



FINAL REPORT 2017

For Public Release

Part 1 - Summary Details

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CRDC Research Program: 1 Farmers

Part 2 – Contact Details

Administrator: Ms Lesley Cox

Organisation: NSW Department of Primary Industries

Postal Address: Programs Unit,
Locked Bag 21, Orange NSW 2800

Ph:02 6363 7869 **Fax:** 02 6391 3134 **E-mail:** programs.admin@dpi.nsw.gov.au

Principal Researcher: Dr Sandra McDougall, Leader Southern Irrigated Cropping

Organisation: NSW Department of Primary Industries

Postal Address: Yanco Agricultural Institute PMB Yanco NSW 2703

Ph:02 6951 2728 **Fax:** 02 6951 2692 **E-mail:** Sandra.McDougall@dpi.nsw.gov.au

Supervisor: Deb Slinger, Director Southern Cropping

Organisation: NSW Department of Primary Industries

Postal Address: Wagga Wagga Agricultural Institute PMB Wagga Wagga
NSW 2650

Ph:02 6938 1901 **Fax:** 02 6938 1809 **E-mail:** Deb.Slinger@dpi.nsw.gov.au

Signature of Research Provider Representative:

Date Submitted: _____

Part 3 – Final Report

Background

1. Outline the background to the project.

The cotton industry in southern NSW has expanded from negligible areas less than a decade ago to 70,680 ha harvested in 2014, 44,201 ha in 2016, and predictions of 90,000 ha in the 2017/18 season, with plantings into Victoria. Three gins have opened in the south; one each at Whitton (2012), Carathool (2014) and Hay (2015). Since cotton production first moved to the south, growers have reported having to control thrips during establishment, and mirids and green vegetable bug (GVB) mid season.

We know that early sprays against thrips can disrupt the natural enemy complex, potentially leading to outbreaks of secondary pests such as spider mites, aphids and whiteflies and that thrips themselves are predatory on mites (Wilson et al. 1996, 1998; Milne and Walter 1998). The risk to reducing natural enemies is further increased if follow-up sprays are made targeting mirids or GVB.

Previous research has shown that cotton has high potential to recover from thrips damage (Wilson et al. 2003, 2009). However this is influenced by thrips density and duration of populations, with recovery poorer from high density populations that persist longer. Sufficient crop compensation is also less likely in shorter season regions, however, data was lacking for the southern regions, and growers and agronomists were unsure whether the Industry thrips thresholds based on data from the northern regions would hold in the south. Similarly, thresholds for mirids were based on data from the Darling Downs region and thresholds for shorter season cotton areas were half those of full season areas (Khan et al. 2004, 2006), but again data was lacking for southern regions.

Another concern for the southern cotton area was the relatively higher incidence of western flower thrips (WFT), *Frankliniella occidentalis* on a range of horticultural crops and the potential for it to be a larger component of the thrips species complex on cotton. WFT was first identified in Australia in 1993 (Malipatil et al 1993) and spread across Australia over the next decade. Given high levels of insecticide resistance for WFT (Herron and James 2005, Thalavaisundaram et al., 2008, Herron et al., 2010, Marshall and Herron 2016), there was concern that it could be a far more significant problem in the south than was experienced in the northern cotton production areas.

The significant expansion and investment in cotton in southern NSW (Hillston, Condobolin, Griffith, Coleambally and Berrigan) led to the commissioned project *Moving in and out of cotton – Identifying farming systems issues in southern NSW irrigation areas* (Sykes et al. 2013) and a subsequent extension think-tank held in Griffith in April 2013 identifying the need for southern research capacity and focusing on early crop establishment as priority issues. The rationale being that the shorter growing season allows for less leeway in crop establishment and harvest, and for higher crop establishment costs. Thrips is a key pest at crop establishment. Analysis of the crops that entered the Cotton Grower's Association crop competition in 2013 highlighted that growers were applying at least 2 and up to 6 insecticides, largely to control sucking pests such as thrips, mirids, GVB and mites (O'Keeffe pers com).

The distances from the Australian Cotton Research Institute (ACRI) and other northern research centres preclude regular visits or high input research experiments, hence the

need to develop some local cotton research capacity. NSW DPI has a major research station based at Yanco with researchers and research development officers with experience working in a range of irrigated cropping systems and available to work in cotton.

This project was developed by the three entomologists at Yanco in conjunction with Kieran O’Keeffe, local Cotton Info officer, local agronomists and growers, and ACRI entomologists: Lewis Wilson (CSIRO) and Robert Mensah (NSW DPI). The project focused principally on validating the thrips threshold (Anon 2012) through commercial scale experiments, understanding potential impact of early season thrips damage on yield through small plot compensation experiments and evaluating efficacy of alternate thrips insecticide options. Seasonal invertebrate pest and beneficial patterns were evaluated in both Bt and conventional cotton, and seasonal conditions permitting evaluating mirid and/or green vegetable bug thresholds. Agronomy and crop phenology data collected from the on-farm experiments could also be used to assist in the validation of the OZCOT model for southern conditions.

Objectives

2. List the project objectives and the extent to which these have been achieved, with reference to the Milestones and Performance indicators.

This project aimed to answer the following research questions, with the overall objective of determining the applicability of recommendations developed for northern cotton to southern production areas, which has a shorter growing season and higher solar radiation.

- *How do thrips communities in southern cotton differ from those in northern cotton growing areas?* Thrips species composition was similar to the north with *Thrips tabaci* being the most dominant followed by *Frankliniella schultzei* and *Thrips imaginis*. *Frankliniella occidentalis* was only a minor component of the thrips community during cotton establishment in the first two seasons but its populations increased greatly in the third year.
- *Are treatment thresholds for thrips developed in the north applicable in southern areas?* Commercial scale experiments with foliar insecticides for thrips control did not support a reduced thrips threshold for southern grown cotton. We did not have data to test threshold for mirids.
- *Are there better alternative treatments for managing WFT and other sucking pests in southern cotton?* This objective has been completed with two small plot experiments evaluating 4 and 7 different chemistries respectively and three new chemistries included in the commercial scale experiments over two years. The third year thrips population was too low for an experiment to be conducted.
- *How effectively does cotton compensate for pest-related defoliation under a shorter growing season?* Simulated thrips defoliations experiments in the south showed that cotton plants were able to recover from early leaf loss of up to 75%, however repeated 100% defoliation delayed cotton maturity and reduced yield in some seasons.
- *Are the pest and beneficial profiles in southern cotton different?* This objective was completed with seedling plant-wash, and both pit fall and bug vac samples collected from unsprayed controls in the thrips threshold experiments and from cotton refuge plots from four sites over three years.

- *Are mirid and GVB thresholds and management options developed in the north applicable in the south (populations permitting)?* This objective is not completed. A single mirid threshold experiment was conducted in the last year and was compromised with multiple herbicide spray drifts. Two other potential experiment sites were investigated – one in each year but numbers of mirids were well below threshold and the grower's not prepared to leave an unsprayed area. GVB were not observed in any numbers across the region for the three years.
- *Is the OZCOT cotton development model suitable for southern cotton regions?* This objective was not completed. Crop phenology, agronomy and yield data has been collected from each of the experiments over the three years of the project but omits some of desirable information to truly test the model. This objective has been included in the Cotton Establishment project DAN1701.
- *Southern IPM and Resistance management plan review:* a two day REFCOM meeting (21–22 March 2017) of key stakeholders was convened in Griffith with one day focused on IPM and the second on the resistance management plan. Recommendations and research gaps were identified and consolidated.

The project team, based at NSW DPI, Yanco Agricultural Institute was:

Dr Sandra McDougall (Principle Researcher) 20%

Dr Jianhua Mo (Entomologist) 10%

Dr Mark Stevens (Entomologist) 5%

Liz Munn (Technical Officer Jan-June 2015 100%)

Sarah Beaumont (Technical Assistant Jan-June 2015; Technical Officer from June 2015 to end of project Oct 2017 100%)

Emma O'Connell (Casual, Technical Assistant June 2015- to June 2017 100%)

Scott Munro (Technical Assistant 10%)

Methods

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

a. Objective 1. Thrips species

Thrips species were identified from both adult and larval thrips collected for Objectives 2 and 6. Thrips were collected during cotton establishment through whole plant washes and after establishment via D-vac samples. Larval thrips were mounted on slides for identification.

b. Objective 2. Thrips thresholds

Seven experiments were conducted over three seasons to test the spray thresholds for thrips in southern-grown cotton. The experiments were conducted in the 2014–15, 2015–16 and 2016–17 at two or three locations each year in the Darlington Point and Whitton areas, 30 km south of Griffith, NSW. Each experiment was conducted on a commercial cotton property, including Point Farms, Darlington Point, NSW and IREC Demonstration Farm or neighbouring Stott's farm located in Whitton, NSW in all three seasons and Ringwood, Darlington Point in 2016–17.

We originally intended to test a low threshold of 1 thrips per plant and the currently recommended 10 thrips per plant (Anon 2017) however due to low thrips numbers and

weather conditions the thresholds were adjusted in some experiments. The treatments were as follows:

2014–15

- Whitton: Transform™ + Cruiser® at 10 thrips/plant; Transform™ at 10 thrips/plant; unsprayed control
- Point Farms: Transform™ + Cruiser® at 1 thrips/plant; Transform™ at 10 thrips/plant; Exirel® at 10 thrips/plant; Canopy® at 10 thrips/plant; unsprayed control

2015–16

- Whitton: fipronil + Cruiser® at 10 thrips/plant; fipronil at 10 thrips/plant; Exirel® at 10 thrips/plant; Canopy® at 10 thrips/plant; unsprayed control
- Point Farms: 2 x fipronil sprays; 1 x fipronil spray; 2 x Exirel®; 2 x Canopy® sprays; Cruiser® seed treatment only

2016–17

- Whitton: fipronil + Cruiser® at 1 thrips/plant; fipronil at 5 thrips/plant; unsprayed control
- Point Farms: fipronil + Cruiser® at 1 thrips/plant; unsprayed control
- Ringwood: no sprays as the 1 thrips/plant threshold was never reached.

The experiments were set up in a randomised block design with four replicates in 2014–15 and 2015–16 and six replicates in 2016–17. Plots were 24 rows wide and ran the length of the field which varied between experiments.

Seedlings were monitored weekly from cotyledon to 8–10 leaf stage. Twenty plants, evenly spaced along the length of the field, were collected from the centre rows of each plot. These were cut at the soil level and placed directly into a zip-loc bag to prevent invertebrates escaping. The plants and bag were then washed with 30% ethanol and then the sample was strained and stored in 70% ethanol. All adult thrips were counted and up to 30 per plot identified. All juvenile thrips were counted and up to 20 from each sample were cleared with NaOH and mounted onto slides for identification.

All sprays were conducted by ground rig except the second fipronil application at Whitton in 2016–17 which was applied aerially for the two fipronil treatments as the soil was too damp for ground application.

Differences in crop phenology between the positive and negative control was tested in each experiment by collecting 20 plants in the early season (mid Dec) and 10 plants in the mid-season (late Jan) from each plot. Data collected were root length, shoot length, nodes, leaf area and whole plant dry weight.

Each plot was hand-harvested by picking two lots of 1 m of cotton from the centre rows. The seed-cotton was weighed and a subsample of 400 g was ginned by a mechanised hand-gin to obtain the turnout. The plots were then mechanically harvested by a John Deere cotton picker so that a minimum of one cotton module could be obtained from each plot. The picked area for each module was measured by GPS and the module was then weighed on a load-cell trailer to calculate the yield.

c. Objective 3. Alternative treatments for thrips

i. Pre-plant insecticides for thrips control (Coleambally 2014–15)

The Coleambally Demonstration Farm grew cotton in 2014-15 and gave an opportunity to test with and without thiomethoxam seed treatment and with and without phorate in furrow treatment at planting for thrips control.

ii. New chemicals for thrips control, efficacy experiment

Field experiments to test the efficacy of new chemicals for thrips control in cotton were conducted in 2014–15 and 2015–16. In 2016–17, thrips pressure in the field was too low to conduct the experiment. The 2014–15 experiment was located at the Coleambally Demonstration Farm, Coleambally and then at Point Farms, Darlington Point in 2015–16.

In 2014–15 the experiment consisted of four different foliar insecticides and an unsprayed control arranged in a randomized design of 15 m x 3 row plots with four replicates. In 2015–16, three additional registered insecticides were tested and we altered the design to include five replicates in a randomized block design with plot sizes of 20 m x 4 rows. The treatments are in Table 1.

Table 1: Insecticides evaluated for thrips control in 2014–15 and 2015–16 seasons

Name	Active Constituent	Rate	Adjuvant	Seasons tested
Exirel®	100 g/L cyantraniliprole	600 mL/ha	500 mL/100L Hasten™	2014–15, 2015–16
Success™ Neo	120 g/L spinatoram	400 mL/ha	60 mL/100L Agral®	2014–15, 2015–16
Sorcerer®	18 g/L abamectin	300 mL/ha		2015–16
Mainman®	500 g/Kg flonicamid	400 g/ha		2014–15, 2015–16
Canopy®	792 g/L paraffinic oil	2 L/ha		2015–16
Shield®	200 g/L clothianidin	250 mL/ha	200 mL/100L Maxx™	2015–16
Transform™	240 g/L sulfoxaflor	300 mL/ha	60 mL/100L Agral®	2014–15, 2015–16
Control	Water			2014–15, 2015–16

The plots were sprayed using a 3-row and 4-row handheld boom in 2014–15 and 2015–16 respectively and two 16 L, 12 V battery operated Rapid Spray backpack sprayers. The sprayers were triple rinsed between applications of different insecticides. Both sprays were conducted prior to the seedlings reaching the 7-node stage in each experiment.

