined on healthy plants and the development of CBT symptoms monitored.	Minimum of 3 aphids
Aphid Instar	Instars 1 – 4, adult aptera and adult alates transferred to healthy hosts and development of symptoms monitored	All instars transmit CBT except 1st instar.

This project built on CSP145C and CSP143C earlier projects to investigate some potential new control options using insecticidal soaps and additives such as oils, to link understanding of aphid population development and epidemiology of CBT to develop a method to estimate the progress of CBT infection across fields and to continue to facilitate screening for elite varieties with resistance to CBT. It also linked with the relay cropping project being proposed by Dr Robert Mensah (NSW Agriculture) 'Conservation and utilization of beneficial insects in IPM programs in cotton: A farming systems approach' and will monitor the abundance of aphids and their predators in the relay cropping system he proposes.

Objectives

2. List the project objectives and the extent to which these have been achieved.

- To investigate potential new control options using insecticidal soaps and additives such as oils and urea
- To develop an understanding of aphid population distribution through winter and of development and spread in cotton fields
- To continue experiments to understand the epidemiology of CBT
- To link the knowledge of aphid spread and the epidemiology of CBT to develop a method to estimate the progress of CBT infection across fields
- To investigate the abundance of aphids and beneficials in relay cropping systems
- To facilitate continued screening for elite varieties with resistance to CBT.

Methods

Field experiments were used to investigate the potential efficacy of several control options. During the course of the project we also included evaluation of two Biopesticides from Dr Mensah's project. The methods for the soaps and oils and for the biopesticides are described separately. During the course of the project the increasing area of Bollgard II, and dramatic reduction in insecticide use meant that it became very difficult to generate useful aphid populations in field experiments.

Aphid colonies We artificially reared large numbers of cotton aphids in six 3m x 3m mesh field tents. We used a cotton bunchy top resistant variety to rear the aphids on. The tents partially protected the aphids from wind and rain and also helped to keep out predators. Nevertheless, control of parasites and predators in the cages was required on occasion. For unknown reasons the aphids did not always do well in the tents, but generally we were able to establish healthy, dense colonies of aphids in the tents. The plants in the tents were cut into small one to two node sections and used to infest the field experiments described below.

*Experiments with soaps and oils 2004-05 (Experiment 1) and 2005-06 (Experiment 2)*In Experiment 1, a range of combinations of Natrasoap (an insecticidal soap), Canopy Oil and mixtures with urea (reported to be an effective additive in China) were investigated, as shown in Table 1. The rates of urea were a guess and designed to span a reasonable range. In Experiment 2, we selected the most promising treatments from the first experiment and also tried the concept of reduced rates of insecticide, alone or with Natrasoap or Canopy oil, see Table 2.

Table 1. Aphid control options investigated in Experiment 1, 2004-05

Treatments	***Product Rate* (ml/ha)**
1. Control (untreated)	-
2. Acetamiprid + Pulse	75ml/ha 0.2%
3.Natrasoap + spraytech oil	6000ml/ha 1000ml/ha
4. Natrasoap + spraytech oil + urea	6000ml/ha 1000ml/ha 5 kg/ha
5. . Natrasoap + spraytech oil + urea	6000ml/ha 1000ml/ha 2.5 kg/ha
6. Natrasoap + spraytech oil + urea	6000ml/ha 1000ml/ha 1 kg/ha
7. Natrasoap	6000ml/ha
8. Canopy oil	2%
9. Natrasoap + Canopy oil	6000ml/ha 2%

* Acetamiprid used at 16.9 g ai/ha

Table 2. Aphid control options investigated in Experiment 2, 2005-06

Treatments	***Product Rate*** **(ml/ha)**
1. Control (untreated)	-
2. Acetamiprid + Pulse	75ml/ha 0.2%
3 Acetamiprid + Pulse	25ml/ha 0.2%
3. Acetamiprid + Pulse + Soap	25ml/ha 0.2% 6000 ml/ha
4. Acetamiprid + Pulse + Canopy oil	25ml/ha 0.2% 2.0%
6. Natra soap + spraytech oil	6000 ml/ha 1000 ml/ha
5. Natrasoap + spraytech oil + urea	6000 ml/ha 1000 ml/ha 1 kg/ha
8. Canopy oil	2%
9. Canopy oil + Natrasoap	2% 6000 ml/ha

* Acetamiprid used at 16.9 g ai/ha or 5.6 g ai/ha.

The experiments used a randomised block design with 4 replications. Plots were 20m x 8 rows, with a 1m gap separating the ends of plots. Before the insecticides were infested with aphids we treated the whole area with a low rate of deltamethrin to suppress beneficial populations. After 3 days we infested the central two rows of each plot with aphids, allowed them to increase and sampled them about 2 weeks later, then sprayed and sampled at 3 ,7 and 12 days after spraying, resprayed and sampled every 5 days thereafter until aphid populations increased. In both cases the experiments were done relatively late in the season beginning just before cut-out (early February). The spray rig set up with 5 nozzles per row was used to apply the treatments.

To sample aphids we collected 20 leaves per plot in the central two rows from node 3. For each plot the leaves were washed and 'live' aphid adults, immatures, mummies, mites, thrips and predators / parasites were counted.

Biopesticide evaluation experiments (Experiments 3,4 and 5)
We evaluated the potential of BC639 (Metarhizium) and NSWDPI Aphid Fungus to control aphids. In 2005-06 we did three experiments – two field experiments and a mesh-house experiment.
Experiment 3, done in early March, compared an untreated control and industry standard (acetamiprid) against the two fungus options; Fungus 1 is 639-Metarrhizium sp, Fungus 2 is NSWDPI Aphid Fungus. The field experiments used a randomised block design with 4 replications. The plots were 18m x 12 r and already had a moderate infestation of both aphids and spider mites The spray rig set up with 5 nozzles per row was used to apply the treatments. Leaves were sampled and aphids washed off and counted in the laboratory.

Experiment 4, done in late March, compared just the control and two fungus options (Fungus 1 is 639-Metarrhizium sp, Fungus 2 is NSWDPI Aphid Fungus) and was sprayed by hand. The aim was to ensure that the aphids were contacted with the fungus spores. Aphids were scored in the field using a simple rating system;

0 = no aphids
1 = 1-10
2 = 11-20
3 = 21-50
4 = 51-100
5 = >100

Experiment 5, done in April in a mesh-house was also to ensure aphids were exposed to the fungal spores so that we could select infected aphids from which to establish a more adapted strain. Fungus 1 is 639-Metarrhizium sp, Fungus 2 is NSWDPI Aphid Fungus.

In 2006-07 we intended to re-screen most of the treatments we screened in 2005-06 (Table 2) and to separately screen the biopesticides. However, we had ongoing problems establishing decent field populations of aphids, despite rearing millions in cages and distributing into the plots. High levels of beneficials and rapid re-invasion of plots by beneficials despite spraying was a problem. We therefore elected to use field cages to try to overcome this problem. We had 10 cages each with 2 rows by 3m. We put two treatments per cage (4 replicates for each treatment). The treatments were; untreated control, Fungus 1 is 667 Beauvaria sp, Fungus 2 is NSWDPI Aphid Fungus, Greenfire applied at 10ml/L, and intruder applied at 2ml/L+2%pulse, all applied by hand-sprayer. The plants were samples by collecting 10 leaves per row pre-spray and at regular intervals for 3 weeks. Leaves showing symptom of aphids with fungus were placed in petri-dishes and cultured in the laboratory. At the end of the experiment leaf samples with infected aphids were packaged and sent to Becker-Underwood for culturing.

To develop an understanding of aphid population distribution through winter and of development and spread in cotton fields

In this component of the work we reduced the winter sampling of aphids as we felt that we had sufficient data from the previous project. We did collect aphids off weeds in spring to provide industry with an indication of likely problems. In spring there are usually many aphids moving around as their hosts senesce and they are forced to move to new hosts.

However a valuable opportunity came up to use out archival collections, amassed over 5 years, to help understand the clonal structure of aphid populations on cotton and in cotton regions. Dr Wilson and Dr Herron (NSW DPI) have developed a collaboration with Dr Falvie Vanlerbeg-Masutti, and her student, Jerome Carletto from the French National Institute for Agricultural Research. This work has been discussed previously with Dr Ian Taylor at CRDC. It arose from a meeting with Flavie and Jerome at a conference where they reported using micro-satellites to study the clonal structure of aphid populations and compare theme between crops and countries. We have a large collection of aphids from cotton and other weed and crops stored in ethanol in a freezer.

Understanding the clonal structure of aphids collected in Australian cotton regions will help define which hosts are most important and, by combining this with data on insecticide resistance status, whether resistance develops in a single clone or multiple clone. This

information can help improve strategies for cultural control of aphids and for resistance managements, so we agreed to collaborate. We applied unsuccessfully for additional funding through the FAST program, and received a letter of support from Mr Bruce Pyke at CRDC, but have continued the work as and when we can fit it in. Some 200 crop specific aphid collections that we had collected and stored at ACRI were transferred to Dr Herron's laboratory at EMAI. The project TO, Ms Tanya Smith, travelled to EMAI for 2 weeks to assist Martin with DNA extractions from the aphids. Five aphids from each collection (1000 in total) had DNA extracted, some of which was subjected to real time PCR followed by a restriction enzyme digest to detect pirimicarb and organophosphate resistance at the ACE1 target site. Finally, the 1000 samples produced dispatched to Flavie and Jerome for micro-satellite screening.

However, the major component of this research was to develop an understanding of the spread of aphids within cotton field and the spread of CBT at the same time. We set up this work to try to partition the effort to answer three basic questions;

1. What effect does CBT have on yield and is this influence by the time of infection?
2. How fast do aphids spread between plants, and how fast does CBT spread between plants
3. How quickly after being fed on by a CBT carrying aphid is a plant capable of re-infecting new aphids (known as the latent period) (note, these experiments are reported below under epidemiology of CBT.

Putting these three pieces of information together should enable us to develop a simple spreadsheet model of aphid and CBT spread across fields.

We set up an initial experiment in 2004-05 (Experiment 6), designed to investigate the rate of spread of aphids from a point source (infected plant). We used 10 plots of CBT susceptible cotton (Sicot71) which were each infested with aphids collected from CBT affected plants. In each plot 5 individual plants were infested, separated by about 2 m (along the row). Aphids didn't thrive, and plants that didn't establish were reinfested on 10/2/05,17/2/05, 23/2/05 and 3/3/05. This included most target plants on 10/2 & 17/2, about 1/2 on 23/2 & 1/4 of target plants on 3/3. Infested plants (target plants) were checked weekly, and then each plant along the row in either direction was checked to determine the distance aphids had spread from infested plant. Plants were checked for CBT development and rated using a simple rating system developed by Dr Amelia Reddall. Surprisingly few plants developed any symptoms at all.

In 2005-06 we set up two field experiments, one to measure the rate of spread of aphids and CBT between plants under sprayed and unsprayed conditions (Experiment 7) and one to determine the yield effects (Experiment 8) of plants infected at different stages of development (Experiment 9). Both experiments used Sicot 71 BR, which is susceptible to CBT but also minimises losses to *Helicoverpa* and allows better management of weeds.

Briefly, In Experiment 8 we set up plots of cotton, and allocated them as either sprayed or unsprayed. The plots were 21 rows by 20 metres with 10 metres of buffer between sprayed plots, and north and south of the experiment, and 4 rows of buffer between sprayed and unsprayed region. The sprayed plots were treated regularly with thiodicarb to suppress natural enemies of aphids. Sprayed plots were bordered by 2 rows of cotton and dirt road to the east, unsprayed by cotton buffer rows and sorghum to the west treatments were in a randomised north south row to help break up the impact of surrounding non-treated area, as well as to make spraying easier on the sprayed plots. There were 4 replicate plots in the sprayed and unsprayed sections. A central plant in the plot was infested with 100 CBT

infected aphids. Weekly checks were done by: visually inspecting the source plants to node 15, recording all arthropods, CBT symptoms and numbers of aptera/alate cotton aphids for each node. To assess the spread of the aphids we inspected plants along the row in either direction to node 10 of each plant, recording as above. Once 5 plants in a row were checked & found to have no aphids, the last plant found along the row with aphids was marked and labelled. All "last plant"s were revisited each week, and then the previous week's last plant becomes the first plant to continue from in checking plant by plant in the next week. Distances and plant numbers are always recorded from the source plant and measurements were taken separately for either direction along the row. We also checked for spread across rows by visually checking a metre of cotton adjacent to source plants. In this metre we checked each plant down to node 5 for aphids. If present, the metre was marked & dated & the following row across (e.g. away from the source plant's row) was checked until no aphids were found. The last aphid containing row was marked and labelled and checked in following weeks for aphids and CBT symptoms. Measurements from the source were made in either direction away from the source plant.

In Experiment 9, we investigated the effect of aphid on yield of cotton. We tagged 1.2m sections of cotton as plots and allocated them randomly to different timings of infection with CBT. The plots were ether not infested, or infested at 14, 18, 20 or 22 nodes. To control for the effects of aphids separately from CBT we included plots infested with 'clean' aphids at the same time. There were 5 replicates of each treatment. After the plots were infested the aphid population was allowed to build for about 2-3 weeks then controlled. Each plant in each plot was checked weekly for the presence of CBT symptoms. Once all bolls had opened they were collected separately for each 1.2m section, weighed and ginned.