The plots were monitored by collecting 10 seedlings from the centre row in 2014–15 and 10 from the centre-right row in 2015–16 which were placed immediately into a zip-loc bag. When the thrips population had reached at least 10 thrips/plant, the experiment was sprayed. Plants were sampled again seven days later and the plots were sprayed again. We continued to monitor thrips for two weeks following the second spray. Plant samples and the zip-loc bags were washed with 30% ethanol and then the sample was strained and stored in 70% ethanol. All adult thrips were counted and identified while all juvenile thrips were counted and a subsample of up to 20 were cleared with NaOH and mounted onto slides for identification.

A harvest assessment was conducted by hand-picking 2 m of cotton in the centre of the plot from the centre row in 2014–15 and the centre-left row in 2015–16. The seed-cotton was weighed and a sub-sample of 400 g was ginned by a mechanised hand-gin to obtain the turnout.

d. Objective 4. Simulated thrips damage and compensation experiments

Field experiment

Four field experiments were conducted over four seasons from 2013–14 (pre-project approval) to 2016–17 at a commercial cotton property, Huddersfield, Darlington Point NSW. The experiments were all sown mid-late October into furrow irrigated 1 m beds using Sicot 74 BRF seed.

The first season was a preliminary experiment and consisted of three treatments which were: 100% of leaves defoliated on all plants (L100), 100% of leaves removed from three out of every four plants (P75) and an undefoliated control (control). The experiments in 2014–15, 15–16 and 16–17 had an additional treatment where 75% of the leaf area was removed from each leaf on every plant (L75). This fourth treatment was added to attempt to more accurately mimic the leaf damage associated with thrips infestations. The experiment was set up in a randomised block design with four replicates. Plots were 5 m x 3 rows with a 2 m in-row buffer between plots. Defoliation treatments were conducted on the 1st true leaf up to the 6-leaf stage. Leaves were cut at the top of the petiole in treatments where the whole leaf was removed. In the L75 treatment the leaf was cut in half horizontally and then in half again perpendicular to the first cut.

Monitoring of the experiment was conducted weekly following the final cut in the first three seasons and fortnightly in 2016–17. Five plants were tagged for monitoring in each plot, except in P75 where five defoliated and five undefoliated plants were monitored. The traits monitored were: height (soil surface to apical bud), nodes, squares, flowers, bolls and cracked/open bolls. In 2013–14 and 2014–15, one plant was used to monitor the nodes in each plot which was changed in 2015–16 and 16–17 to monitoring the nodes on all five plants. We also monitored the maturity indicators: nodes above white flower (NAWF) and nodes above cracked boll (NACB).

A 2 m section from the centre of the centre row in each plot was hand harvested and the seed-cotton was then ginned by hand-gin to obtain the turnout. In 2015–16, the ginned L100 and control samples were sent to ProClass Griffith for cotton classing using the USTER HVI 1000. The samples were kept in laboratory conditions (21 °C, 65% humidity) for 24 hours prior to being classed.

Laboratory experiment

A laboratory experiment was conducted to assess whether severe thrips damage could be reproduced on cotton seedlings. Thrips collected from field weeds were extracted and placed in screw top vials with cotton wool balls soaked in 5-10% honey prior to introduction into the test units (Diagram 1). A sub-sample of each field collection of approximately 20 thrips were put in ethanol for identification. Field collected thrips were introduced into five test units per rate: 0, 1, 5 or 10 adult thrips per unit per week for five weeks from first true leaf stage. Test units were kept in a controlled temperature room at 23°C day (6am-6pm) and 17°C night (6pm-6am); with 12hrs light (6am-6pm) and 12hrs dark (6pm-6am). At 6 node stage, all seedlings removed, thrips washed off and counted, plants were measured for height, number of nodes, fully expanded leaves and distorted leaves were counted. Leaf area measured for each leaf.

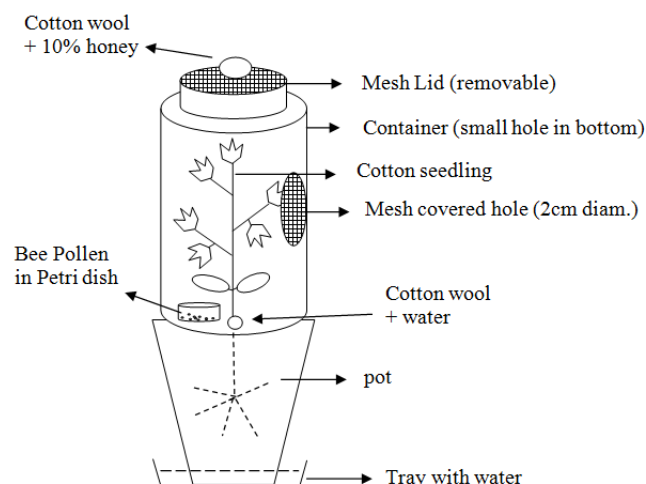


Diagram 1. Test unit for cotton seedlings and thrips

e. Objective 5. Control options for mirids experiment

A experiment was conducted at De Bortolis, Bilbul NSW in 2016–17 to test options for mirid controls. The block was planted on 25 October 2016 with SICOT 714B3F. The experiment consisted of two treatments (Table 2) which were replicated six times in a randomised block design. Each plot was 24 rows of cotton wide and ran the length of the field (440 m). Due to constraints from the cooperating grower, we were unable to replicate the unsprayed control so this consisted of one area 24 m wide in the middle of the experiment area.

Table 2 Mirid treatments for cotton field experiment 2016–17

Treatment	Active Constituent	Rate	Replicates
Regent [®] 200SC + Canopy [®]	fipronil + 792 g/L paraffinic oil	0.125 L/Ha + 5% oil	6
Canopy [®]	792 g/L paraffinic oil	5%	6
Control	Unsprayed	n/a	1

Plots were monitored using two methods: four 1 m beat sheets and four 5 m D-vac samples which were spread evenly long the length of the field. D-vacs samples were taken from rows to the right of the centre of the plot while beat sheets were conducted to the left of the centre to prevent overlap. Care was taken not to shade plants before sampling to prevent mirids escaping. The experiment was monitored on 12 and 19 Dec 2016, 3, 16 and 24 Jan 2017. Insects collected in the D-vac samples were killed by freezing then transferred into 70% ethanol for storage.

Both treatments were sprayed on 6 Jan by a Spra-Coupe 7660 sprayer when the beat sheets indicated the area was over the mirid spray threshold. No further mirid sprays were applied.

A harvest assessment was conducted by hand-picking two 1 m sections of cotton from the centre bed of each plot. The seed cotton was then weighed and a sub-sample of 400 g was ginned by a mechanised hand-gin to obtain the turnout. The plots were then mechanically harvested by a John Deere cotton picker so that one cotton module could be obtained

from each. The picked area for each module was measured by GPS and the module was then weighed on a load-cell trailer to calculate the yield.

f. Objective 6. Seasonal patterns of invertebrates in cotton fields

Invertebrates were monitored throughout the cotton growing seasons from 2014–15 to 2016–17 at four commercial cotton growing properties each season. At each location we monitored a Bt crop and a refuge crop of non-Bt cotton, pigeon pea or both (Table 3).

Table 3: Collection sites for plant wash, pit fall and D-vac samples for monitoring seasonal patterns of invertebrates associated with cotton.

Farm	Location	Seasons	Refuge crop
Point Farms	Darlington Point	2014–15	Non-Bt cotton
		2015–16	Non-Bt cotton & pigeon pea
		2016–17	Non-Bt cotton
IREC/ Stott's	Whitton	2014–15	Non-Bt cotton
		2015–16	Non-Bt cotton & pigeon pea
		2016–17	Non-Bt cotton
Huddersfield	Darlington Point	2014–15	Non-Bt cotton
		2015–16	Non-Bt cotton & pigeon pea
		2016–17	Pigeon pea
Coleambally Demonstration Farm	Coleambally	2014–15	Non-Bt cotton
		2015–16	Non-Bt cotton & pigeon pea
Ringwood	Darlington Point	2016–17	not monitored

From emergence to the 10–12 node stage, plants were monitored by collecting the above-ground portion of 20 plants, equidistant along the length of the field from two rows. After this point foliar invertebrates were collected fortnightly by D-Vac in 2014–15 and 16–17 then monthly in 2016–17. Soil surface invertebrates were sampled monthly from December to March using pitfall traps in 2014–15 and once in January and March in 2015–16 and 16–17. The D-Vac consisted of a Stihl blower-vac with a bag attached to the front of the vacuum tube to catch the invertebrates. We vacuumed 5 m lengths, repeated four times at different spots in the crop so there was a total of 20 m vacuumed foliage for each sample. One sample was collected for each crop. Five pitfall traps were placed in a transect 10 m apart, along a single row in each crop. Pitfall traps were constructed of a 250 mL white plastic cup, half-filled with ethylene glycol and placed in a housing of white PVC pipe which was dug into the soil to be flush with the surface. The PVC housing remained in the soil until the final traps were removed. Pitfall traps were placed in the field for a period of seven days. Invertebrates collected in the D-vacs were killed by freezing and stored in 70% ethanol. Those collected in pitfall traps were removed from the ethylene glycol and stored in 70% ethanol. Invertebrates were counted and catalogued by morphospecies then identified where possible.

Results

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

a. Objective 1. Thrips species.

Thrips communities in the southern cotton cropping region varied by site and between years. Ten thrips species were identified from the foliage samples: tobacco (onion) thrips (*Thrips tabaci*), plague thrips (*T. imaginis*), tomato thrips (*Frankliniella schultzei*), western flower thrips (*F. occidentalis*), *Haplothrips* sp., *Anophothrips* sp., *Australothrips bicolor*, *Tenothrips frici*, *Desmothrips* sp., and *Andrewarthaia kellyana*. The first four species are common pest thrips of crops and the first three can vector tospoviruses. Plague thrips are sporadic and rarely associated with significant damage (Wilson and Bauer 1993). The remaining six species are facultative predators (*Desmothrips* sp., and *Andrewarthaia kellyana*), native species usually associated with eucalyptus feeding (*Anophothrips* sp. and *Australothrips bicolor*) or introduced flower feeding Thripidae (*Tenothrips frici*) (Thrips Thysanoptera in Australia Ozthrips.org, Mound and Tree accessed 5/1/2018).

Wilson and Bauer (1993) similarly reported *Thrips tabaci*, *T. imaginis*, *Frankliniella schultzei* as the most dominant species in cotton with eleven other species collected including three *Haplothrips* species, *Andrewarthaia kellyana*, and two *Desmothrips* species. *Frankliniella occidentalis* was first reported from Australia in 1993 (Malipatil et al., 1993) and according to Wilson in Maas (2012) is not normally abundant in establishing cotton but can be locally abundant in some seasons.

Thrips tabaci was the most common thrips collected from plant washes of establishing cotton plants in all three seasons with 79% of all adult thrips collected in 2014 and 2015 seasons and 41% in 2016 (Figure 1). Depending on the year and site tomato (2014) or plague thrips (2015 and 2016) were the next dominant species collected (Figure 1). Numbers of adult thrips far out numbered nymphs and identification of nymphs requires slide mounting and hence more difficult and fewer individuals were identified. Despite this constraint, when comparing proportions of adults to nymphs it appears that in 2014 there were almost four times more tomato thrips nymphs (40%) than would be expected from adult numbers (12%), where as there were fewer tobacco thrips nymphs (Figure 1). In 2015 proportionally there were 2.5 times the numbers of tomato thrips nymphs than expected, twice the western flower thrips nymphs and proportionally few tobacco thrips. In 2016 there were proportionally twice the numbers of tomato and western flower thrips nymphs, slightly more tobacco thrips nymphs and a quarter the numbers of plague thrips nymphs than expected from proportions of adult thrips collected. Wilson and Bauer 1993 also noted the increasing proportions of tomato thrips nymphs relative to tobacco thrips but reported very few plague thrips nymphs.