In 2006-07 we repeated the experiments of 2005-06 with some modifications to improve their chance of success. Experiment 10, was the same as Experiment 8, except that we used a heavily aphid infested and CBT affected target plant taken from the glasshouse and put into the centre of each plots. Experiment 11 was the same as Experiment 9, except that we put higher numbers of aphids in the plants and caged the +CBT aphid and + clean aphid treatments. Unfortunately we did not have enough cages to cage controls as well. The cages were to exclude predators and increase the chances of the aphid successfully transmitting CBT to the plants.

To compliment this field based research we also investigated the effect of CBT on the yield of cotton plants in the glasshouse (Experiment 12). The treatments were, uninfested control, or infested at 5, 10, 15 or 20 nodes with either 'clear' or CBT infected aphids. A first experiment in early 2007 was unsuccessful because transmission of CBT was very poor, so the experiment was repeated beginning in late March 2007 (seeds sown) and this experiment is in its final stages (August 2007).

To continue experiments to understand the epidemiology of CBT

This research focussed on identifying the latent period for CBT. These experiments are complex and take months to complete. More research is required. However, the basic technique we used in Experiment 13 was to place 100 CBT carrying aphids onto each of 5 healthy plants (source plants), allow them to feed and presumably transmit CBT for 1 day then remove them by squashing each day for the next three days. This is important as CBT is semi-persistent in the aphids. The day that the aphids were first placed on these source plants is Day 0. Once we are sure the plants are aphid free we reinfest them with 'clean' aphids. We are interested how long it takes for the plant to have sufficient CBT infection that these clean aphids become infected and can transmit the disease to new plants. Hence, we then transferred 20 aphids off the source plants onto each of 5 healthy 'recipient' plants at each of

10, 14, 18, 22 and 26 days after Day 0. At the same times we also transferred 20 aphids from the 'clean' colony onto each of two plants at each of 10, 14, 18, 22 and 26 days after Day 0 and also had 2 completely uninfested plants for the same dates. After about 20 days we controlled the aphids on the 'recipient' plants from a particular date. We monitored the source plants, the recipient plants and the 'clean' aphid and no aphid controls for symptoms of CBT. If any of the 'recipient' plants on a particular transfer date become infected then we know that the source plants were capable of infecting 'clean' aphids at that date (Diagram 1).

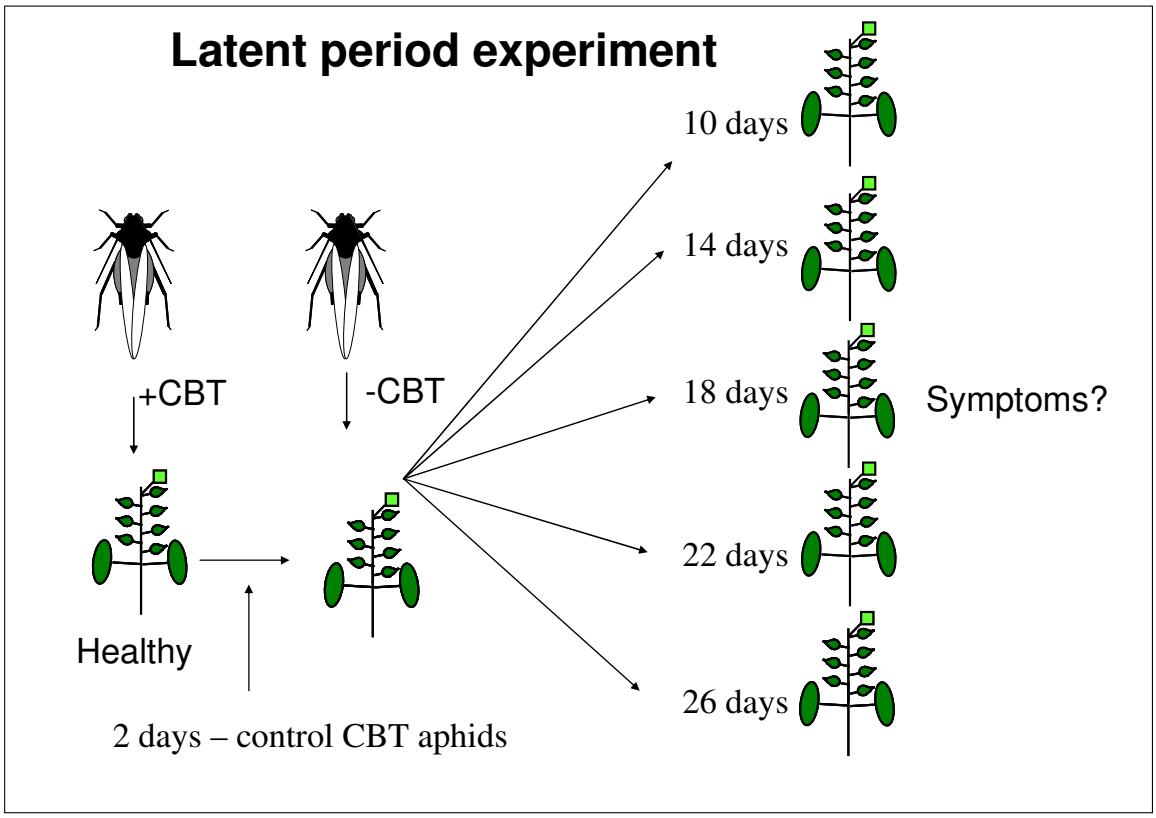

Diagram 1. Design of latent period experiments.

We also noticed that we often got very poor transmission of CBT by aphids, both in the field and in the glasshouse. This meant that we sometimes only achieved partial or in some cases no results. When aphids are cultured in the glasshouse they often gradually become yellow dwarves – basically very small aphids, generally because something is not suitable to them. We evaluated the transmission capacity of yellow dwarfs in comparison to large healthy dark green aphids in Experiment 14. There were 4 plants per treatment and the treatments were 1, 5, 10 or 50 aphids per plant of either healthy aphids or yellow dwarfs, both infested with CBT, and control with no aphids. The aphids were allowed to feed for 1 week then controlled. The plants were monitored for CBT symptoms.

To link the knowledge of aphid spread and the epidemiology of CBT to develop a method to estimate the progress of CBT infection across fields

This objective uses data from the experiments above to investigate the risks from CBT infected aphids entering a field and creating a CBT outbreak. We have made significant progress on this objective, but after discussion with Dr Ian Taylor we decided to obtain another year of data on the spread of aphids and on the latent period to increase our confidence in any predictions.

To investigate the abundance of aphids and beneficials in relay cropping systems

In collaboration with Dr Robert Mensah we evaluated the risk that a range of relay crops will act as hosts for aphids – which could act as a source of host continuity for aphids, allowing populations to build and move into cotton (Experiment 15). We evaluated this by sampling the relay crops regularly for the presence of cotton aphid. We also tested if the relay crops were hosts for cotton aphid by enclosing plants of the relay crops in fine mesh bags into which were placed some cotton aphids. The population growth of these aphids was monitored. The relay crops included conventional and Bollgard II cotton, lucerne, mung beans, pigeon peas, sorghum, soybeans and sunflowers.

To facilitate continued screening for elite varieties with resistance to CBT. The CSIRO Cotton Breeding team have been selecting plants for CBT resistance. We have provided support to this effort by assisting in evaluating the CBT resistance of selected lines. This has been done in the field and the glasshouse. To do this we have maintained a culture of CBT infected plants and aphids in a small glasshouse for the duration of the project. The basic strategy used to assist the Breeding Group is shown in Figure 1, and basic methods are described below.

Field screening
For the field screening of resistance we have sown 4 rows of a susceptible variety, infested it with CBT affected aphids, then ratooned these plants so that they regrow with CBT symptoms the following year. The plants generally started to re-shoot in late September. In mid November we place 8 large field cages over sections of ratoon plants and introduced aphids from a glasshouse culture. These were allowed to build in the absence of predators (theoretically!), then some were collected and used to infect larger areas of the uncaged ratoons, generating a substantial outbreak of CBT infected aphids. Sections of the ratoon cotton heavily infested with aphids were then used to infest the breeding lines. These aphids were allowed to build on the breeding lines to high levels, then controlled and the lines assessed for symptoms. This sounds simple and straightforward, but predators, parasites, unwanted mite outbreaks and problem with aphid establishment make this a challenging process every year. Samples of CBT affected aphids were provided to Deltapine as requested (mainly in 2004-05). The advantage of the field screening is that large numbers of lines can be screened, but the disadvantage is that many problems can occur to make the results less reliable due to uncertainty that lines were exposed to CBT.

Glasshouse Bioassay
Breeding lines were planted in pots, allowed to grow and as early as possible infested with aphids carrying CBT. The aphids were allowed to increase for about 2 weeks then controlled and plants monitored thereafter for CBT symptoms. A CBT susceptible and resistant line were included as controls. The glasshouse experiments are generally more reliable and faster, but smaller numbers of lines can be screened. It is important to note that with another aphid borne disease, Blue Disease' it is possible to mass screen in the glasshouse. This is largely because the symptoms of the disease appear quickly. In contrast, the symptoms of CBT can take 3 to 8 weeks to appear so even if plants are infested at a young age they must be grown out for at least 2 months to be certain of the results.

Results

6. Detail and discuss the results for each objective including the statistical analysis of results.

To investigate potential new control options using insecticidal soaps and additives such as oils and urea

Soft options - Experiment 1.

Acetamiprid plus pulse provided excellent control of a very heavy aphid population (Figure 2)($p < 0.001$). None of the other treatments provided satisfactory control. Canopy oil provided moderate initial expression, but was not able to provide sustained control against such high aphid pressure and re-invasion of aphids from adjacent plots. Significantly, plots sprayed with acetamiprid plus pulse had significantly more spider mites than other treatments (Figure 3) ($p < 0.001$), possibly due to effects on a range of predator species (Figure 4) ($p < 0.001$).

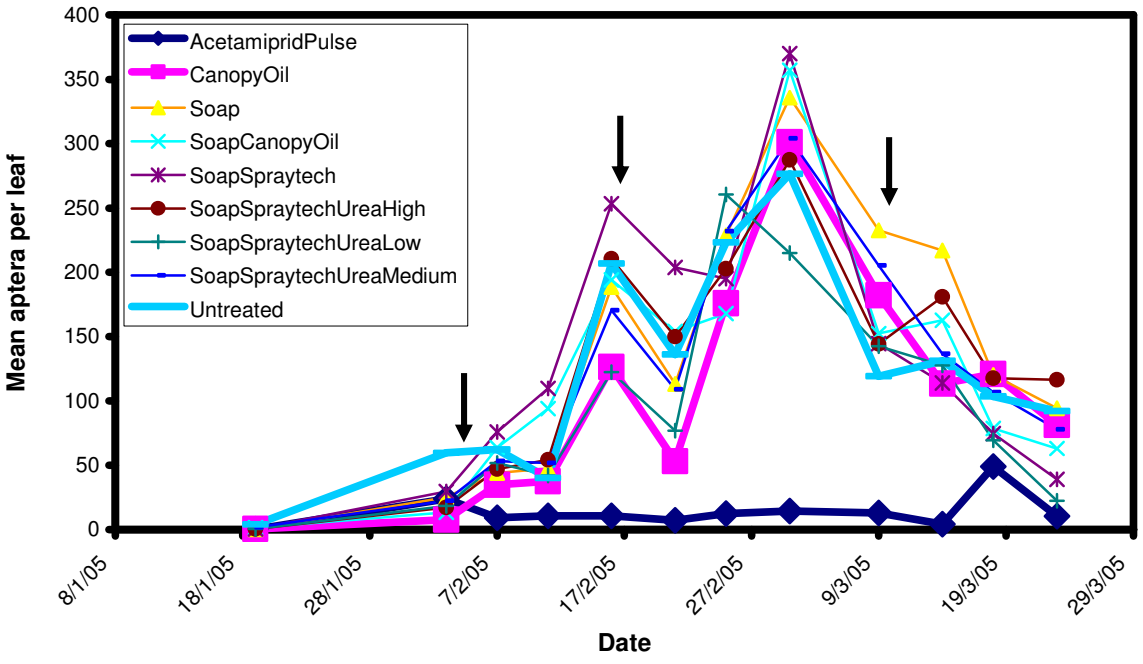

Figure 2. Efficacy of different insecticidal options against cotton aphids, ACRI, 2004-05. Arrows indicate spray dates.