ADULTS

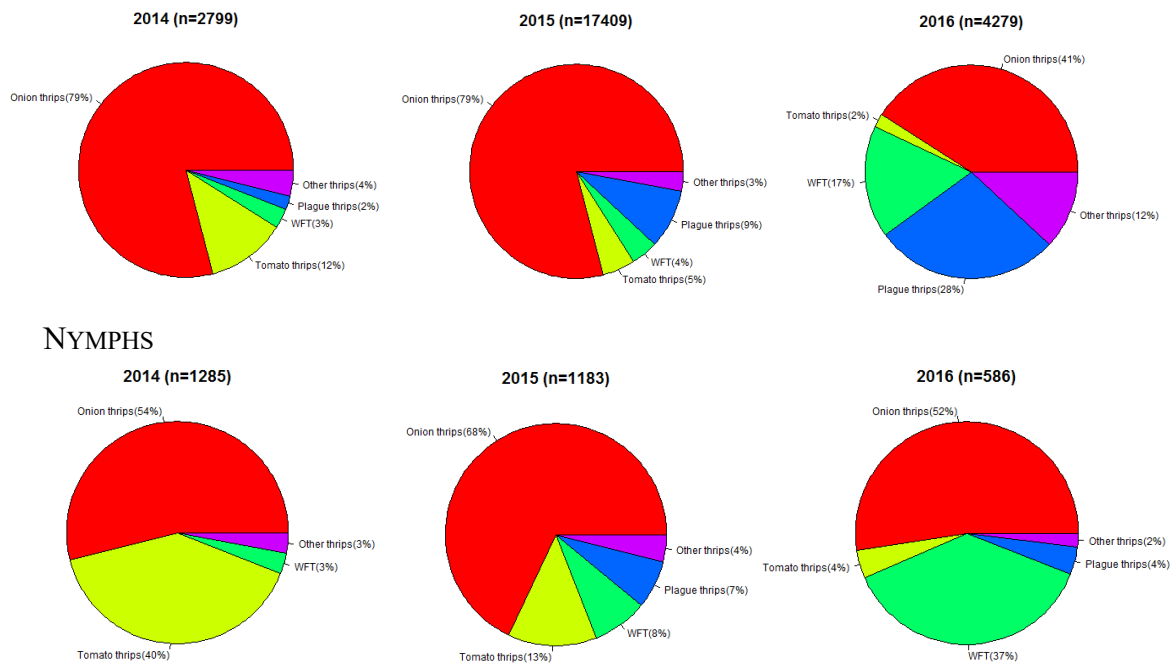
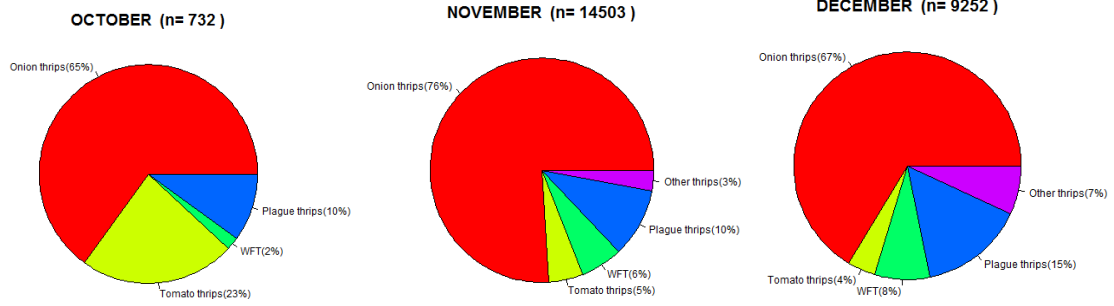


Figure 1. Adult (top) and nymph (bottom) thrips species composition during cotton establishment in 2014, 2015 and 2016 seasons from four sites in the Murrumbidgee Irrigation District of southern NSW. WFT= western flower thrips = *Frankliniella occidentalis*; Onion thrips = Tobacco thrips = *Thrips tabaci*; Plague thrips = *Thrips imarginis*; Tomato thrips= *Frankliniella schulzei*.

Tomato thrips adults were more numerous earlier (October) than plague thrips (November and December) and tomato thrips nymphs were consistently more numerous than plague thrips nymphs (Figure 2). Western flower thrips nymphs were also proportionally more numerous than adult WFT. This would suggest that cotton seedlings are a more suitable hosts for breeding *Frankliniella* species and not quite as an attractive host for breeding for the other thrips species. Another explanation is that the *Frankliniella* spp. breed at relatively lower temperatures than *Thrips* spp. Tobacco thrips have a very wide host range and was the most numerous thrips found on crop weeds during winter surveys in the Riverina (Mo et al. 2007).

Given the populations of insecticide resistant western flower thrips found in horticultural crops and their proximity to cotton in the southern region there was the potential for western flower thrips to be a key establishment pest in cotton. Although it currently represents a small proportion of the thrips found, it consistently represented a larger portion of the establishment thrips population at the IREC site near Whitton (Figure 3). The relative proportion of western flower thrips increased each successive season to 17% in 2016 (Figure 1) and given insecticide resistance has been detected in Australia to fipronil, spinosad, pyrethroids and some dimethoate (Herron and James 2005, Thalavaisundaram et al. 2008, Herron et al 2010, Marshall and Herron 2016) they may become more significant if spraying for thrips becomes more routine across cotton fields in southern NSW.

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NYMPHS

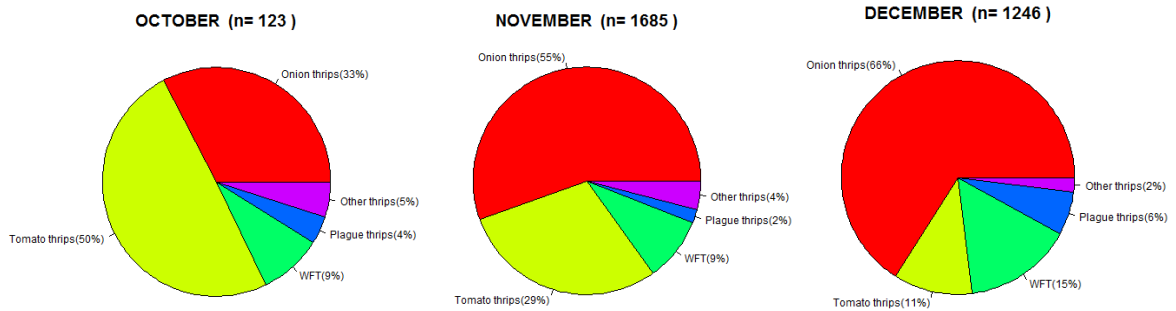
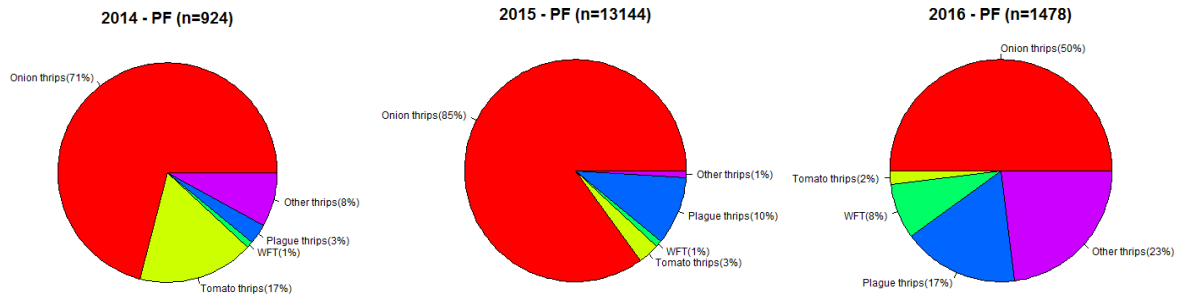


Figure 2. Monthly changes in overall compositions of adult (top) and nymph (bottom) thrips species across the four sites over three seasons. WFT= western flower thrips= *Frankliniella occidentalis*; Onion thrips = Tobacco thrips = *Thrips tabaci*; Plague thrips = *Thrips imaginis*; Tomato thrips= *Frankliniella schulzei*

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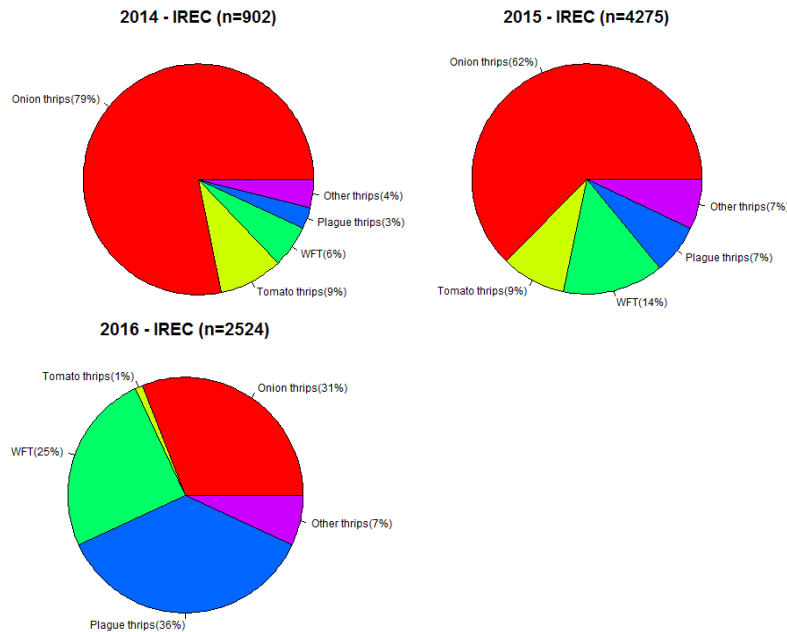


Figure 3. Composition of adult thrips species during cotton establishment at Point Farms PF (Darlington Point) [Top] and IREC (Whitton) [Bottom] in southern NSW over three seasons. WFT= western flower thrips = *Frankliniella occidentalis*; Onion thrips = Tobacco thrips = *Thrips tabaci*; Plague thrips = *Thrips imaginis*; Tomato thrips= *Frankliniella schulzei*.

b. Objective 2. Thrips thresholds

Commercial scale field experiments comparing the industry thrips threshold of 10 thrips per plant in cotton up to 6 node stage were compared to unsprayed controls and a positive control of seed treatment with thiomethoxam (Cruiser®) and foliar sprays at 1 thrips per plant over three seasons.

In the 2014–15 season thrips threshold experiment thrips pressure was similar in all plots at the IREC Demonstration site near Whitton, before the first spray. The low threshold of 1 thrips per plant was reached in late October 2014 and the high threshold in mid-November. Two sprays of Transform™ were applied before the high-threshold sprays were triggered. Neither showed any effects in thrips control ($P > 0.05$) (Figure 4). In fact, thrips nymph numbers had continued to increase despite the two sprays. In an effort to bring down thrips numbers in the positive control plots, fipronil (Regent®) was applied in lieu of Transform™ in these plots at the time when the first high-threshold sprays were triggered. Following this round of sprays, thrips nymph numbers in both fipronil treated plots (positive control plots) and plots receiving the high-threshold Transform™ sprays were significantly reduced as compared to that the negative control plots ($P < 0.05$). The significant effects persisted at the last assessment following a further round of high-threshold sprays ($P < 0.05$). It is worth noting that although thrips pressure remained relative high in the two spray treatments (> 10 thrips per plant), the density was less than a quarter of that in the negative control plots.

There were no significant differences in lint yield (kg/ha) among the threshold treatments in the hand harvest data ($P > 0.05$) at the IREC site (Figure 5). Although a machine

harvest was completed the harvested rounds could not be removed from the paddock for weighing until early spring by which time many were split and all had been water logged.

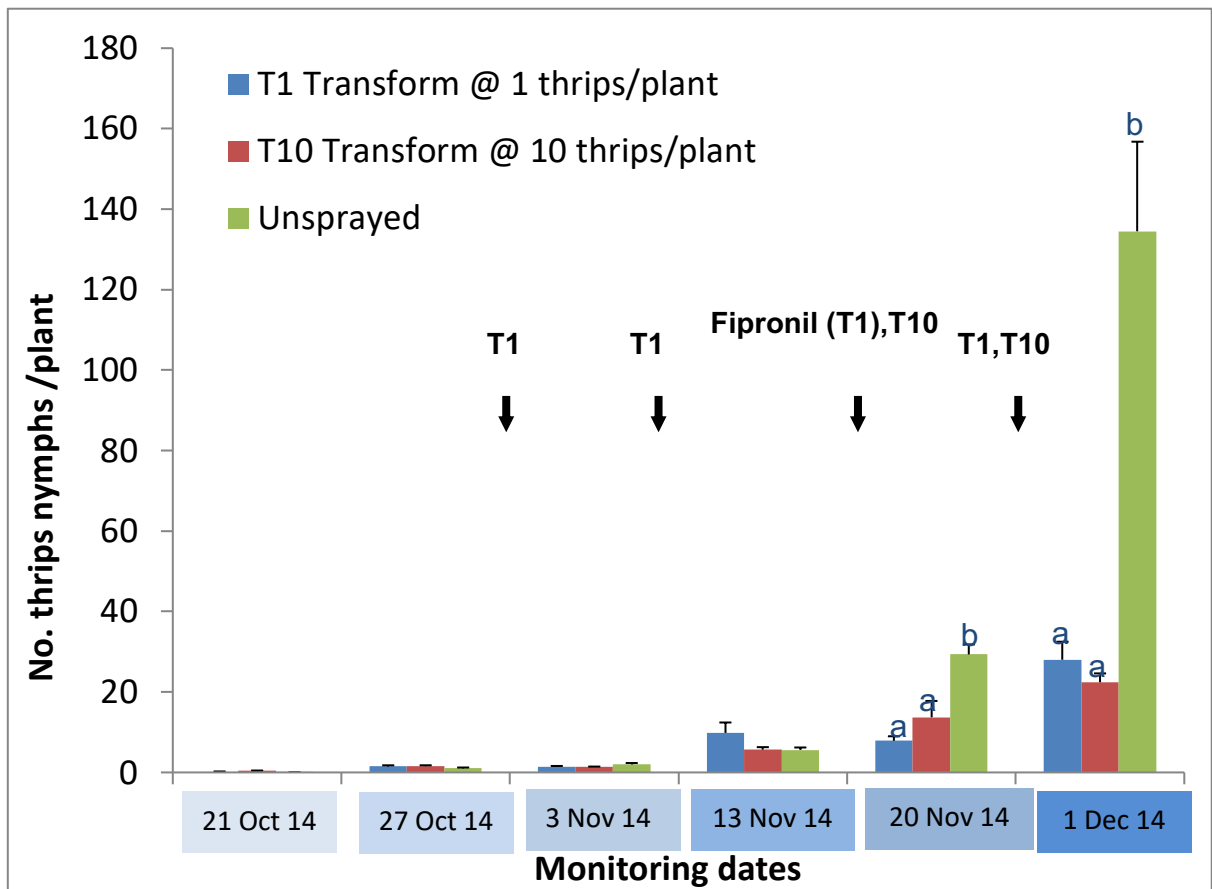


Figure 4. Comparisons of average numbers of thrips nymphs in different threshold treatments at IREC in 2014 during cotton establishment. T1 -Transform applied at 1 thrips/plant, T10 -Transform applied at 10 thrips/plant. Arrows indicate spray applications and notated with treatments applied. Bars in the same group labelled with different letters were significantly different at $P = 0.05$ by Fisher's LSD tests following detection of significant overall treatment effects by ANOVA. Error bars show the standard errors. Arrows indicate spray timings.

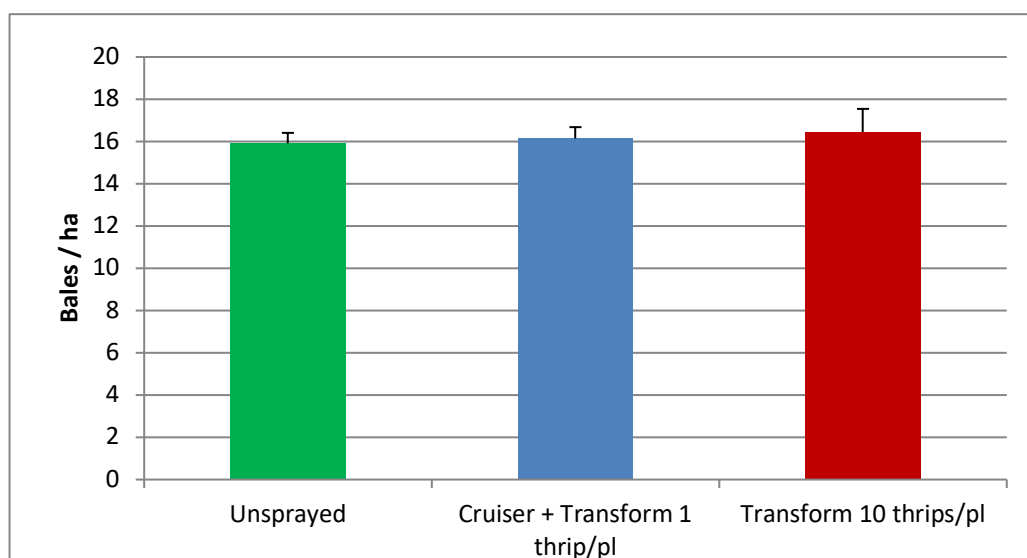


Figure 5. Effects of threshold treatments on lint yield (bales/ha) from the hand harvest on 7 May 2015 at the IREC Demonstration site, Whitton. Transform applied at 1 thrips/plant, Transform applied at 10 thrips/plant, There were no significant treatment effects by ANOVA. Error bars show the standard error.

A second commercial scale experiment was conducted at Point Farms, Darlington point and thrips pressure was similar in all plots before the first spray (Figure 6). The low threshold was reached in late October 2014 and the high threshold in mid-November. Five sprays of Transform™ were applied at the low threshold, one spray each of Transform™ and Exirel® at the high threshold, and two sprays of Canopy® oil at the high threshold. The first two low-threshold sprays of Transform™ were applied before any of the high-threshold sprays were triggered. Both sprays reduced the numbers of thrips nymphs in the positive control plots to about half of that in the un-sprayed plots (negative control plots and plots assigned for the three high-threshold treatments) (Figure 6). In mid-November, a single spray of Transform™ and Exirel® at the high threshold also significantly reduced thrips nymph numbers ($P < 0.05$), bringing down the population to a similar level as those in the positive control plots, which had already been sprayed twice before with Transform™. The first Canopy® oil spray at the high threshold also significantly reduced thrips nymphs as compared to the negative control plots ($P < 0.05$), however the extent of the reduction was significantly less than other two high-threshold treatments. Canopy® oil was applied again at the high threshold in the following week but failed to show significant effects of thrips control ($P > 0.05$). At the last assessment, only the positive control plots maintained significantly lower number of thrips nymphs than the negative control plots ($P < 0.05$).

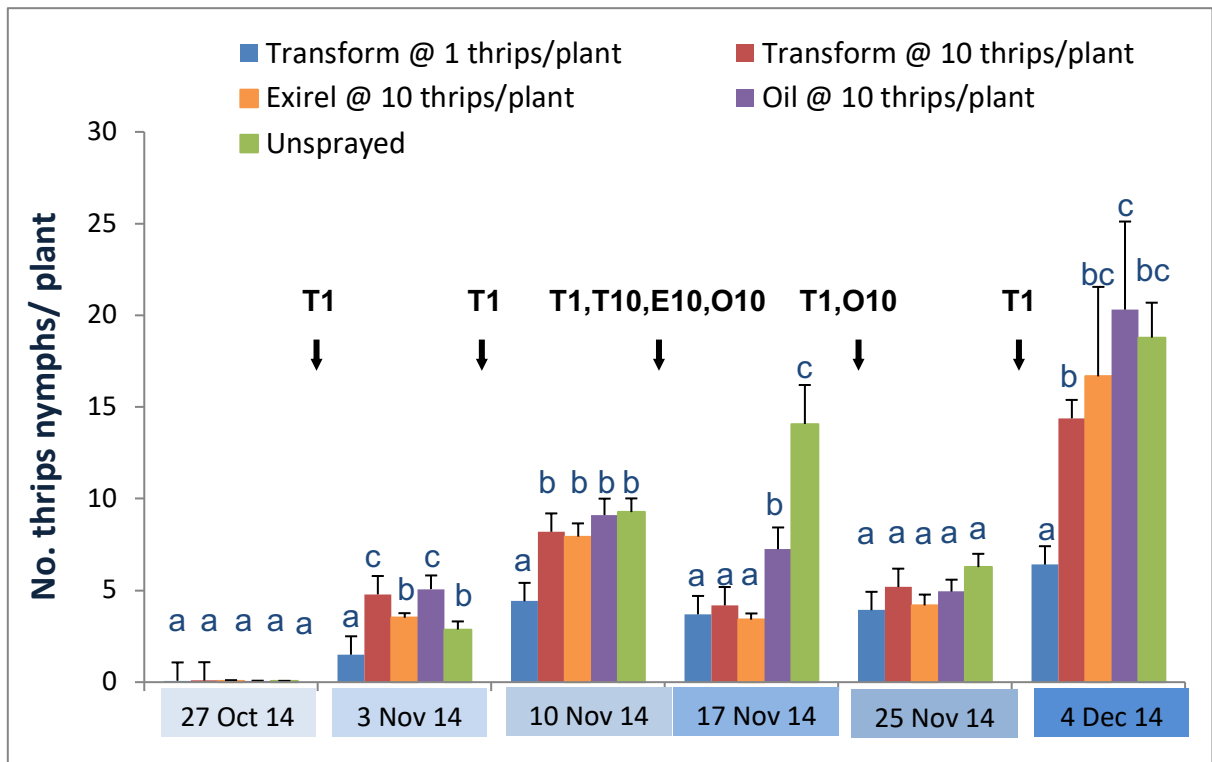


Figure 6. Comparisons of average numbers of thrips nymphs in different threshold treatments at Point Farms, Darlington Point, NSW in establishing cotton 2014. T1 -Transform applied at 1 thrips/plant, T10 -Transform applied at 10 thrips/plant. E10 – Exirel applied at 10 thrips per plant and O10 Canopy oil applied at 10 thrips per plant. Arrows indicate spray applications and notated with treatments applied. Bars in the same group labelled with different letters were significantly different at $P = 0.05$ by Fisher's LSD tests following detection of significant overall treatment effects by ANOVA. Error bars show the standard errors. Arrows indicate spray timings.

There were no significant differences in lint yield among the threshold treatments in either the hand harvest data or the machine harvest (23 May 2015) data at the Point Farm site ($P > 0.05$) (Figure 7).

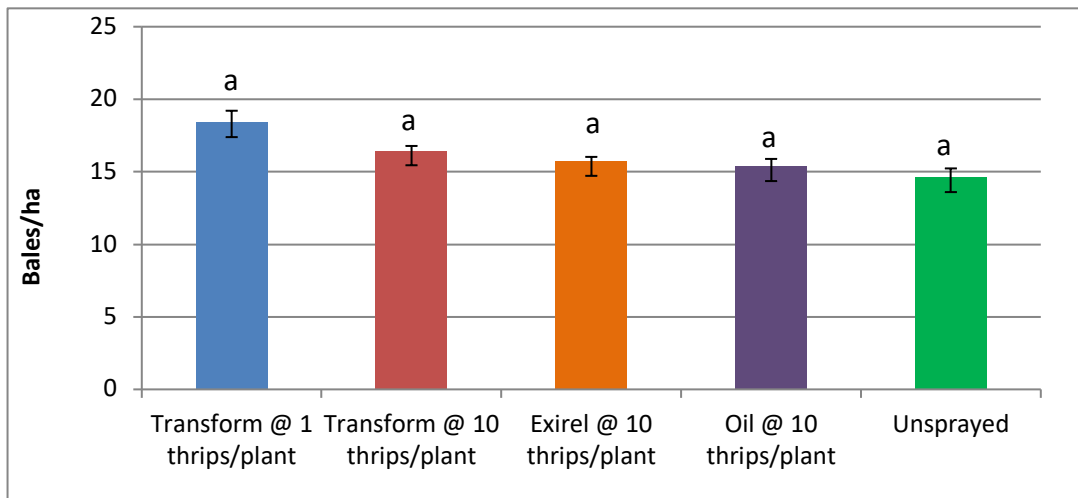


Figure 7. Effects of threshold treatments on lint yield (bales/ha) from the machine harvest on 23 May 2015 at the Point Farm site, Darlington Point. Transform applied at 1 thrips/plant, Transform applied at 10 thrips/plant, Exirel applied at 10 thrips/plant, Oil 10 –Canopy oil applied at 10 thrips/plant. There was no significant treatment effect by ANOVA ($P < 0.05$). Error bars show the standard error.

In 2015–16 a second set of commercial scale thrips threshold trials were conducted in fields near to the 2014–15 experiment sites in Whitton and Darlington Point. Rain during cotton establishment and a breakdown in the spray rig meant that the experiment plots could not be sprayed at the 1 thrips per plant threshold as planned and were not sprayed prior to 16 November 2015 when at the IREC demonstration site the cotton was already at 6 node although at Point Farms the cotton was only 4–5 node. Figure 8 shows the number of thrips nymphs per plant at the IREC site for three monitoring periods. On 28 October 2015 when plants were at 1-2 leaf stage (15 DAE) there were significantly lower numbers of nymphs in the plots with Cruiser® seed treatment (thiomethoxam). By the 9 November the crop was at 3–4 leaf stage, cupping was evident on most plants and the Cruiser® effect was no longer evident. Thrips numbers had increased and were highly variable hence no treatment effects were evident in thrips counts on 23 November a week after the spray application.

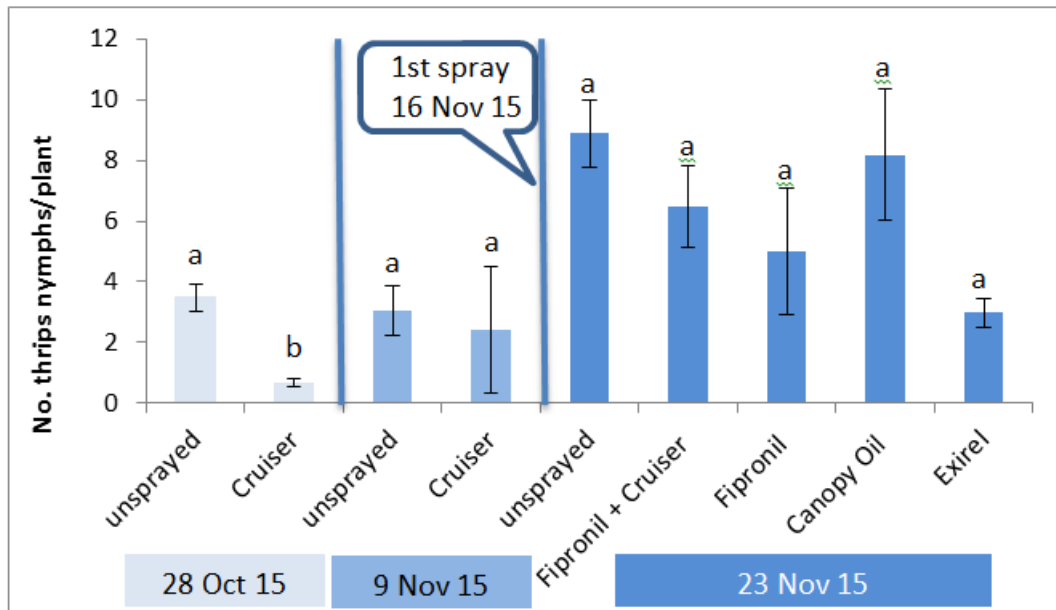


Figure 8. Number of thrips nymphs per cotton plant at three monitoring dates in November 2015 during crop establishment at IREC site, Whitton NSW. Bars sharing the same letters were not significantly different at $P = 0.05$ by Fisher's LSD tests following detection of significant overall treatment effects by ANOVA. Error bars show the standard error.

The Point Farms cotton was sown (16 October 2015) a week later than the IREC cotton, was more patchy and slower to establish. The Cruiser[®] seed treatment appeared to have no effect on numbers of nymphs per plant approximately 10 DAE (Figure 9) and about 50% of plants were showing leaf cupping. Thrips numbers increased prior to the 16 November spray, most leaves at 4-5 node were cupped at spraying, thrips numbers dropped off post spray in all treatments including the unsprayed. In both the Canopy[®] oil and Exirel[®] plots replicate 3 had seven times more thrips than the other replicates hence the very large error bar. If those replicates were removed then the thrips numbers were similar to the unsprayed and Cruiser[®] treatments. The Regent[®] (fipronil) treatment was significantly more effective than the other treatments. Over the next 9 days the thrips numbers again were above 10 thrips per plant and although the plants were 6-8 leaf a second spray was applied to the Exirel[®], Canopy[®] Oil and one of the fipronil treatments. Both fipronil treatment (including the one not sprayed) and the Exirel[®] had lower thrips numbers relative to the Canopy[®] oil or Cruiser[®]-only treatment.