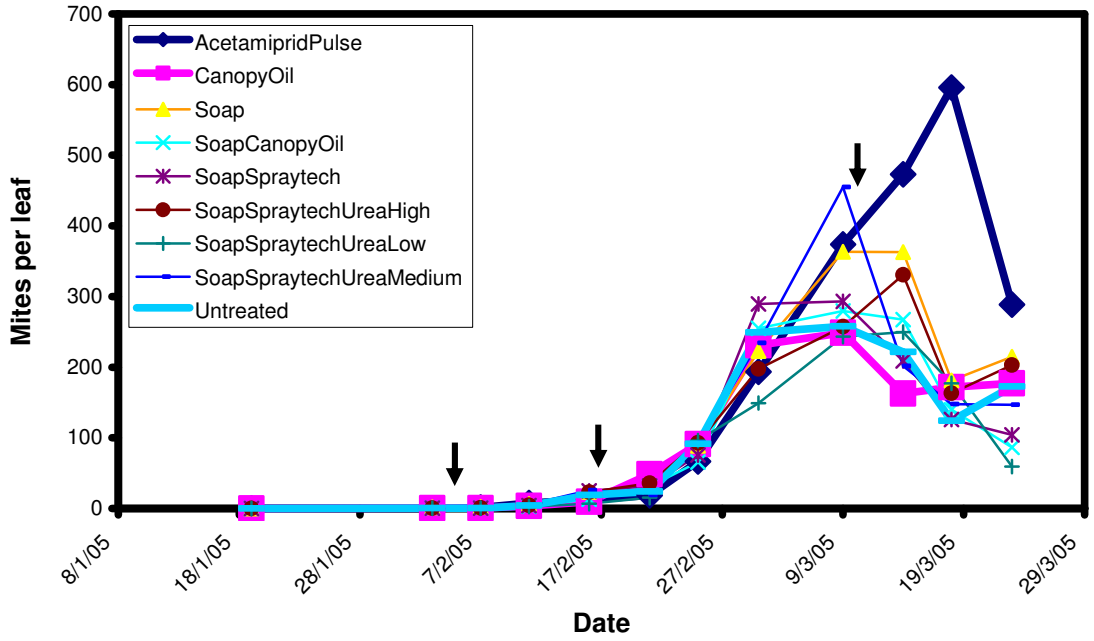

Figure 3. Effect of different insecticide options applied against aphids on spider mites, Experiment 1, ACRI, 2004-05. Arrows indicate spray dates.

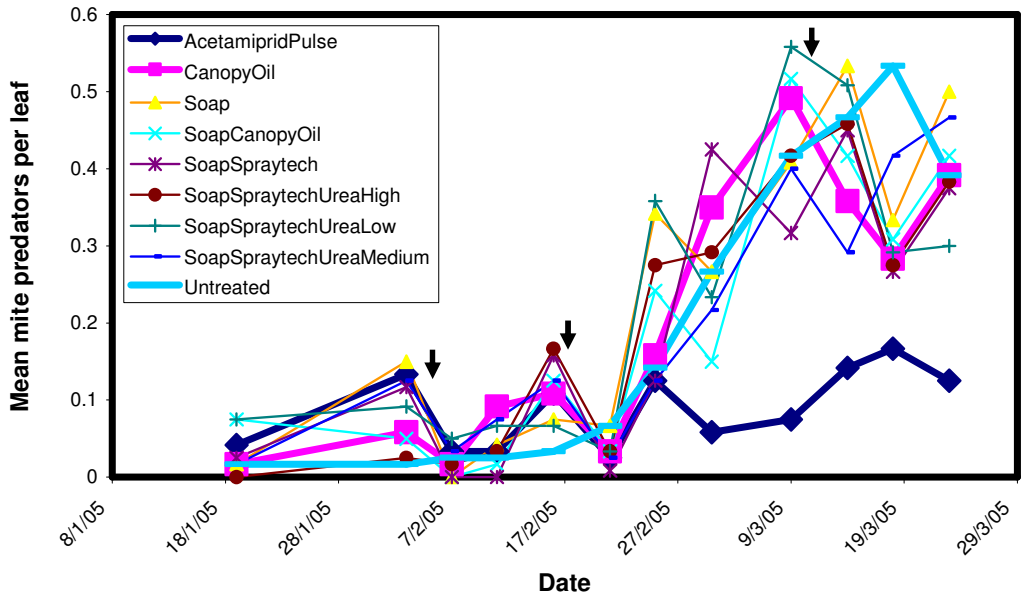

Figure 4. Effect of different insecticide options applied against aphids on predators of spider mites, Experiment 1, ACRI, 2004-05. Arrows indicate spray dates.

Soft options - Experiment 2.

This experiment was later than desired due to difficulties in establishing aphid populations. The plants were cut-out and leaves were quite hard which may explain the poor efficacy of all treatments, including the full rate of acetamiprid plus pulse (Intruder). Though there were significant differences between treatments ($p<0.001$, Figure 5) none of the treatments was

different from the unsprayed control. Initial counts were used as a co-variate in the analysis to allow for differences between plots in starting levels of aphids. The full rate of acetamiprid plus pulse again initially flared mites ($P < 0.001$ across all dates) but mite populations declined naturally at the end of the season as food quality declined (Figure 6). Aphids were not affected in the same way as bacteria in their gut allow them to use even poor quality food.

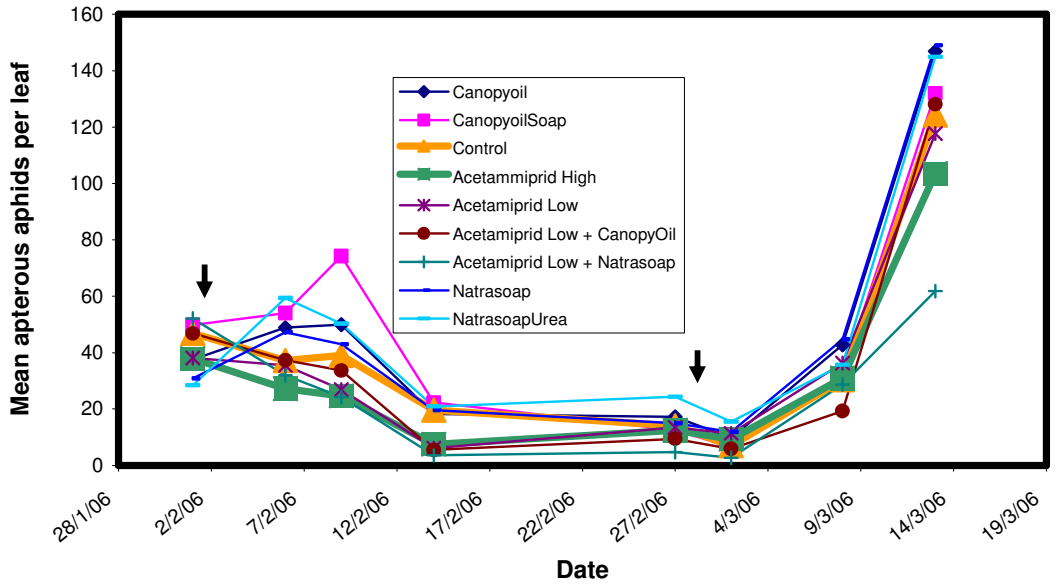

Figure 5. Effect of different insecticide options applied against aphids, Experiment 2, ACRI, 2005-06. Arrows indicate spray dates. Acetamiprid alone at both rates included Pulse.

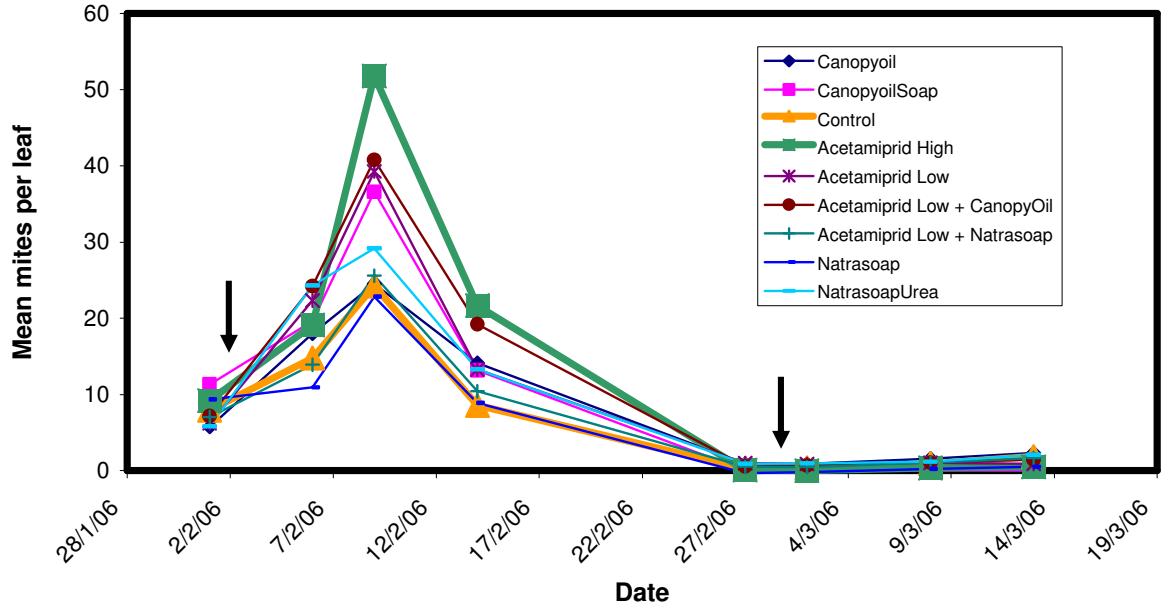

Figure 6. Effect of different insecticide options applied against aphids on spider mites, Experiment 2, ACRI, 2005-06. Arrows indicate spray dates. Acetamiprid alone at both rates included Pulse.

Biopesticides - Experiment 3

Acetamiprid (Intruder) at the full rate plus pulse provided moderate control of the aphids, reducing numbers by about 50% (P = 0.047, Figure 7). Neither of fungal insecticides provided adequate control, though some mortality was seen. Conditions were not idea as the weather in this period was generally hot and dry and the canopy was hard and mature (1st bolls opened during the experiment). Acetamiprid plus pulse also flared spider mite populations (Figure 8).

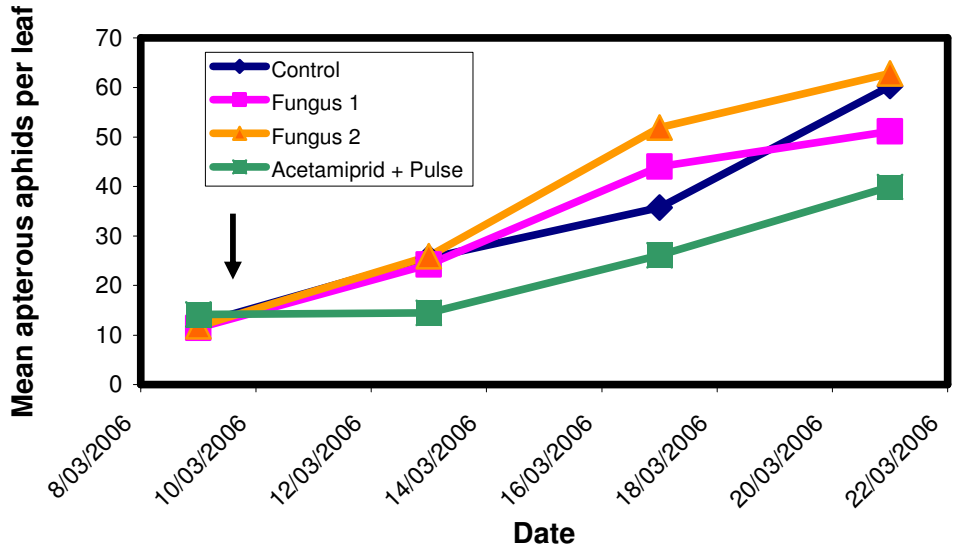

Figure 7. Effect of different insecticide options applied against aphids, Experiment 3, ACRI, 2005-06. Arrows indicate spray dates. Fungus 1 is 639-Metarrhizium sp, Fungus 2 is NSW DPI Aphid Fungus

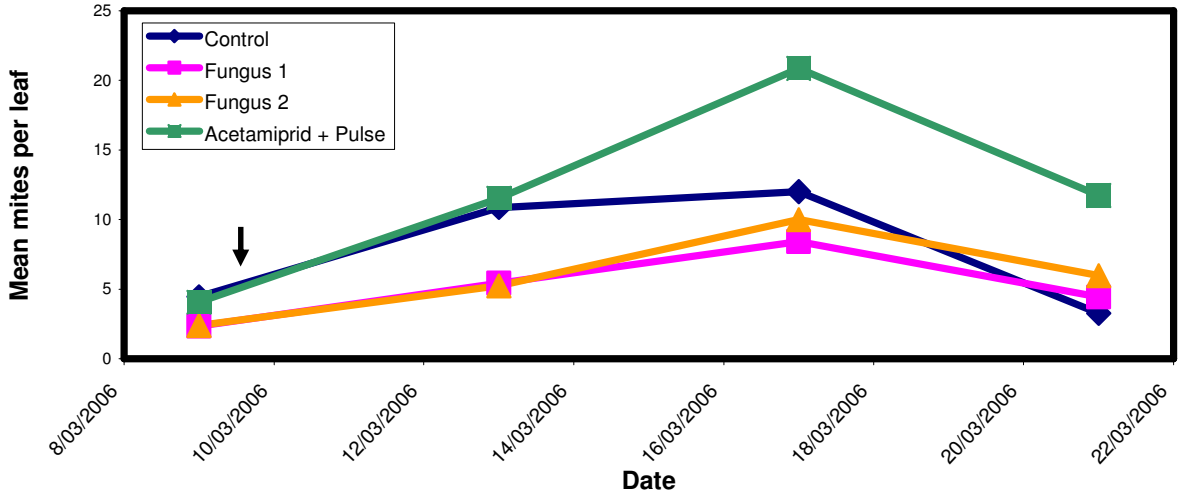

Figure 8. Effect of different insecticide options applied against aphids on spider mites, Experiment 3, ACRI, 2005-06. Arrows indicate spray dates. Fungus 1 is 639-Metarrhizium sp, Fungus 2 is NSW DPI Aphid Fungus

Biopesticides – Experiment 4

Conditions for this experiment were again less than ideal with a mature crop, low relative humidity and high light levels. Nevertheless, when we applied the fungal biopesticides directly to aphids in the field there was significant ($p = 0.04$, Figure 9) though modest control. Initial counts were used as a co-variate in the analysis to allow for differences between plots in starting levels of aphids score. Samples of leaves with sprayed aphids were collected and cultured in the laboratory, resulting in some aphids showing clear fungal infection and death. These aphids, collected from a fungal application under extreme conditions were sent to Becker-Underwood for culturing. The drop from an average score of 4.3 (e.g. about 75 aphids per leaf) to 3.3 (e.g. about 30 aphids per leaf) was quite noticeable for the two Fungal biopesticides.

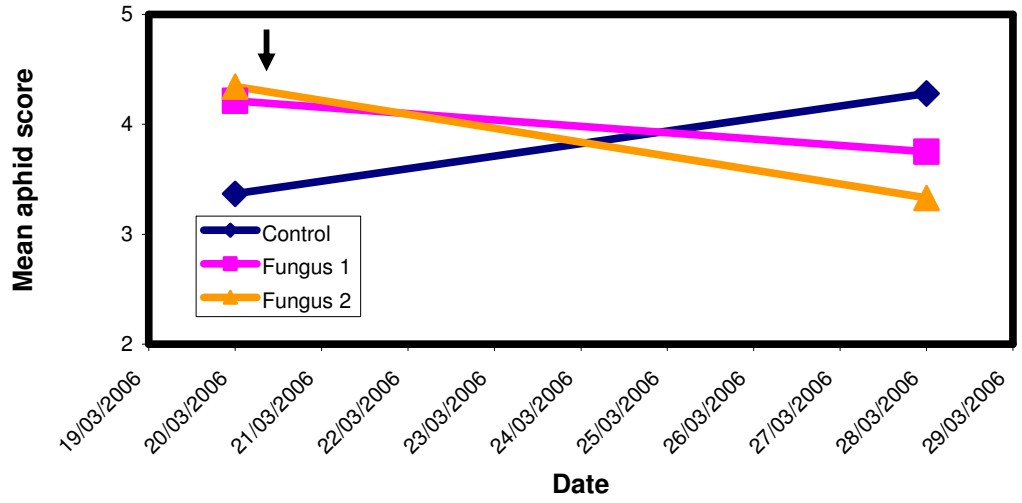

Figure 9. Effect of different insecticide options applied against aphids on spider mites, Experiment 4, ACRI, 2005-06. Arrows indicate spray dates. Fungus 1 is 639-Metarrhizium sp, Fungus 2 is NSWDPI Aphid Fungus

Biopesticide - Experiment 5

The experiment was sprayed on time, but as it was late and cool (April) there were high numbers of parasites that swamped any effect of the fungal pesticides. No aphids were collected.

Biopesticide and Soft options – Experiment 6 (cages)

This experiment was conducted in large field tents. The pre-spray counts were used as co-variates in the analysis to allow for differences in starting values between tents and treatments. Acetamiprid plus pulse provided very good control of aphids; however, the two biopesticides and Greenfire also gave moderate control, preventing aphid populations from increasing ($p < 0.001$, Figure 10). Acetamiprid plus pulse also flared mite populations, similar to earlier experiments (Figure 11). Surprisingly, for the last two sample date Fungus 1 (BC667) provided moderate control of spider mites ($p < 0.001$). When aphid infested leaves were collected and cultured in an incubator it was clear that aphids had been infected with fungus (Figure 12). We noted different types of fungus (data not shown). Infection levels increased initially following a spray, but declined thereafter. Aphids cultured for longer

period showed more infection. Collections of infected aphids were collected and sent to Becker-Underwood for culture.

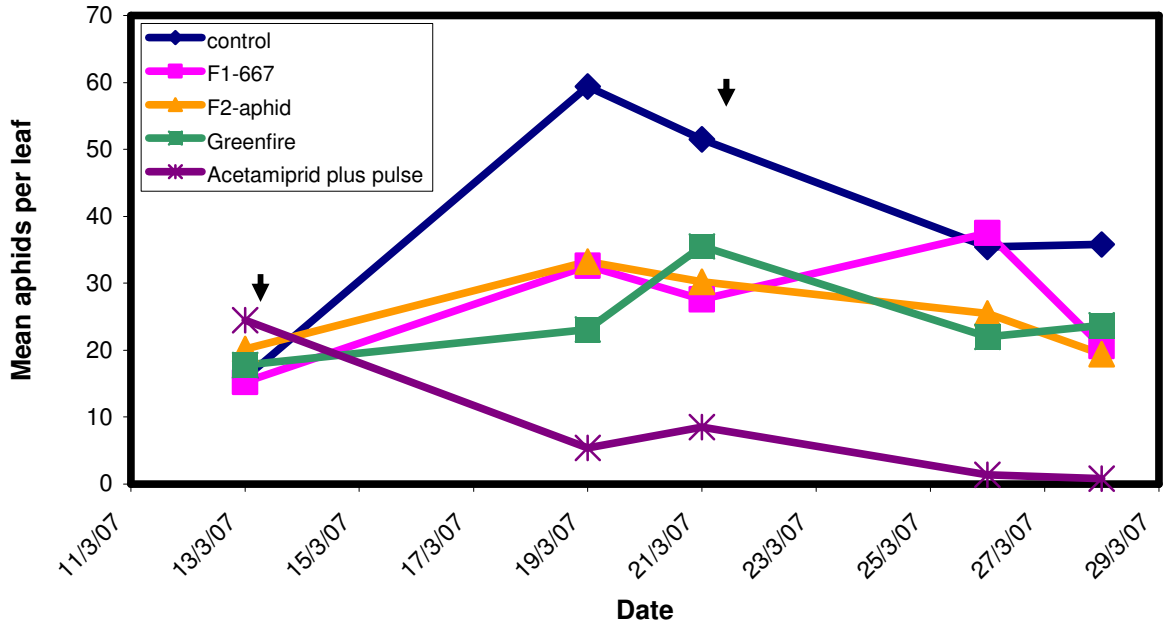

Figure 10. Effect of different insecticide options applied against aphids, Experiment 6, ACRI, 2005-06. Arrows indicate spray dates. Fungus 1 is 667 Beauvaria sp, Fungus 2 is NSWDPI Aphid Fungus

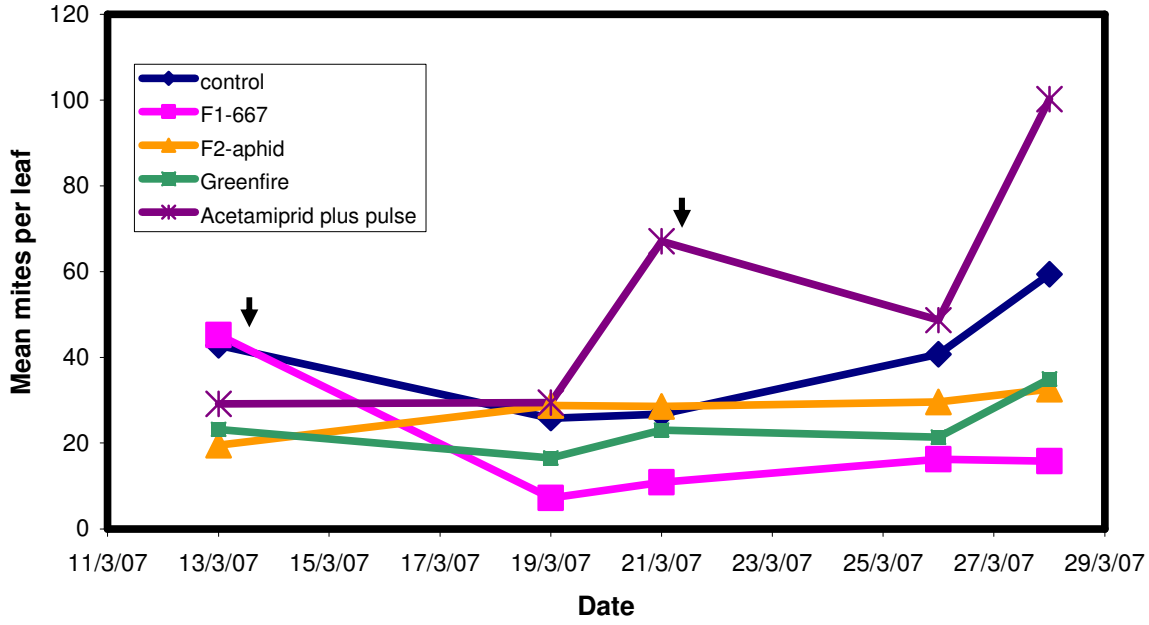

Figure 11. Effect of different insecticide options applied against aphids on spider mites, Experiment 6, ACRI, 2005-06. Arrows indicate spray dates. Fungus 1 is 667 Beauvaria sp, Fungus 2 is NSWDPI Aphid Fungus

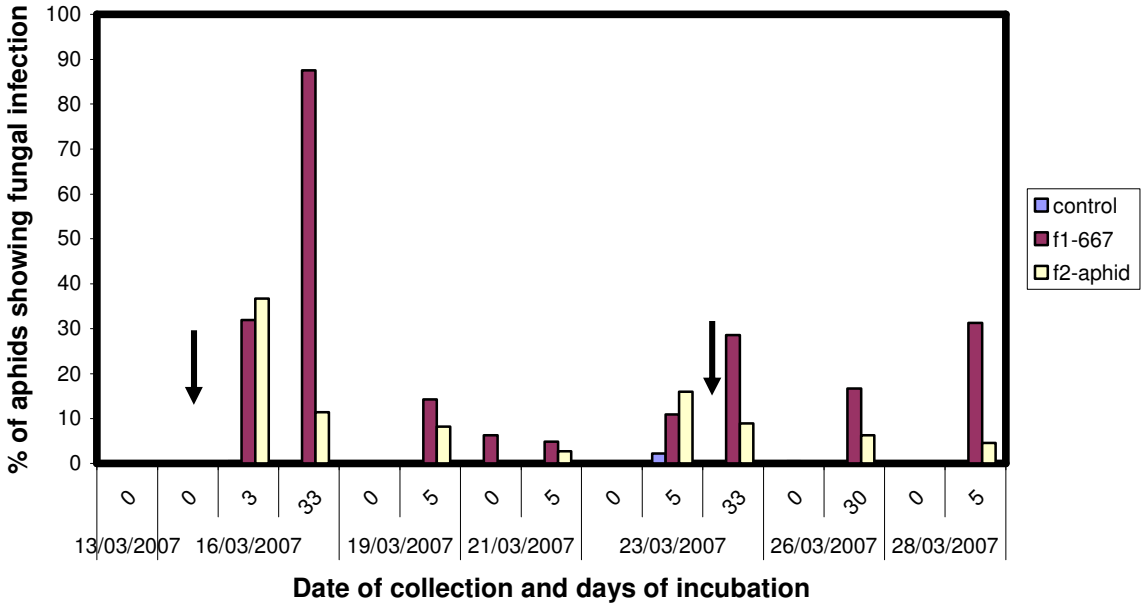

Figure 12. Fungal infection levels of aphids on leaves collected at 3 or 6 days after spraying and cultured in an incubator. Arrows indicate spray dates. Fungus 1 is 667 Beauvaria sp, Fungus 2 is NSWDPI Aphid Fungus

Conclusions for aphid control experiments

Research with aphid control is increasingly difficult due to high numbers of beneficials in a low spray Bollgard II environment. Often experiments are done too late due to time spent waiting for aphid populations to build – despite spraying to control beneficials. Nevertheless, the results from these experiments suggest

12) Acetamiprid plus pulse provides good control of aphids but has a high risk of flaring mites. This will also be a risk if this product or other neonicotinoids are used against mirids.

13) None of the soap or oil options provides adequate control of heavy aphid populations. Canopy oil may be effective if applied to lower density aphid populations (e.g. less than 10-15 aphids per leaf) in a regular program.

14) The lower rates of insecticide with canopy should be examined further as we were unable to evaluate them properly. They may offer greater selectivity, dual modes of action and be cheaper.