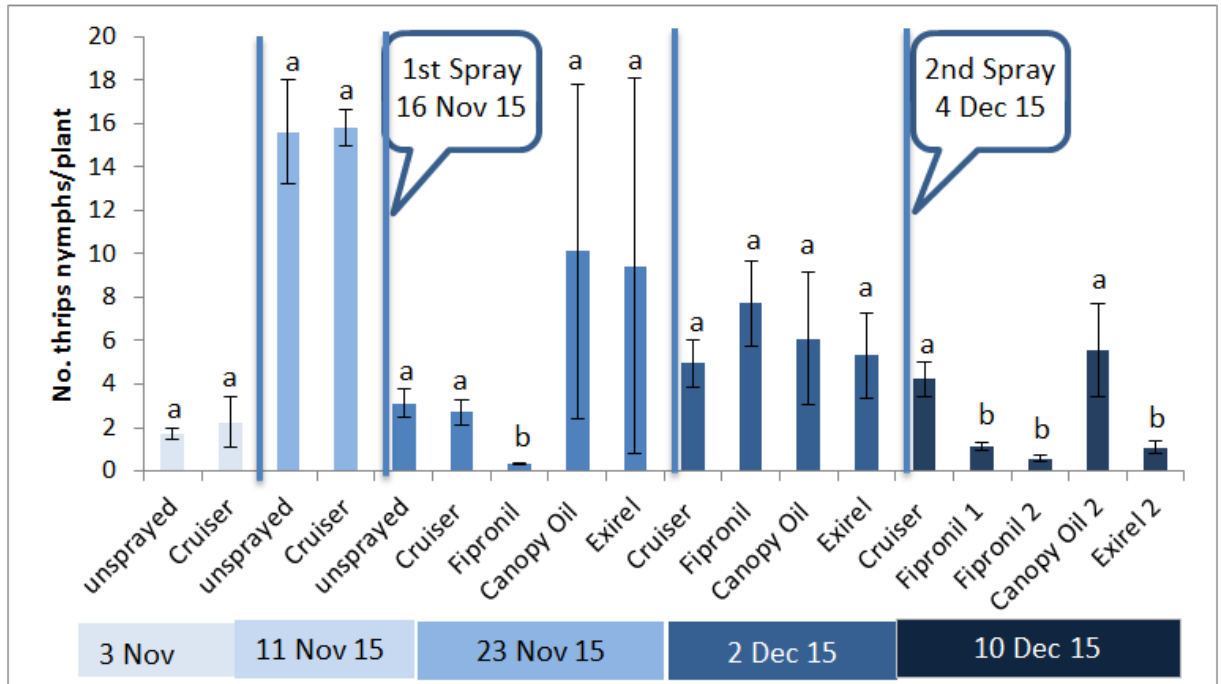


Figure 9. Number of thrips nymphs per cotton plant at five monitoring dates in November and December 2015 during cotton crop establishment at Point Farms, Darlington Point NSW. Bars sharing the same letters were not significantly different at $P = 0.05$ by Fisher's LSD tests following detection of significant overall treatment effects by ANOVA. Error bars show the standard error.

There was no significant treatment effects in cotton yield between treatments at harvest at either IREC or Point Farms (Figure 10).

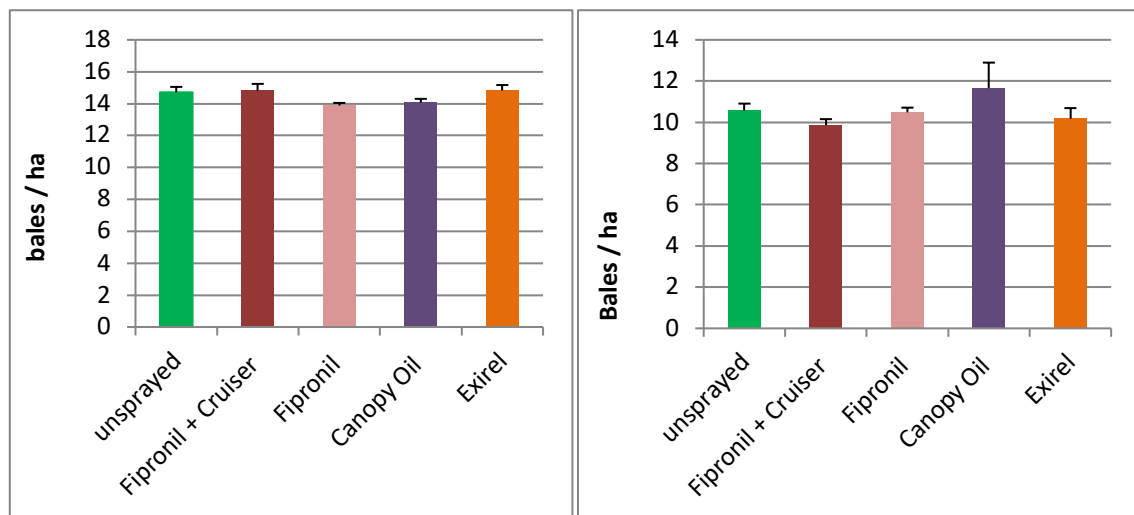


Figure 10. Cotton yields by thrips treatment at Whitton site from machine harvest on 15 and 18 April 2016 (Left) and Point Farms, Darlington Point from machine harvest on 2 June 2016 (Right). There was no significant treatment effect by ANOVA ($P < 0.5$). Error bars show the standard error.

For the 2016–17 season three commercial scale thrips threshold experiments were initiated with two at the previous sites and a third (Ringwood) with a Bollgard 3 crop between Darlington Point and Coleambally. Thrips numbers were low during

establishment at all three sites, and did not even exceed the 1 thrips per plant at Ringwood hence no treatments were applied (Figure 11).

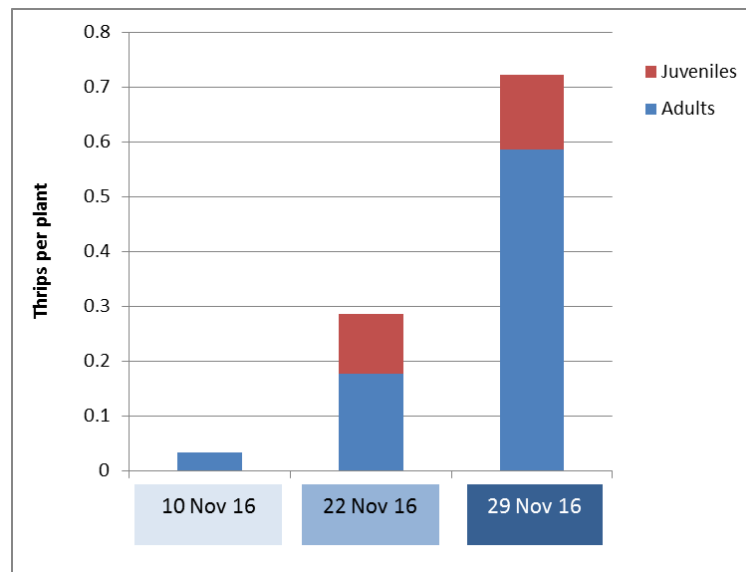


Figure 11. Number of thrips adults and nymphs per cotton plant at three monitoring dates in November 2016 during crop establishment at Ringwood, Coleambally.

The Whitton site was on a farm neighbouring the IREC Demonstration site, and only reached the 1 thrips per plant threshold 26 days after emergence on 22 November 2016 (Figure 12). Very low thrips pressure prevented any detectable effect of the Cruiser® seed treatment in the weeks after emergence. The application of Thimet® (phorate 200 g/kg), targeting wireworm at planting, could also have affected the establishment of a thrips population in the early weeks of the trial. The low threshold plots were sprayed on 25 November by ground rig at the 3–4 leaf stage with less than 10% thrips damage to seedlings. Fipronil provided moderate thrips control, not reducing numbers but their growth was suppressed by 1.5 thrips per plant compared to the unsprayed plots (Figure 8).

A second fipronil application at 1 thrips per plant threshold and a first at 4 thrips per plant were sprayed aerially on 2 December at the Whitton site. Seedlings were at the 5–6 leaf stage and damage remained minor on less than 10% of plants. Adult thrips were reduced in all treatments, including the unsprayed, but a simultaneous increase of juvenile thrips prevented an overall population decline. The population increased by less than 1 thrips per plant in the unsprayed plot while it was reduced from 4 thrips to 3 thrips per plant in the new treatments and remained the same at the 1 thrips per plant threshold. Predatory thrips made up 40% of adult thrips in the unsprayed treatment and 30% in the sprayed. Adult western flower thrips had dropped off by over 80% in all treatments following the second spray application. The industry threshold of 10 thrips per plant and 80% leaf damage was never reached in the establishment phase of this trial so there were no further fipronil applications.

At Point Farms, Darlington Point thrips numbers also did not reach the industry thrips threshold of 10 thrips per plant during cotton establishment (Figure 13). A fipronil application at the low threshold occurred on 25 November when thrips density averaged just under 1 thrips per plant with no visible thrips damage and the crop was at 4 leaf stage. Thrips numbers in the treated plots did not reduce however the unsprayed plots increased to 1.4 thrips per plant. Similar to the Whitton trial, there was very little residual

effect on newly hatched thrips nymphs. By 8 December, a surge in thrips nymph numbers increased the density in both treatments to 6 thrips per plant. This was at the 8 true-leaf so no further applications were conducted and we were unable to test the industry threshold of 10 thrips per plant.

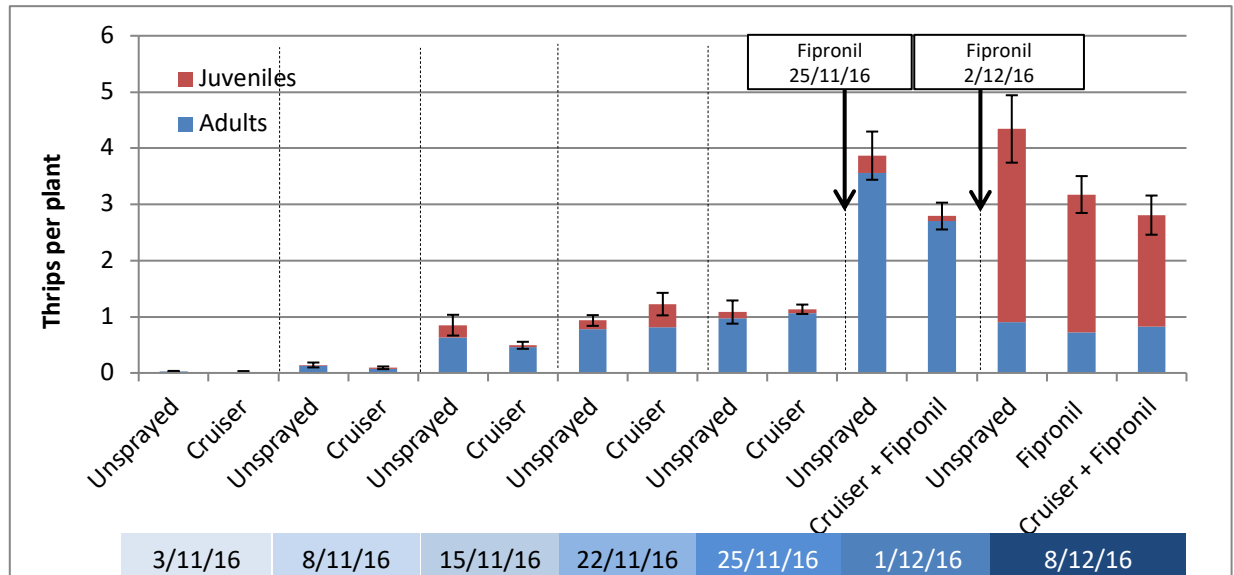


Figure 12. Number of thrips adults and nymphs per cotton plant during crop establishment at Whitton site 2016, NSW. There was no significant treatment effect by ANOVA ($P < 0.05$). Error bars show the standard error of adult and juvenile thrips combined.

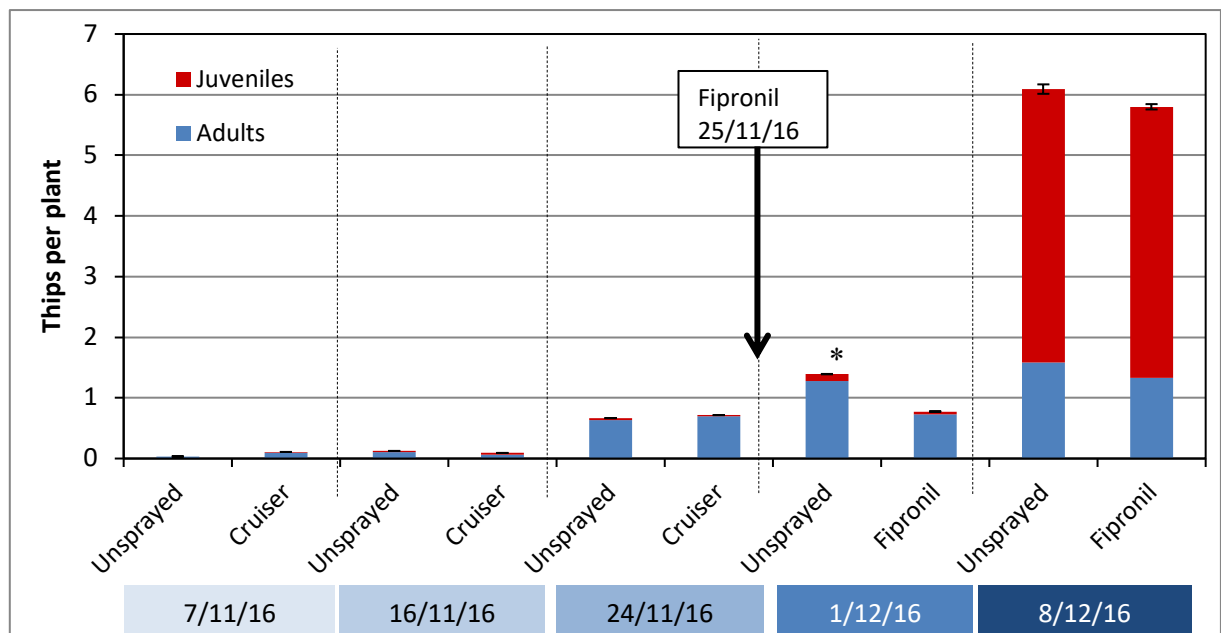


Figure 13. Number of thrips adults and nymphs per cotton plant at five monitoring dates in November and December 2016 during crop establishment at Point Farms, Darlington Point NSW. The asterisk denotes a significant difference between the two treatments ($P < 0.05$). Error bars indicate standard error of adult and juvenile thrips combined, $n = 6$.

Leading up to the fipronil application at Point Farms the thrips population comprised of an even mix of plague thrips, *Thrips imaginis* and tobacco thrips, *Thrips tabaci*. After

spraying, tobacco thrips became the dominant species in both the sprayed and unsprayed treatments. Two and three weeks after the application tobacco thrips decreased proportionally as predatory thrips moved into the area.

The thrips threshold experiments were harvested by commercial picker on 18 May 2017 at Point Farms (Figure 14, Right) and on 1–3 June 2017 at Whitton (Figure 14, Left). At Whitton the fipronil application at 4 thrips per plant yielded the highest with 9.4 bales per ha on average and the 1 thrips per plant the lowest with 8.7 bales per ha however the results were variable between replicates hence the differences are not statistically significant. There were no treatment effect at Point Farms with an average of just over 9 bales per ha produced from both treatments.

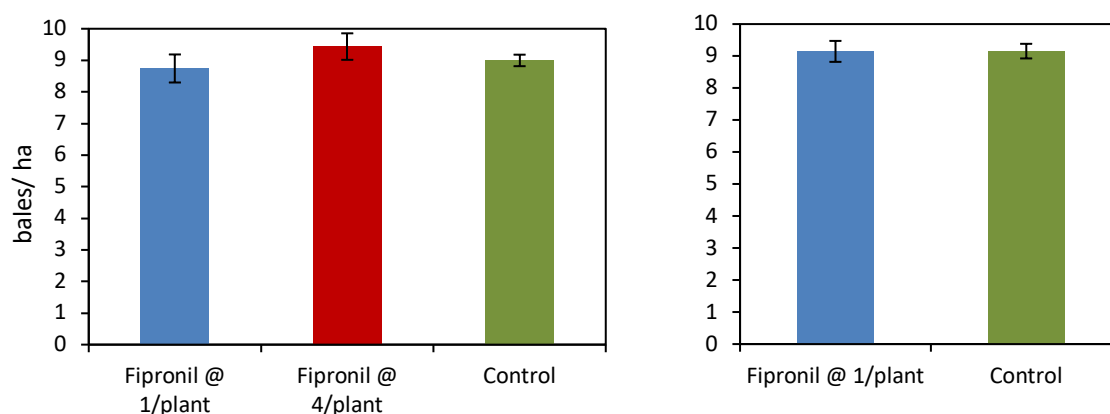


Figure 14. Commercial harvest yields at the Whitton site (1-3 June 2017) [Left] and from Point Farms, Darlington Point (18 May 2017) [Right] There was no significant treatment effect by ANOVA ($P < 0.05$). Error bars show the standard error.

c. Objective 3. Alternative treatments for thrips

i. Pre-plant insecticides for thrips control (Coleambally 2014–15)

The Coleambally Demonstration Farm grew cotton in 2014-15 and gave an opportunity to test on a commercial scale cotton planted with and without thiomethoxam seed treatment, and with and without phorate in furrow treatment at planting for thrips control.

Thrips numbers were well below threshold 8 days after emergence (DAE) or on the 28th October 2014; there was a significant treatment effect for the three treatment combinations, Cruiser[®] (thiomethoxam) and Thimet[®] (phorate) and both treatments alone relative to an untreated control for thrips nymph numbers (Figure 15). Cruiser[®] alone was not as effective for reducing adult thrips populations as the Thimet[®] combination or alone treatments, but still significantly more effective than the untreated control (Figure 16). Treatments with Thimet[®] still had significantly lower thrips nymph numbers than the untreated control or the Cruiser[®] treatment 22 DAE (Figure 1) but no longer had any effect on adult thrips (Figure 16).

Thrips numbers exceeded the industry threshold of 10 thrips per plant at 22 DAE (11 November 2014), with adult thrips numbers alone ranging from 15.2–17.3 per plant and 8.5–17.2 nymphs per plant. By 28 DAE adult numbers had naturally dropped to between 7.3–9.6 adult thrips per plant but the nymph numbers had greatly increased to between 52.9–66.2 thrips nymphs per plant. By 36 DAE both thrips adults and nymphs had reduced, with adult thrips ranging between 2.3–3.3 per plant and nymphs ranging from

7.8–11.4 per plant. These numbers were just above threshold however the cotton plants were at 6–8 leaf, hence outgrown the stage at which thrips thresholds apply, but a decision was made by the crop agronomist to spray all plots with fipronil (Regent®) on 26 November 2014. Thrips nymph numbers at 42 DAE remained similar to those at 36 DAE and adult numbers increased slightly to between 5.5–7.3 per plant, so it does not appear the spray application was effective.

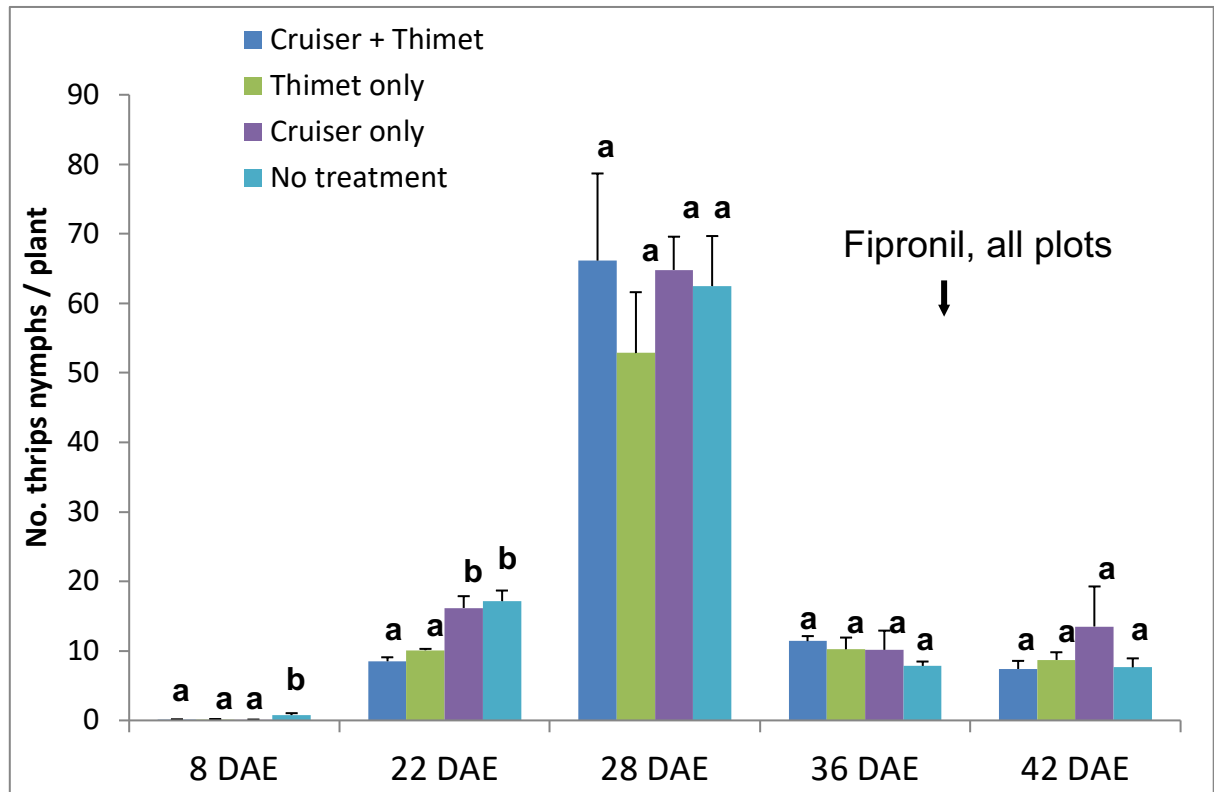


Figure 15. Thrips nymphs per plant during early establishment from 8-42 days after emergence (DAE). Error bars show the standard errors. Differences in larval thrips numbers between treatments are denoted by different letters above the treatments at $P = 0.05$ level of significance, based on Fisher's LSD test following the detection of significant overall treatment effects by ANOVA. Error bars show the standard errors. All plots were sprayed with fipronil 37 DAE (26 November 2014).

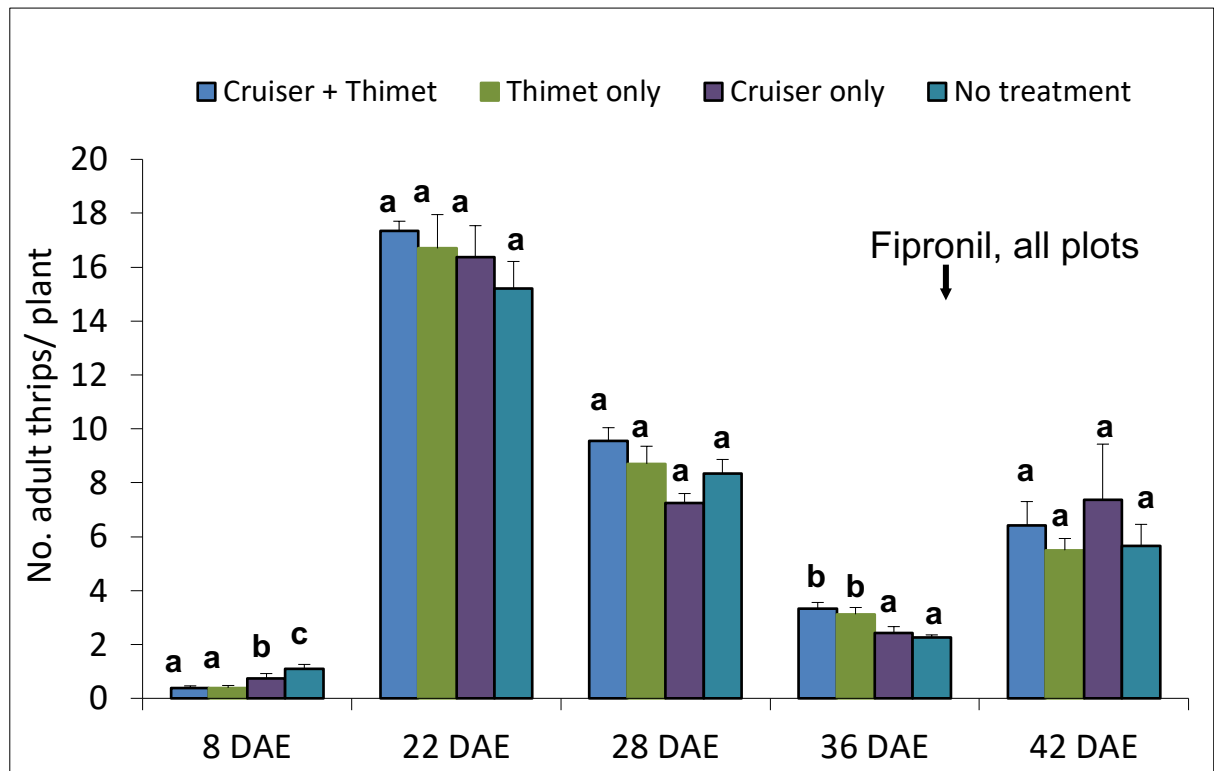


Figure 16. Adult thrips per plant during early establishment from 8-42 days after emergence (DAE). Differences in adult thrips numbers between treatments are denoted by different letters above the treatments at $P = 0.05$ level of significance, based on Fisher's LSD test following the detection of significant overall treatment effects by ANOVA. Error bars show the standard errors. All plots were sprayed with fipronil 37 DAE (26 November 2014).

The impact of the insecticide treatments at establishment did not appear to have a major or lasting impact on the thrips numbers. Machine harvest average treatment yields ranged from 13.7–15.4 bale per hectare, however the variability between replicates, meant there was no significant statistical difference (Figure 17). Hand harvest samples were from a very small proportion of each treatment and would be expected to be more variable as well as an over-estimate compared to machine harvests. However there were significant differences in treatment yields from hand harvest samples with the Cruiser[®] only treatment was significantly lower than the Thimet[®] only and combined Cruiser[®] and Thimet[®] treatments (Figure 17). The combined Cruiser[®] and Thimet[®] treatments were also significantly higher yielding than the untreated control.