15) The biopesticides evaluated are unlikely to provide the high level of control provided by acetamiprid plus pulse. However, efficacy is likely to improve as we select more field adapted strains. If used early these products may be effective at preventing aphid populations from increasing. These products have the added benefit of not flaring mites, and in fact the acaricidal activity of BC667 should be investigated.

To develop an understanding of aphid population distribution through winter and of development and spread in cotton fields

Experiment 7 – Aphid and CBT spread, Leitches Block 2004-05

Although the target plants were infested quite heavily with CBT infected aphids, the aphid populations developed slowly. Nevertheless we were able to record the spread of the aphids in the first 30 days after infestation, and develop a rate of infestations spread (Figure 13). At the fastest, the aphids spread at a rate of 11.6 cm per day along the row, and at the slowest, only 0.3 cm per day. A highly significant finding however is that aphids had spread considerable distances within the first ten days, in some instances. But did this did not result in spread of CBT – only 4 plants developed CBt symptoms, 2 of the target plants developed symptoms at 85 days after infestation, 1 target plant developed symptoms at 62 days after infestation and 1 plant on to which aphids had spread, which was 20cm from the target plant developed symptoms after 85 days. Hence even under potentially ideal condition only 3 of 50 target plants showed infection with CBT.

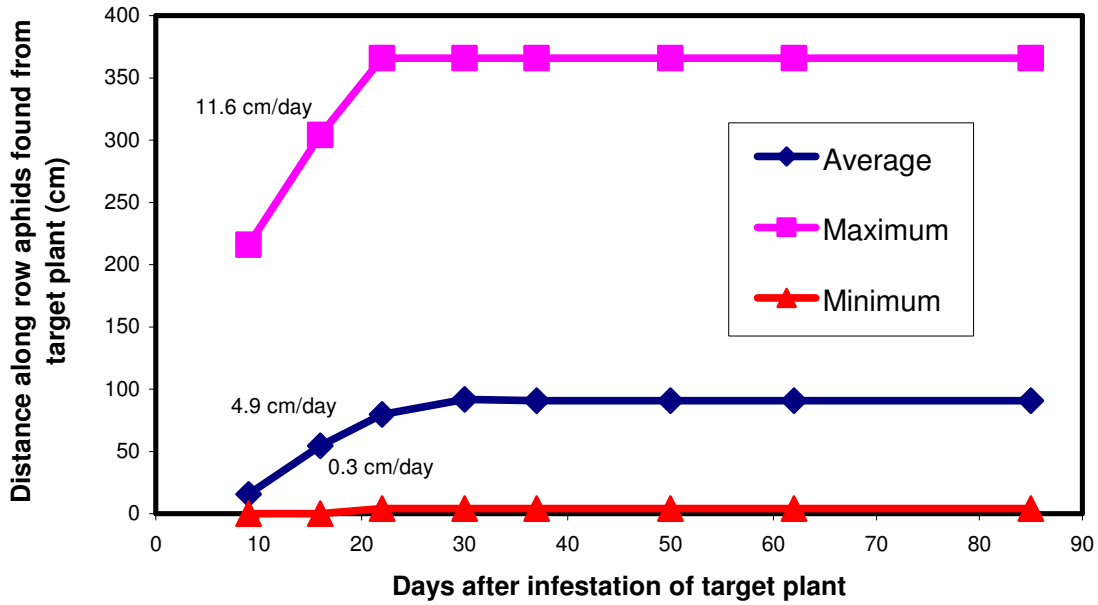

Figure 13. Distance moved by aphids along the row from an infested target plant, Leitches Block, February, 2005.

Experiment 8 – Aphid and CBT spread, Field 1, ACRI, 2005-06.

We measured the spread of aphids both along rows and across rows. Aphid populations in both the sprayed and unsprayed treatments spread at about the same rate across rows (Figure 14). The spread across rows was basically a linear progression. The minimum rate of spread was 0.1 rows per day and the maximum was 0.24 rows per day. In sprayed and unsprayed there a lag of about 17 days before there was any spread across rows. The spraying did caused slightly faster movement across rows.

Movement along the rows showed an exponential progression, slow at first then increasingly faster – these were capture by regressing ln(days since infestation +1) against distance moved. The realationships for the maximum, mean and minimum distances moved were all highly significant ($p < 0.001$, $r^2 > 0.9$), and they are shown in Figure 15.

Of the 8 initial target plants infested with CBT aphids, only 4 developed CBT symptoms, despite being infested with and these did not show until 28th February, almost 8 weeks after infestation. In terms of CBT spread, only two plants showed symptoms, after 8 weeks, and the furthest of these was only 30 cm from the target plant (Figure 16). No CBT plants were found in other rows.

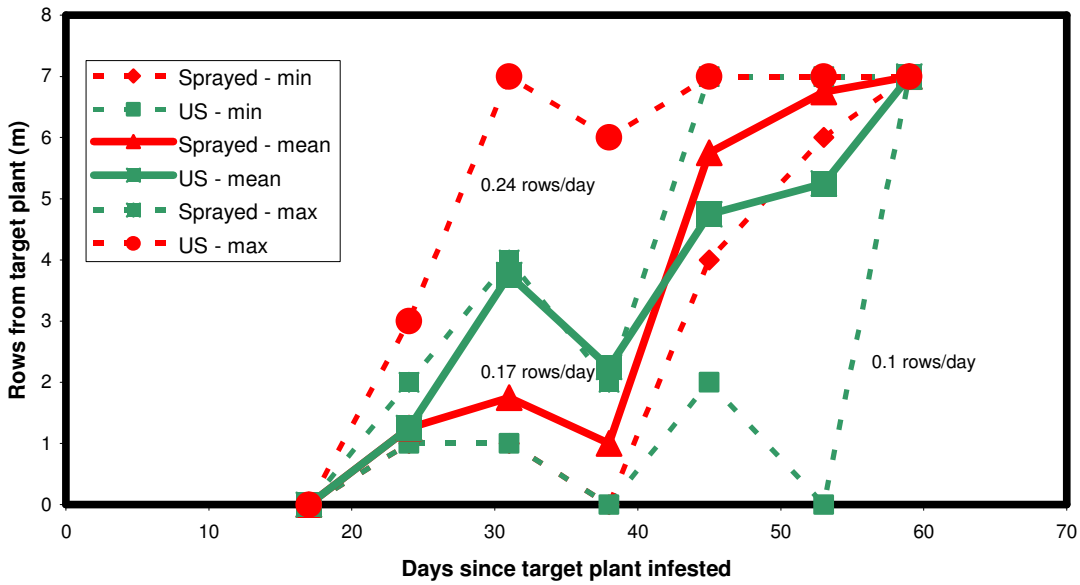

Figure 14. Distance moved by aphids across rows from an infested target plant under unsprayed and sprayed conditions, Field 1, February, 2005-06

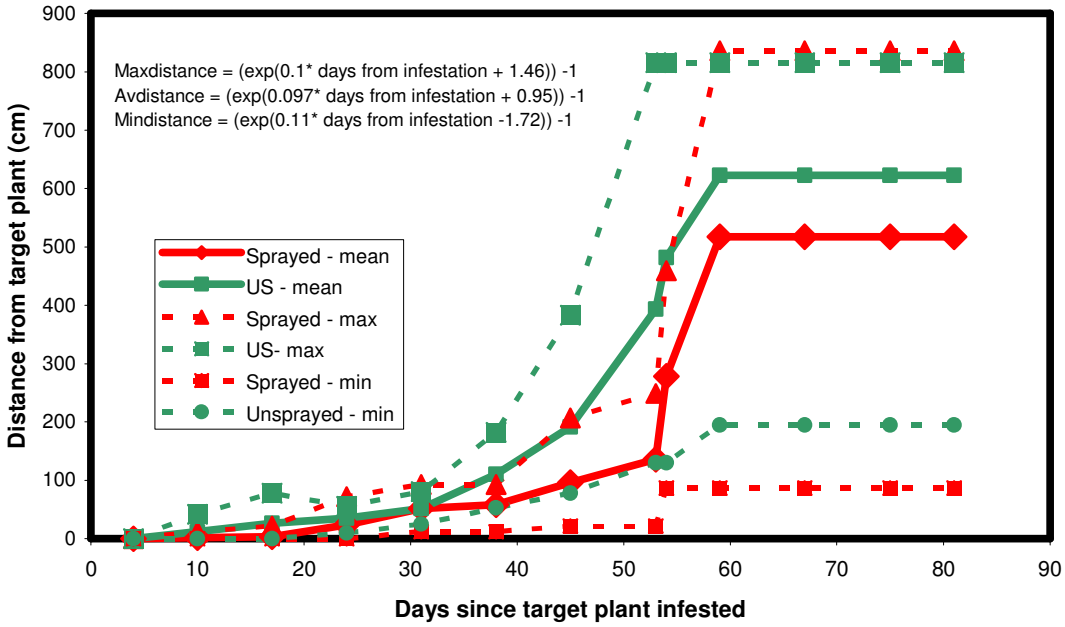

Figure 15. Distance moved by aphids along the row from an infested target plant under unsprayed and sprayed conditions, Field 1, February, 2005-06

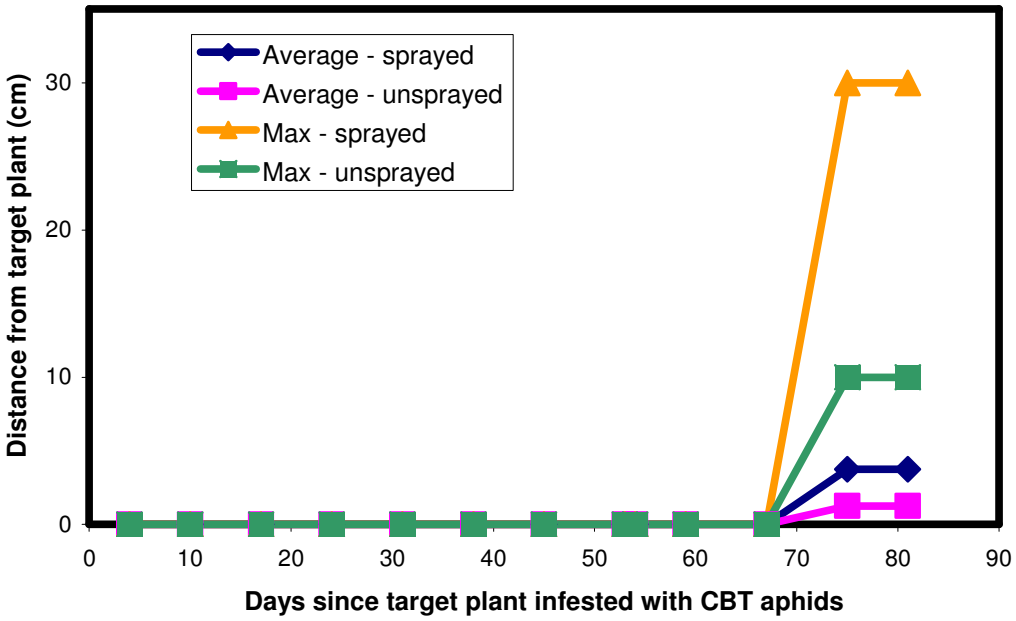

Figure 16. Distance of furthest CBT affected plant along the row from an infested target plant under unsprayed and sprayed conditions, Field 1, February, 2005-06

Experiment 9 –CBT effects on yield, Field 1, ACRI, 2005-06

The aphid populations developed in the treatments (clean or CBT) and were controlled after about 2 weeks. Despite every plant being infested in the CBT treatment symptoms took a long time to develop and only a maximum of about 25% of plants developed symptoms of the disease (Figure 17). The % of plants showing symptoms can decline sometimes as plants 'lose' symptoms and redevelop them. Note that some plants in a 'clean' treatment also developed CBT symptoms.

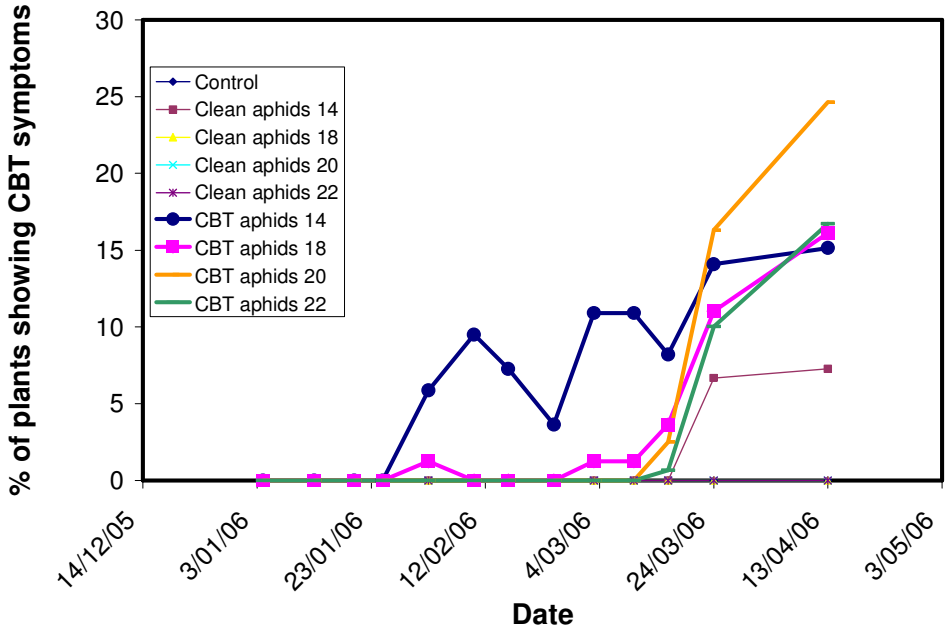

Figure 17. Proportion of plants showing symptoms of CBT infection in each treatment, Field 1, February, 2005-06

Despite the small proportion of plants showing CBT there was a trend toward the CBT infested plots having lower field (P = 0.06), but only the infestation at 14 nodes was marginally significant (Figure 18).

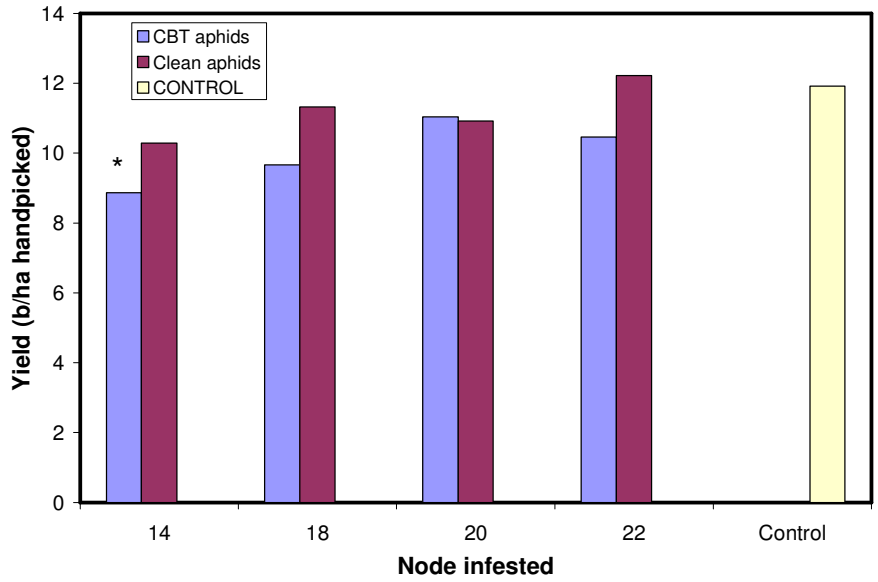

Figure 18. Yield of cotton infested with CBT carrying aphids, clean aphids or not infested at different stages of development (nodes), Field 1, February, 2005-06. * is significantly different from the Control at p = 0.06.

Experiment 10 – Aphid and CBT spread, Field 1, ACRI, 2006-07

In this experiment a CBT affected plant infected with aphids was placed in the centre of each plot and dispersal was monitored. Aphids in the sprayed treatment spread faster across rows than those in the unsprayed treatments (Figure 19). Spread of CBt across rows was fairly limited; one plant infected with CBT was found in row 1 after 5 days but CBT was not found in row 3 until 61 days (1 plant) after infestation. Along the rows aphids moved about 4.5m in about 40 days, but thereafter the spread was very low, probably to low numbers. Spread was again faster in the sprayed treatment. The spread of CBT along the row was much further than in the previous years experiment, and lagged behind the spread of aphids by about 40 days.

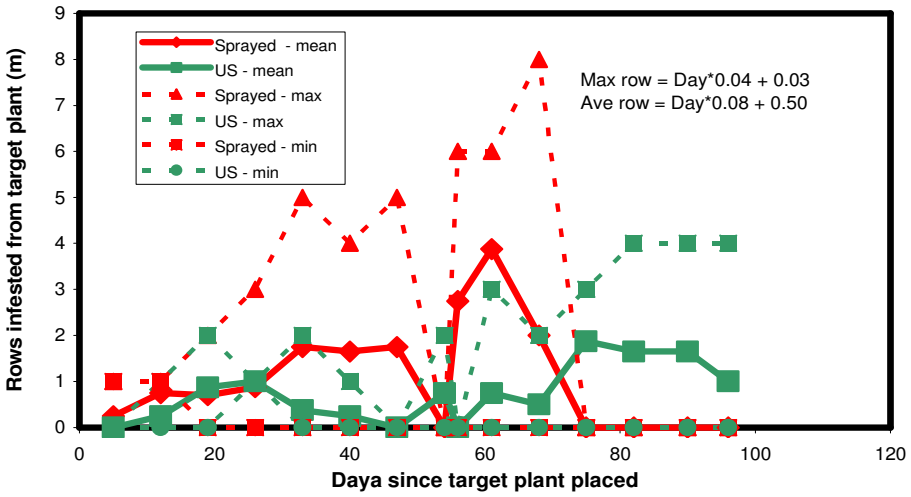

Figure 19. Distance moved by aphids across rows from an infested target plant under unsprayed and sprayed conditions, Field 1, February, 2006-07

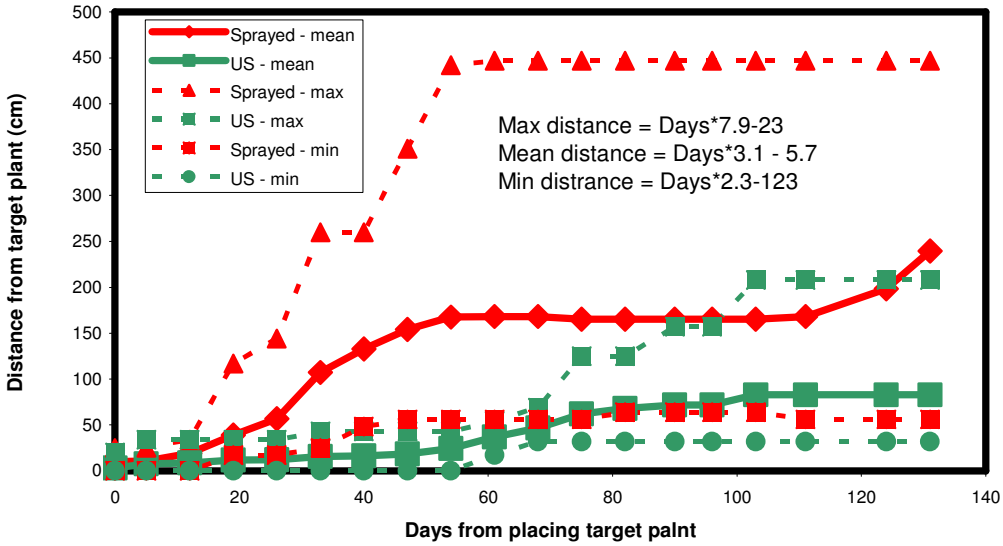

Figure 20. Distance moved by aphids along rows from an infested target plant under unsprayed and sprayed conditions, Field 1, February, 2006-07.

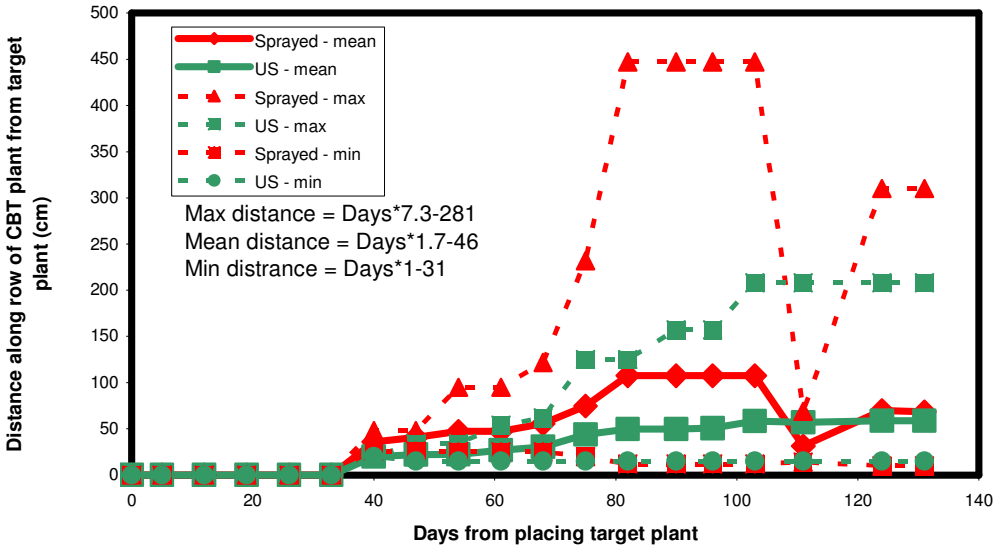

Figure 21. Distance moved by CBT along rows from the source plants under unsprayed and sprayed conditions, Field 1, February, 2006-07.

Experiment 11 –CBT effects on yield, Field 1, ACRI, 2006-07

Caging aphids on the plants was much more effective at ensuring transmission of CBT disease and the proportion of pl;ants infected with the disease increased to at least 60% in all treatments and was as high as 80%(Figure 22). The mean rating of symptoms also increased over time, indicating plants with more severe symptoms of the disease (Figure 23). It is important to note that the lag between infestation with aphids and the disease being first found is about 6 weeks.

CBT significantly reduced the yield of infected plants compared with 'control' or 'clean aphid' plants. However, it is noticeable that even the apparently CBT free plants in the +CBT treatments also had reduced yield – indicating that they are probably also infected but are not showing definitive symptoms. It is also noticeable that the presence of the aphids and cages has reduced yield compared with the completely uncaged and aphid free controls and this effect is stronger the earlier the treatment was imposed (as expected).

Looking at overall yield per treatment (rather than per plant) it is clear that the earlier infestation more strongly reduced yield. This is not unexpected as the yoiunger plant have less fruit at the time of infection so more of the fruit that produce after this point will be affected. In comparison, infection occurring later has little potential to reduce yield a plants will have matured

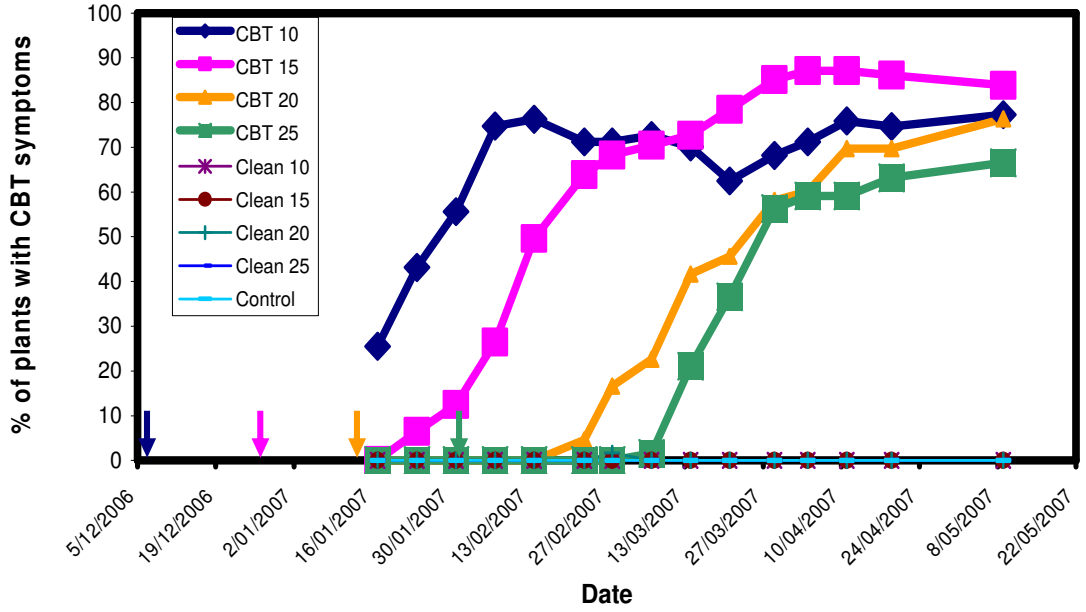

Figure 22. Proportion of plants showing symptoms of CBT infection in each treatment, Field 1, February, 2006-07