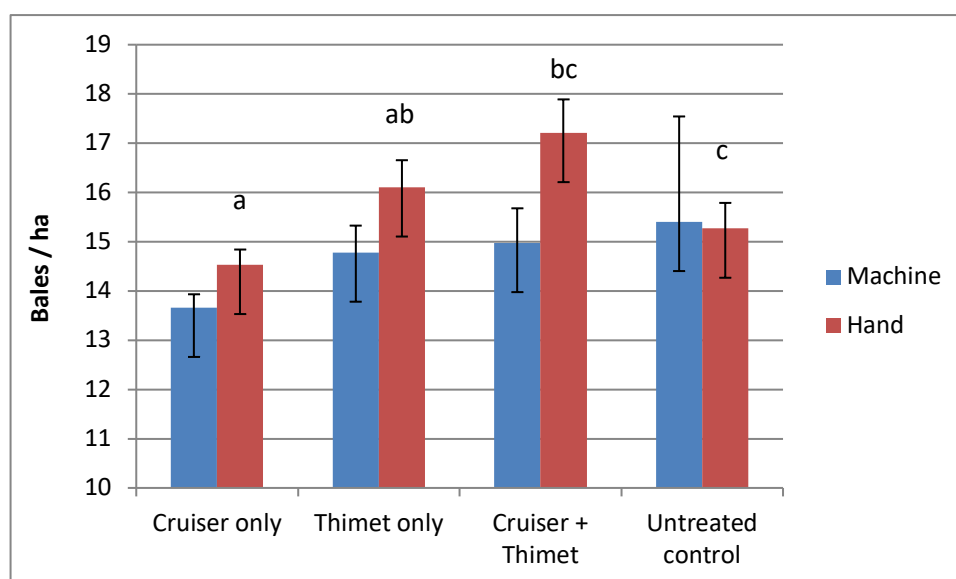


Figure 17. Yield data based on commercial machine (weight and area of single round per plot) and hand harvests (two 1 m rows per plot), turn out based on hand harvested sample and yields calculated out to bales per hectare. No significant difference between machine harvest yields at P=0.5 level. Differences in hand harvest yields between treatments are denoted by different letters above the treatments at P = 0.05 level of significance, based on Fisher's LSD test following the detection of significant overall treatment effects by ANOVA. Error bars show the standard errors.

ii. New chemicals for thrips control, efficacy experiment

SMALL PLOT TRIAL Coleambally Demonstration Farm 2014/15

The small plot replicated trial conducted at Coleambally Demonstration Farm evaluated four insecticides: spinatoram (Success™ Neo), flonicamid (Mainman®), sulfoxaflor (Transform™), cyantraniliprole (Exirel®) for thrips activity in establishing cotton against a water only control.

The cotton crop was at 4–6 leaf stage at the start of the trial and 18–20 leaf stage at the end of the trial. Prior to the first spray, adult thrips density averaged 8–10 per plant and thrips nymphs density 40–60 per plant, and there were no significant differences between the treatments in either the adult or nymph thrips density (Figures 18 and 19). Significant treatment effects were detected at 14 and 21 days after the first spray for adult thrips and 7, 14, and 21 days after the first spray for thrips nymphs (Table 4).

Table 4. Overall differences in adult and larval thrips densities between the treatments before and after sprays as revealed by ANOVA.

Date*	Adult thrips			Thrips nymphs		
	F	DF _{1,2}	P	F	DF _{1,2}	P
1 DBS1	0.33	4, 15	0.8544	2.58	4, 15	0.0796
7 DAS1	1.27	4, 15	0.3243	6.61	4, 15	0.0028
14 DAS1 & 7 DAS2	7.27	4, 15	0.0018	8.42	4, 15	0.0009
21 DAS1 & 14 DAS2	5.82	4, 15	0.0049	7.05	4, 15	0.0021

*DBS1, DAS1, and DAS2: days before the first spray, and day after the first and second sprays.

For adult thrips, Transform™, Mainman®, and Exirel® significantly reduced thrips numbers at 14 days after the first spray or 7 days after the second spray, with Exirel®

significantly out-performing the other two insecticides, reducing thrips density by about 32% as compared with the control ($P < 0.05$) (Figure 18). No significant effect was detected for Success™ Neo on this date. One week later, adult thrips density in all plots bounced back, with none of the four insecticides performing better than the control. In fact, Transform™ and Success™ Neo treated plots had significantly more adult thrips than control plots. This surprising result may have been due to new influx of adult thrips from outside and/or inter-plot movements of the adult thrips at the trial site.

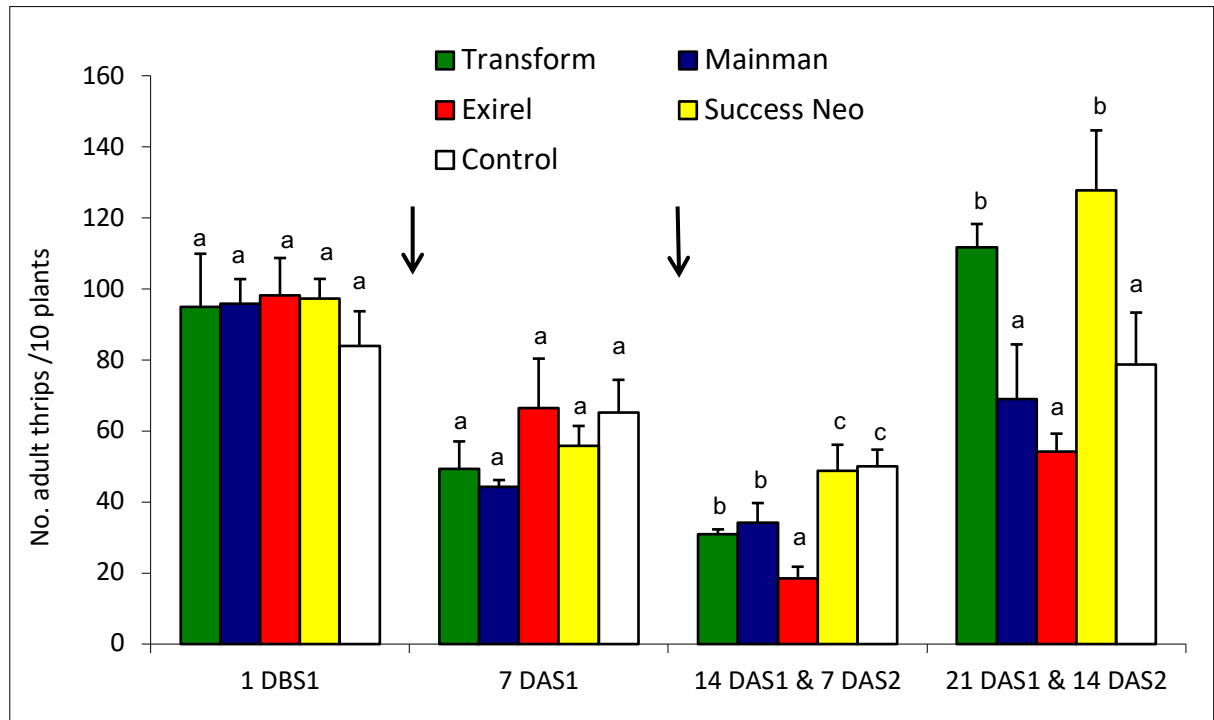


Figure 18. Mean adult thrips densities before and after sprays. Bars in the same group labelled with different letters are significantly different at $P = 0.05$ by Fisher's LSD following the detection of significant overall treatment effects by ANOVA. Error bars show the standard errors. Arrows show timing of sprays. DBS1, DAS1, and DAS2: days before the first spray, and day after the first and second sprays.

Treatment effects were more clearly seen in larval thrips (Figure 19). All four insecticides showed significant efficacy against thrips nymph density on all three post-treatment occasions. Success™ Neo outperformed Transform™ and Mainman® on two occasions and Exirel® outperformed the same two insecticides on one occasion. In comparison to the control, all four insecticides reduced thrips nymphs by at least 50% 7 days after the first spray, with reduction rate as high as 77% for Success™ Neo 7 days after the second spray.

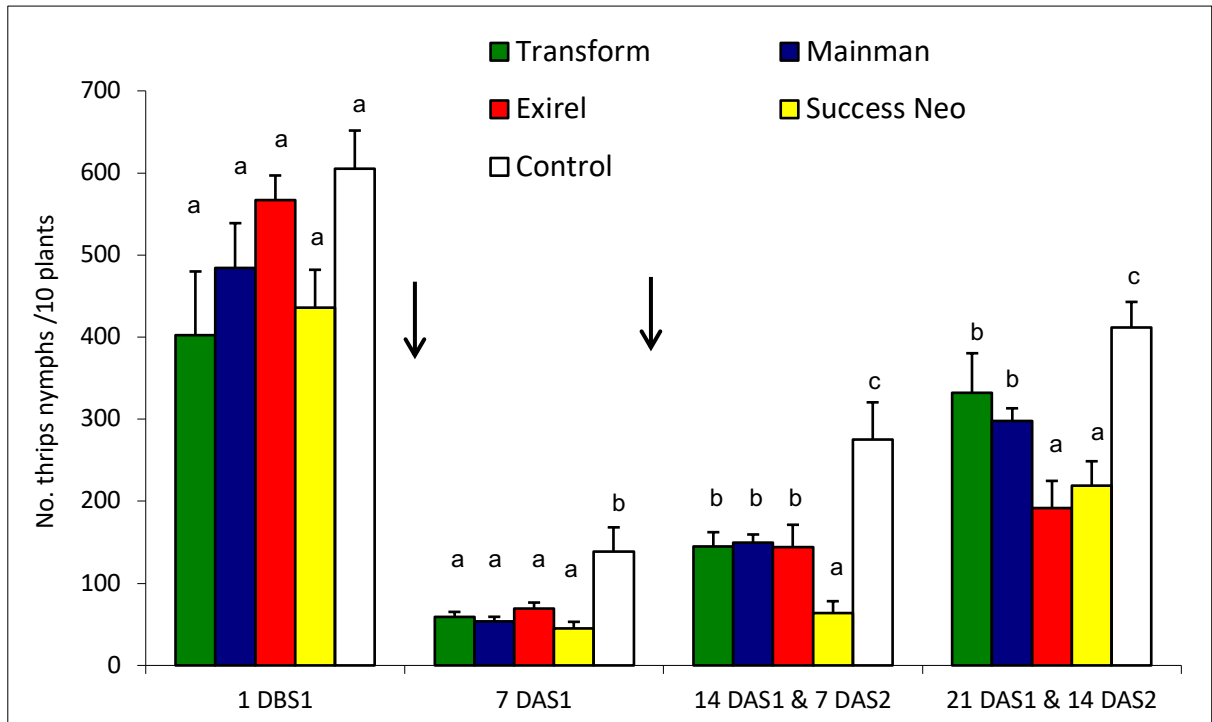


Figure 19. Mean thrips nymph densities before and after sprays. Bars in the same group labelled with different letters are significantly different at $P = 0.05$ by Fisher's LSD following the detection of significant overall treatment effects by ANOVA. Error bars show the standard errors. Arrows show timing of sprays. DBS1, DAS1, and DAS2: days before the first spray, and day after the first and second sprays.

The trial was hand-harvested with two 1 m sections from the centre rows of the trial plots. Harvest samples were weighed and sent to CSIRO ACRI for hand ginning. There was no significant difference between seed cotton weight or lint calculated from plot turn-out. Using the plot turn-out results the bales per hectare were calculated and although ranged between 13.9–15.2 bales per hectare the differences were not significant with an ANOVA at significance of 0.05 (Figure 20). The machine harvest results for the surrounding crop averaged 14.7 bales per ha, within the range of the average yields for the treatment plots.

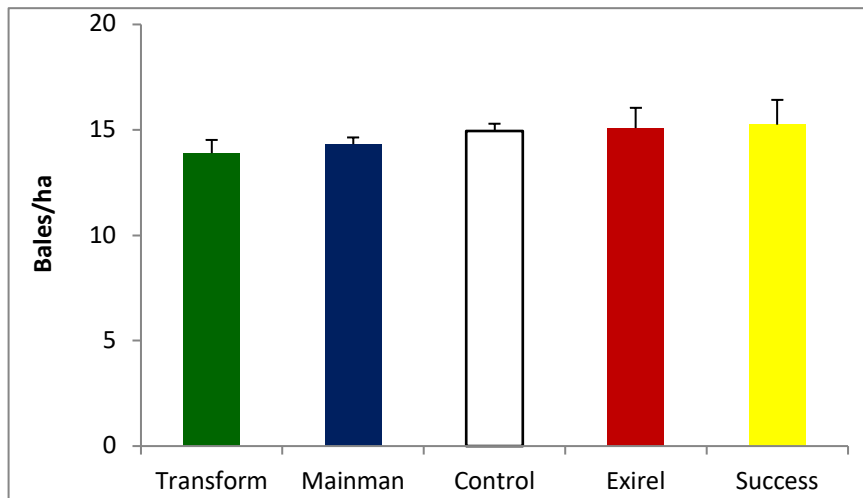


Figure 20. Mean bales per ha calculated from hand harvest samples and hand gin turn-out figures. Error bars show the standard errors. The differences are not significantly different, effects by ANOVA at significance level of 0.05.

SMALL PLOT TRIAL Point Farms 2015/16

A second small plot replicated trial was conducted at Point Farms, Darlington Point in 2015–16 cotton season and evaluated seven insecticides: spinetoram (Success™ Neo), flonicamid (Mainman®), sulfoxaflo (Transform™), cyantraniliprole (Exirel®), petroleum spray oil (Canopy® oil), abamectin (Socerer®) and clothianidin (Shield®) for thrips activity in establishing cotton against a water only control.