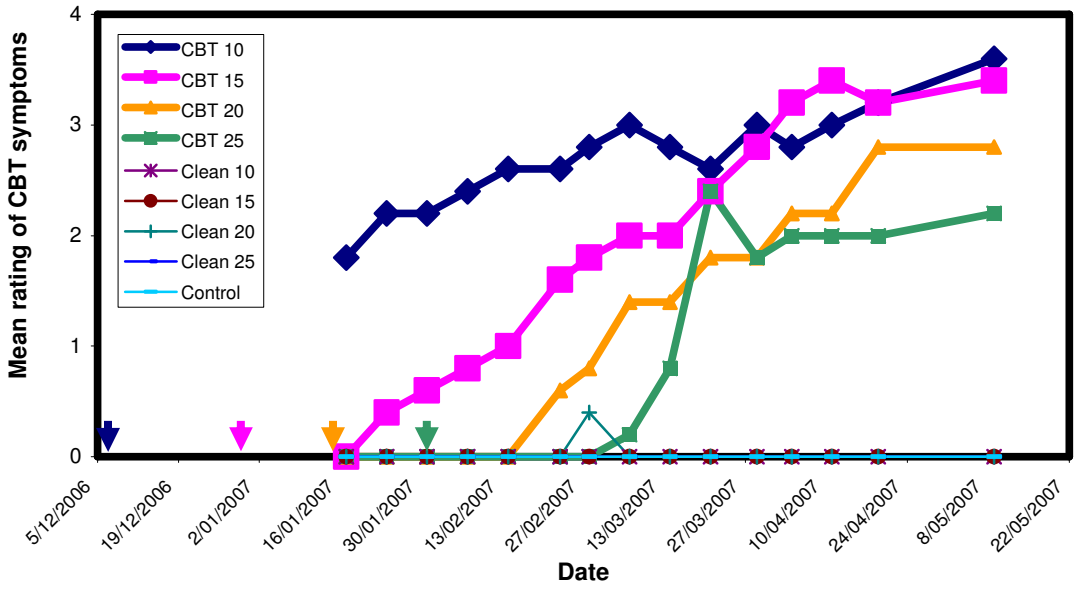

Figure 23. Mean rating of symptoms of CBT infection in each treatment, Field 1, February, 2006-07

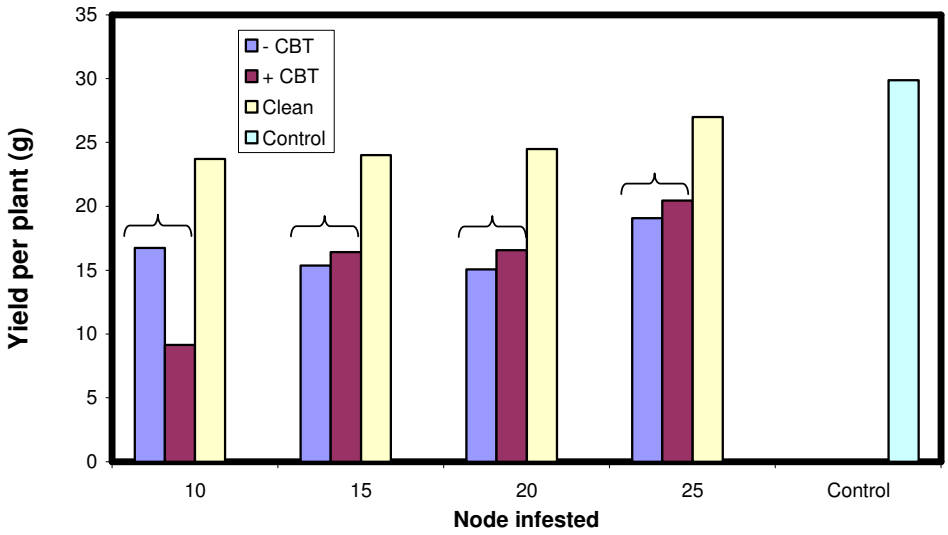

Figure 24. Yield of cotton plants infested with CBT carrying aphids, clean aphids or not infested at different stages of development (nodes), Field 1, February, 2006-07. The –CBT and +CBT indicates plants showing symptoms of CBT or not showing CBT in plots infested with the disease.

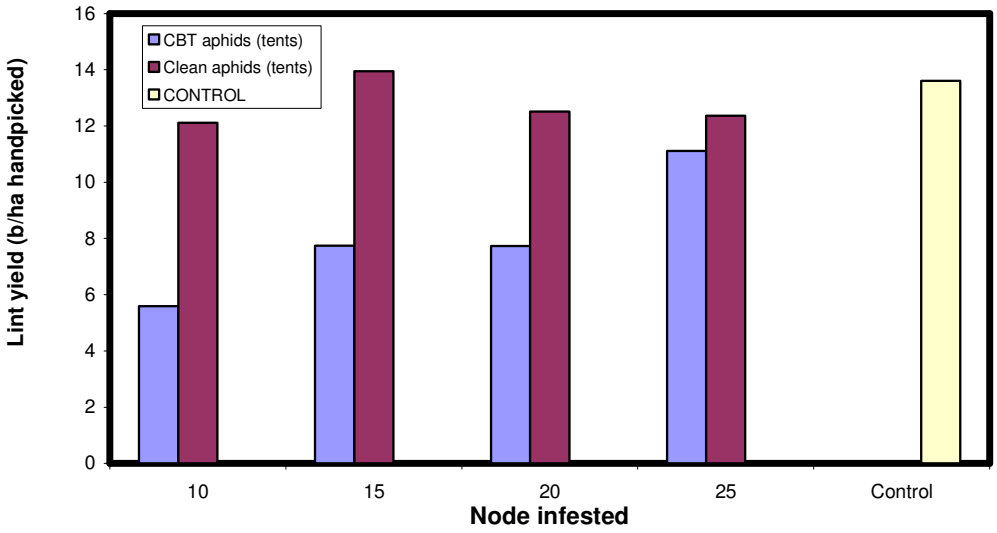

Figure 25. Yield of cotton infested with CBT carrying aphids, clean aphids or not infested at different stages of development (nodes), Field 1, February, 2006-07.

Conclusions for CBT epidemiology experiments

Research with the spread of aphids and CBT and on the effect of CBT on yield has been completed, though further research on the spread would be beneficial. Key conclusions are

1) The aphid spread experiments indicate that if CBT infected aphids enter a field and settle on cotton plants, it is likely that the aphids that were borne on these plants will

spread to adjacent plant before the diseases latent period has been reached. This means the aphids will spread much faster than the disease, which may well be left behind at the initial infested plant. This situation is likely to be more extreme in the field because it is likely that only one or two aphids will settle on a plant – so the effectiveness of transmission is likely to be low and the latent period longer (see next section) which reduces the risk from the disease unless the level of influx of aphids with CBT is very high.

2) In contrast, if the infection is initiated by placing a CBT affected plant with aphids into the field then the latent period is basically overcome. Aphids spreading from this infection plant would already be carrying the disease and any aphids moving to nearby plants will likely infect them. This situation is exacerbated by the semi-persistent nature of the disease – e.g. adult aphids with the disease will be capable of infesting new plants probably for their life span. This situation is analogous to stubb cotton carrying CBT in a field and highlights the key role of field hygiene.

3) Rates of spread of aphids and CBT have been documented and are generally faster where insecticide was applied.

4) CBT affects yield more strongly the earlier it enters a crop. We now have date on the likely yield effects. Significantly, some plants that do not show symptoms are also probably infected.

To continue experiments to understand the epidemiology of CBT

Latent period of CBT in plants

Our experiment was managed successfully and showed that plants that had been infested with CBT carrying aphids 10 days earlier were capable of transferring the disease to clean aphids. However, it should be noted that this was when we infested the source plants with 100 CBT carrying aphids. In the field this is likely to be a much lower number, eg one or two colonising aphids per plant. Earlier studies have shown that at these densities transmission success is very low (1 plant in 20 successfully infected), and it is also likely that the time taken for the disease to build up in the plant will be much longer as well and hence the latent period could be longer. This would mean that the rate of spread in commercial field may be quite slow.

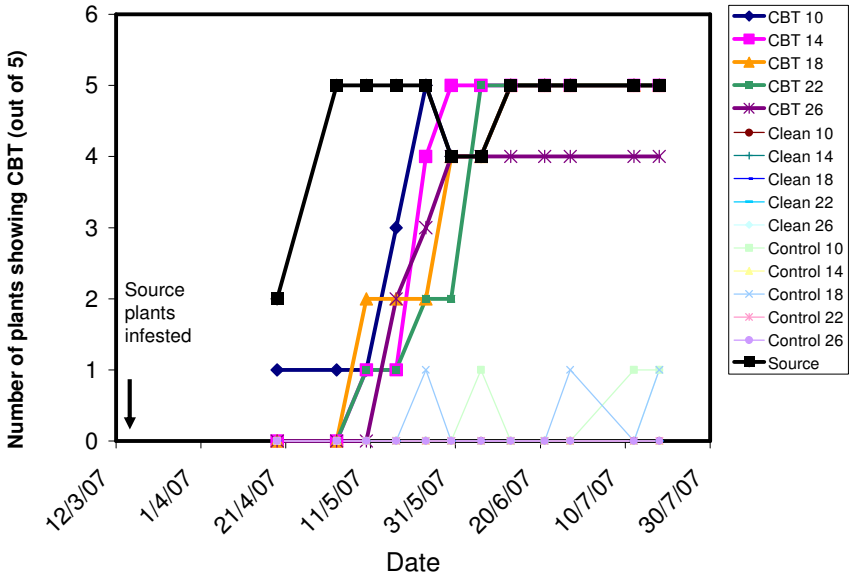

Figure 26. Transmission of CBT from CBT infected cotton plants to healthy plants at 10, 14, 18, 22 or 26 days after infection, glasshouse, ACRI, 2006-07.

Transmission by 'Yellow Dwarfs'

Our experiment showed that yellow dwarfs can transfer CBT between plants but do so poorly compared with healthy normal sized aphids (Figure 27). Transmission by 50 yellow dwarfs was similar to that of 5 normal aphids.

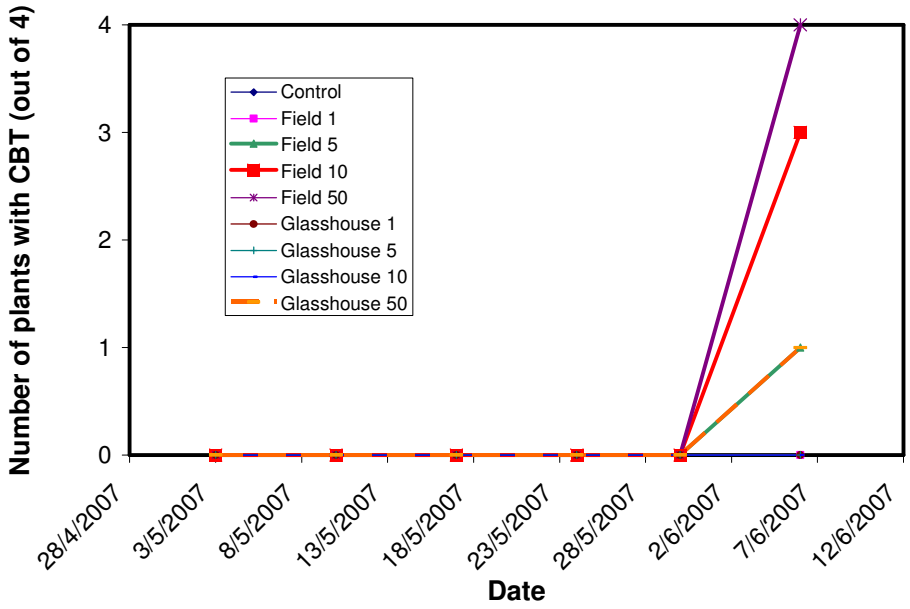

Figure 27. Transmission of CBT from CBT infected cotton plants to healthy plants at 10, 14, 18, 22 or 26 days after infection, glasshouse, ACRI, 2006-07.

To investigate the abundance of aphids and beneficials in relay cropping systems

We monitored aphid populations in each of the relay crops. Significant aphid populations were found in sorghum and lucerne, but these were species that do not attack cotton (Figure 28). Only cotton hosted Aphis gossypii.

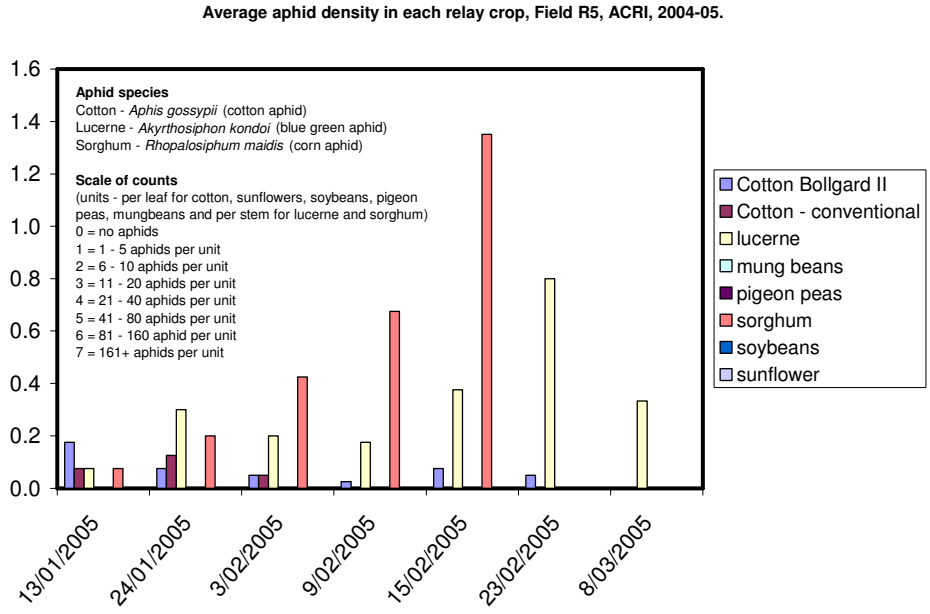

Figure 28. Aphid populations on relay crops. River Block 5, ACRI, 2004-05.

When we caged cotton aphids on plants we found that only sunflowers and cotton sustained populations (Figure 29). Aphids died off on the other hosts. This suggests that sorghum or lucerne as relay crops could help build aphid predators and possibly parasites with little risk to cotton.

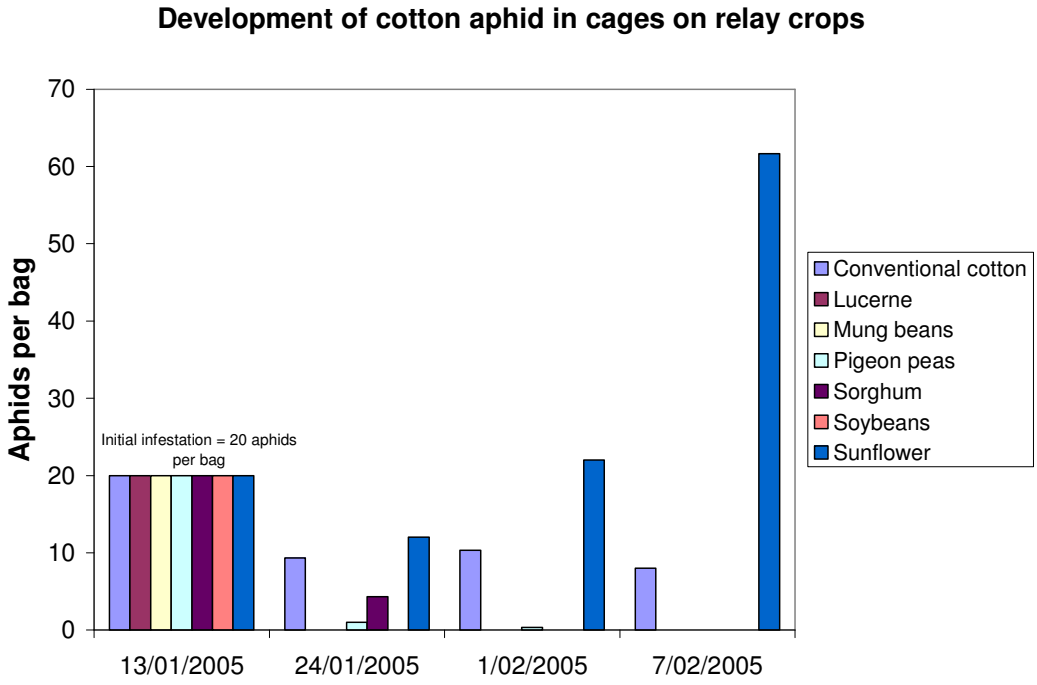

Figure 29.Development of cotton aphid populations caged on a range of crops. River Block 5, ACRI, 2004-05.

To facilitate continued screening for elite varieties with resistance to CBT.

The basic strategy used to facilitate screening of cotton lines for resistance to CBT is outlined in Figure 30. Screening for resistance was predominantly done in the field, where large numbers of lines can be evaluated. However, generating outbreaks of aphids infected with CBT in the field is difficult due to the effects of predators and parasites. To back up the field screening we also screened some lines in the glasshouse. This is generally more reliable, but the numbers of lines that can be screened at a time is limited. The variable lag between the plants being infested and the symptoms of the disease showing up – anywhere from 3 to 8 weeks means that plants must be retained to a large size in the glasshouse. In contrast, screening for resistance to Blue Disease can be completed in a little over two weeks because symptoms of the disease show up quickly.

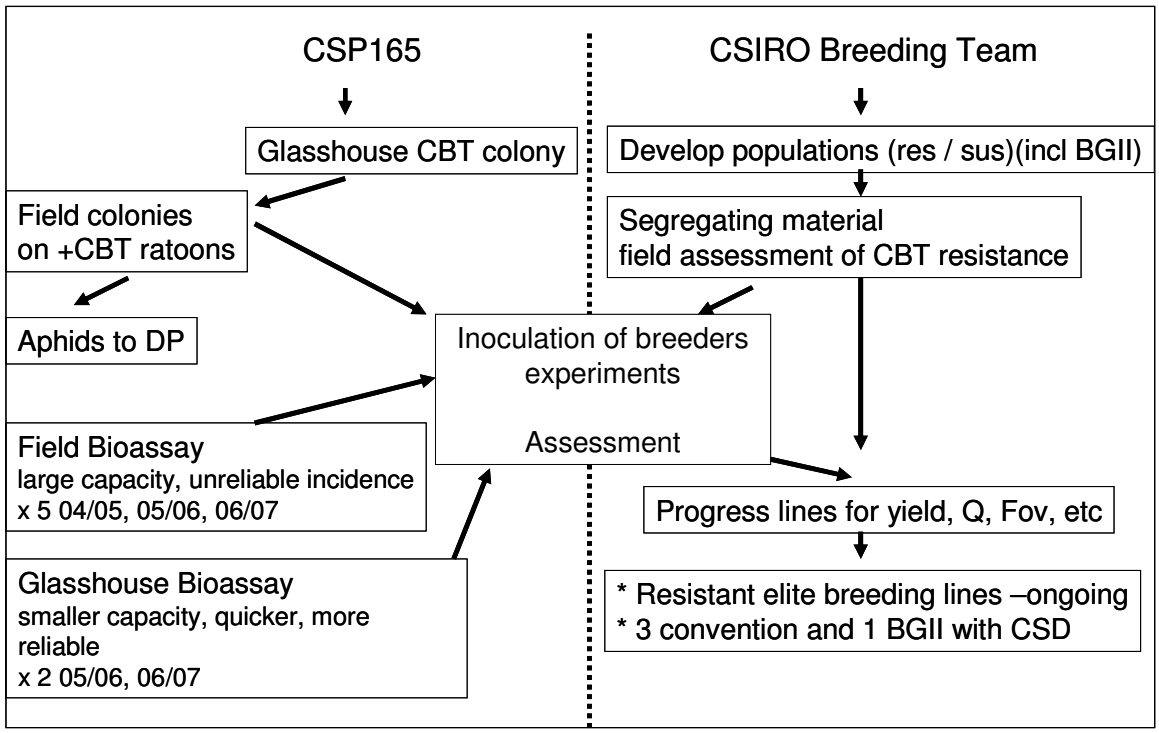

Figure 30. Strategy to facilitate screening of resistance to CBT in breeding lines.

To link the knowledge of aphid spread and the epidemiology of CBT to develop a method to estimate the progress of CBT infection across fields

Progress on this objective needs additional data, which with agreement from Dr Ian Taylor at CRDC will be collected in the 2007-08 cotton season. However, some broad conclusions can be made about the risk of CBT entering fields:

1. CBT appears to be relatively common in aphid populations. This is based on observations made when surveying field to collect aphids for insecticide resistance testing (With Dr Grant Herron, NSW DPI). CBT affected plants are often observed in the centre of aphid hotspots – often only one or two infected plants are found. For instance, in 2005-06 we found CBT affected plants in aphid hotspots in 6 of 8 sites.
2. Transmission efficiency of CBT by aphids depends on density and at the low densities of aphids that are likely to typically colonize individual plants this may be a major factor in limiting the level of infection in field. Exceptions would be in years were season conditions generated high numbers of aphids and of alternative hosts with CBT – which could then colonise cotton crops at higher densities.
3. The rate of spread of aphid populations while they are in the apterous form (non-winged) is relatively modest, both across and along rows. Once populations reach densities that produce alates (winged forms) the spread of aphids could be much faster.
4. The latent period can be relatively short (about 10 days), however, in the field it is likely to be longer due to lower numbers of aphids colonising plants. This needs further experimentation to sort out. These experiments are complicated to do, but we aim to investigate the latent period when low numbers of colonising aphids are involved.

5. The effect of CBT on yield is greater the earlier that plants are infected.

Putting these issues together it would seem that the risk of CBT is limited to years in which high cotton aphid populations occur in spring and/or where there is a lot of stubb cotton carrying the disease from one season to the next combined with an aphid populations. Management strategies will of course influence these situations with factors that favour aphid build up making the risks higher.

Outcomes

7. Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

This project has made significant progress toward all of the planned outcomes, despite the many difficulties of working with a disease, host, crop system. In particular we have;

- Identified direction and options for aphid control + mite risks
- Quantified spread of aphids and CBT, and yield effects
- Identified the latent period
- Identified best relay crops for aphid management
- Successfully facilitated screening for resistance to CBT.

8. Please describe any:-
   a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.); nil
   b) other information developed from research (eg discoveries in methodology, equipment design, etc.); nil
   c) required changes to the Intellectual Property register: nil

Conclusion

9. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?

This project has four main conclusions

1. There are opportunities to develop biopesticides for aphids in cotton though this may be limited by the capacity to effectively deliver the pesticide in the field. Low rates insecticides with soaps or oils should also be explored further.

2. Due to the relatively poor transmission of CBT, the latent period and modest rate of spread of aphids CBT would appear to be a low risk to cotton, especially in years with low winter rainfall that provides few overwinter hosts for aphids or the disease. This has been the situation over recent seasons, and aphid populations and CBT incidence have been low. Nevertheless, we have still been able to find CBT affected plants in aphid hotspots. Cotton crops following wetter winters have a greater risk, but this could be managed by careful monitoring and if necessary control of aphids if natural enemies do not control them anyway. Inappropriate management of aphids in low risk years, such as using very low thresholds, simply selects for resistant clones, creating control problems. Similarly, inappropriate management in high risk years, such us using broad spectrum products to which aphids are resistant, could transform an easily managed situation into a problem.

3. Lucerne and sorghum may be good relay crops for management of cotton aphids as they do not host cotton aphid but do host other species on which predators and parasites could build up.

4. This project has contributed to screening methods to identify cotton lines that are resistant to CBT.

Effective transmission of these messages to industry may help alleviate some the concerns about the risk of CBT and allay the fears of growers and consultants that now have a zero tolerance towards aphids. This attitude has in the past contributed to the rapid development of resistance in aphids to the carbamates and organophosphates.

Extension Opportunities

10. Detail a plan for the activities or other steps that may be taken:
    (a) to further develop or to exploit the project technology.
    Ongoing screening of lines for resistance to CBT is proposed as part of the joint venture between CSIRO and CSD.

    (b) for the future presentation and dissemination of the project outcomes.
    The outcomes of this project have been presented at the final report presentations in August 2007 and have also been presented in detail to the leader of the Insect Extension Team. Discussion will need to be held to develop a plan to extend outcomes from this project.

    (c) for future research.
    The need to complete research on the latent period and on the spread of aphids and CBT has been raised with Dr Ian Taylor who has agreed this could be included as part of a recently funded project. It would also be very beneficial to determine the agent of CBT. This has been done recently for blue disease in Brazil. We are progressing the opportunity to work with on of the Brazilian group (Regis Correa) to evaluate of primers developed for blue disease work for CBT.

8. A. List the publications arising from the research project and/or a publication plan.
    (NB: Where possible, please provide a copy of any publication/s)

    Outcomes of this research have been progressively extended to growers at industry meetings including the CSD/CSIRO Science updates and at the CCA AGM meetings. Presentations on CBT, aphid hosts and management have also been made to the FUSCOM group, CSD Board. Ms Smith, Dr Mensah and Dr Wilson also participated in the Cotton Aphid Management Project Team (CAMPT) meetings to review research on aphids (December 2006).

Industry publications

Wilson, L., Heimoana, S., Smith, T., Herron, G. and Franzmann, B. (2004) Research on aphid ecology and management. Proceedings of the 12th Australian Cotton Conference, Broadbeach, 10th-12th August, Broadbeach Qld, pp 523-531

Wilson, L., Hickman, M. and Deutscher, S. (2006) Research update on IPM and secondary pests. Proceedings of the 12th Australian Cotton Conference, Broadbeach, 8th-10th August, Broadbeach Qld, pp 249-258\

Smith, T., Wilson, L., Heimoana, S., Herron, G. and Franzmann, B. (2006) Overwinter host plants of cotton aphid (*Aphis gossypii*) and implications for managing abundance and resistance. Proceedings of the 12th Australian Cotton Conference, Broadbeach, 10th-12th August, Broadbeach Qld, pp 479-483

Scientific Publication

A. Ali, A. Reddall, J. Roberts, LJ Wilson and MA Rezaian (2007) Cytopathology, mode of aphid transmission and search for the causal agent of cotton bunchy top disease. Journal of Phytopathology 155: 220-227.

B. Have you developed any online resources and what is the website address?

Outcomes from this study have contributed to updating the 'Impact of insecticides and miticides on beneficial insects' table that is published in the Cotton Pest Management Guide and is also available via the Cotton CRC website at (http://web.cotton.crc.org.au/content/Industry/Publications/PestsandBeneficials/IntegratedPestManagementGuidelines.aspx).