Thrips density was 12.5 thrips/plant at the first spray date and cotton seedlings were at the 2–3 leaf stage. The thrips population consisted of 83% tobacco thrips, 2% tomato thrips, 2% western flower thrips (WFT), 10% plague thrips and 3% other thrips before spraying (Figure 7A). The species composition had changed very little 14 days after the second spray (14 DAS2), with a slight increase in tobacco and tomato thrips and a slight decrease in WFT, plague thrips, and other thrips (Figure 21B).

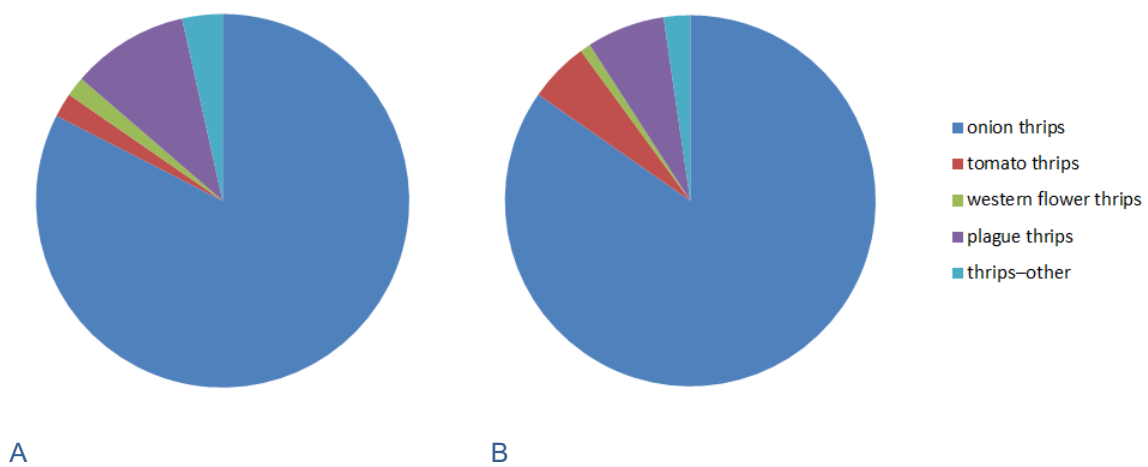


Figure 21. Thrips species composition observed on seedling cotton on 17 November 2015 (A) before starting spray treatments and (B) on 15 December 2015 after receiving two spray treatments on November 18 and 25. Western flower thrips = *Frankliniella occidentalis*; Onion thrips = Tobacco thrips = *Thrips tabaci*; Plague thrips = *Thrips imaginis*; Tomato thrips = *Frankliniella schulzei*.

The first spray had no effect on adult thrips density seven days after spraying (7 DAS1) (Figure 22). Seven days after the second spray (7 DAS2), adult density was reduced by some insecticide treatments more than others, however no insecticides were significantly more or less effective than the control. The lack of significant difference between treatments and control remained at 14 days and 21 days after the first spray (7 days and 14 days after the second spray), except for more adult thrips in Shield® (clothianidin)-treated plots at 7 DAS2.

All insecticide treatments and the water-sprayed control reduced thrips nymph density from 7–14 thrips per plant to less than 2.5 thrips per plant at 7 DAS1 (Figure 23). As no insecticide was significantly more effective than the control, this reduction in thrips nymphs cannot be attributed to chemical action. Thrips nymph density was not further reduced by any insecticide treatments at 7 DAS2; however, larval thrips populations increased with the Canopy® oil, Shield® and Transform™ (sulfoxaflo) at 7 DAS2. Success™ Neo (spinetoram) suppressed thrips nymphs more effectively than Canopy® oil or Transform™ following the second spray, however, these were not significantly more

effective than the control. As with the adults, there were no significant effects of the on thrips nymphs at 14 DAS2.

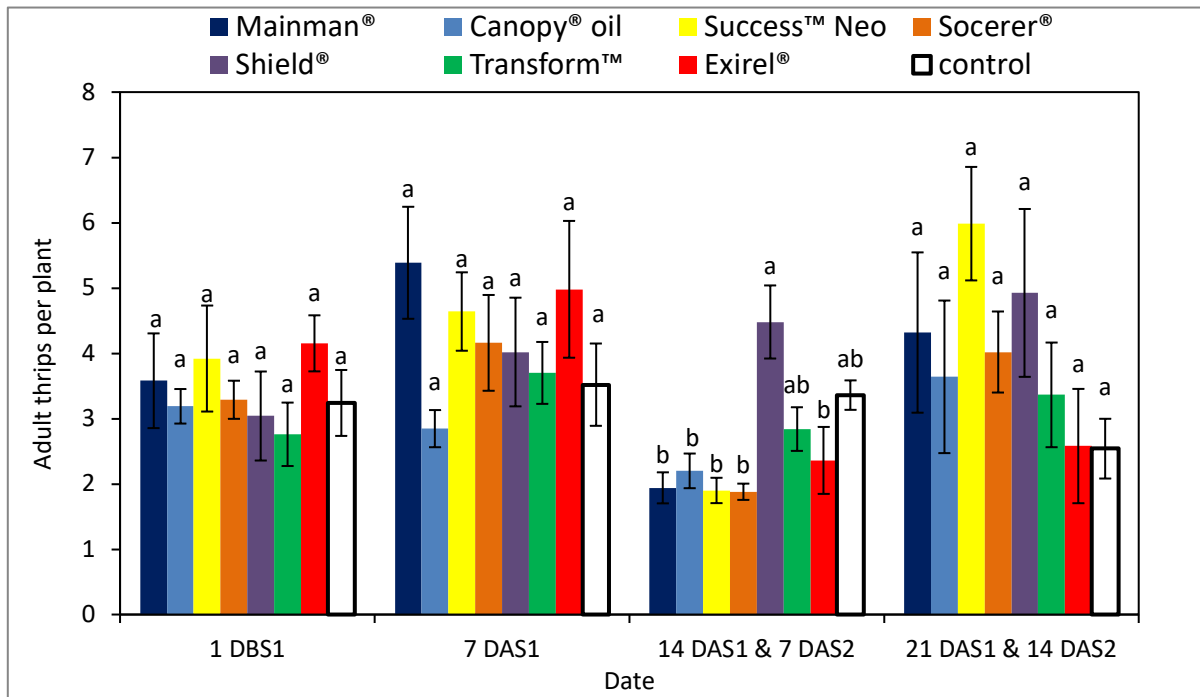


Figure 22. Mean adult thrips densities before and after sprays. Bars in the same group labelled with different letters are significantly different based on log transformed data at $P < 0.05$ by Fischer's LSD following the detection of significant overall treatment effects using ANOVA. Data presented in graph is untransformed data and error bars indicate standard error. DBS: days before spray, DAS1 and DAS2: days after first and second spray.

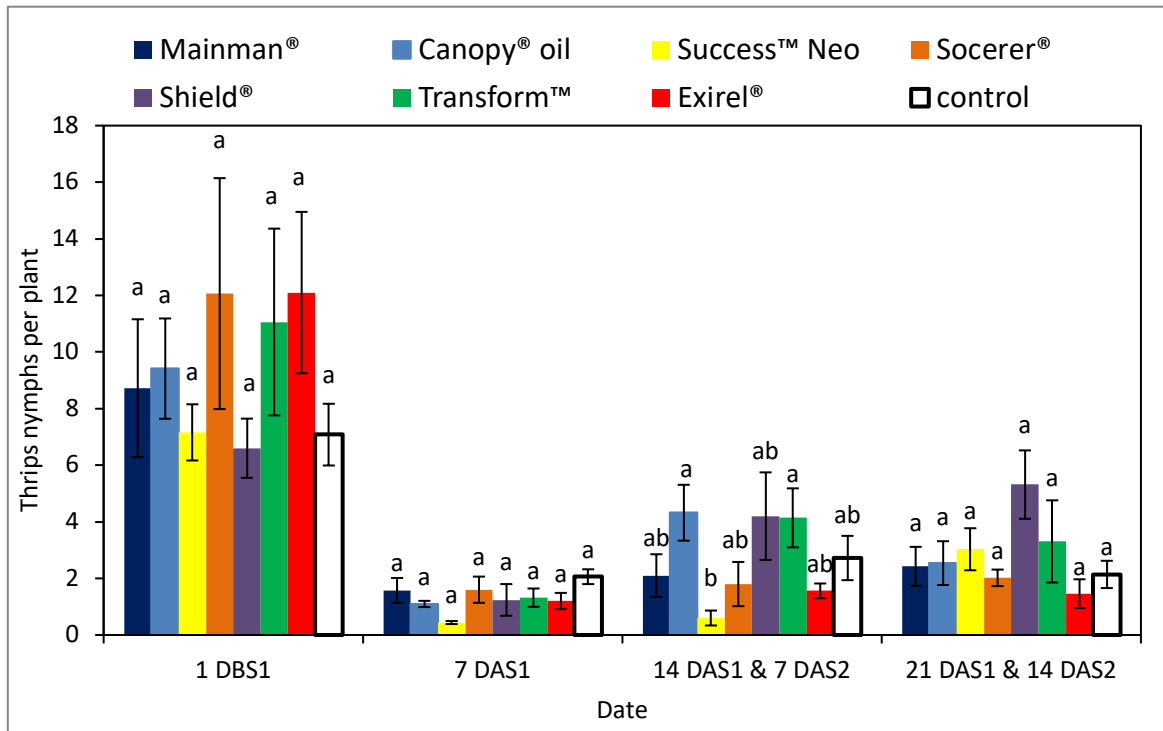


Figure 23. Mean thrips nymph densities before and after sprays. Bars in the same group labelled with different letters are significantly different based on log transformed data at $P < 0.05$ by Fischer's LSD following detecting

significant overall treatment effects using ANOVA. Data presented in graph is untransformed data and error bars indicate standard error. DBS: days before spray, DAS1 & DAS2: days after first and second spray.

In comparison with the 2014–15 trial where thrips pressure was as high as 70 thrips per plant, this season’s trial did not identify any clear efficacy in the tested insecticides for thrips control. In 2014–15, all four tested insecticides reduced thrips nymphs by at least 50% 7 DAS1 and by as much as 77% following two spray treatments.

No significant differences were found in the seed cotton yield despite some treatments having a lower thrips density (Figure 24).

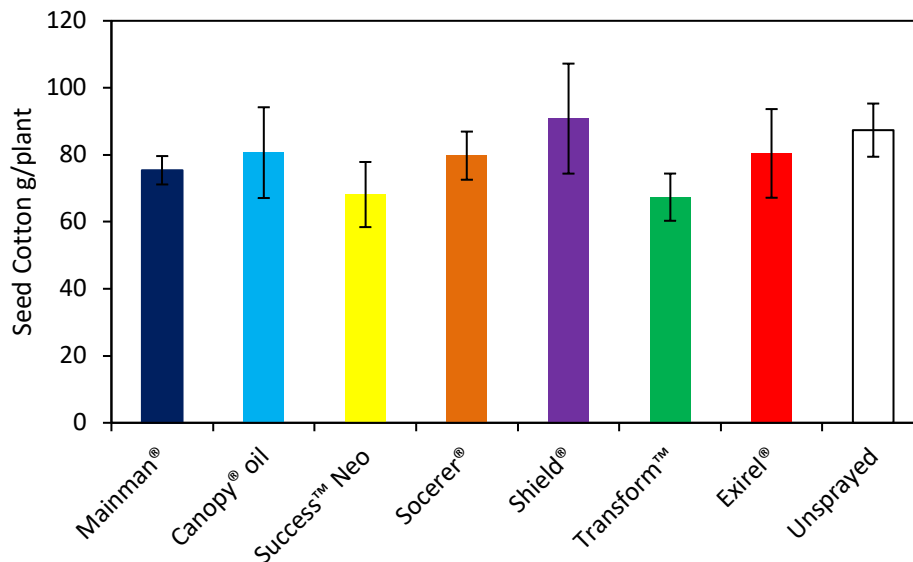


Figure 24. Mean seed cotton weight calculated from hand-harvested sub samples. Error bars indicate standard error. The differences are not significant; effects using ANOVA at a significance level of 0.05

d. Objective 4. Simulated thrips damage and compensation experiments
i. Field simulated thrips damage experiments

Simulated thrips damage experiments were conducted at Huddersfield, Darlington Point for the three years cotton seasons of this project and the data from a subset of defoliation treatments (P100 and P75) conducted over the 2013–14 season has also been included. The treatments involved physically removing whole true leaves at 2, 4 and 6 nodes on all plants (P100) or from three in every four plants (P75), or removing 75% of each true leaf (L75) versus uncut control plants.

Seasonal patterns of cotton plant height for the different defoliation treatments over the four seasons are shown in Figure 25. Some reduction of plant height in defoliated plants relative to undefoliated plants can be seen in all seasons before 100 DAE. The height difference remained till the end of the monitoring periods during 2013–2014 and 2016–2017. During 2014–2015 and 2015–2016, however, the average height of plants in some defoliated treatments caught up with that of undefoliated plants towards the end of the monitoring periods. With a few exceptions when there were significant effects the undefoliated control plants were taller than defoliated plants. When a difference was observed between the defoliation treatments the L75 were taller than P75 or L100 treatments and on some dates P75 was taller than L100.

Significant effects of artificial defoliation on plant height were detected on all assessment dates (52–136 DAE) in 2013–2014, before 75 DAE in 2014–2015, before 99 DAE in 2015–2016 and all but one date (148 DAE) in 2016–2017.

Final plant height ranged from 80.8 cm in P75 to 93.2 cm in the control during 2013–2014, 76.5 cm in L100 to 81.3 cm in P75 during 2014–2015, 70.8 cm in L75 to 81.1 cm in P75 during 2015–2016, and 68.9 cm in P75 to 81.1 cm in the control during 2016–2017. The highest relative different between any two treatments was 15% and the lowest 5%.

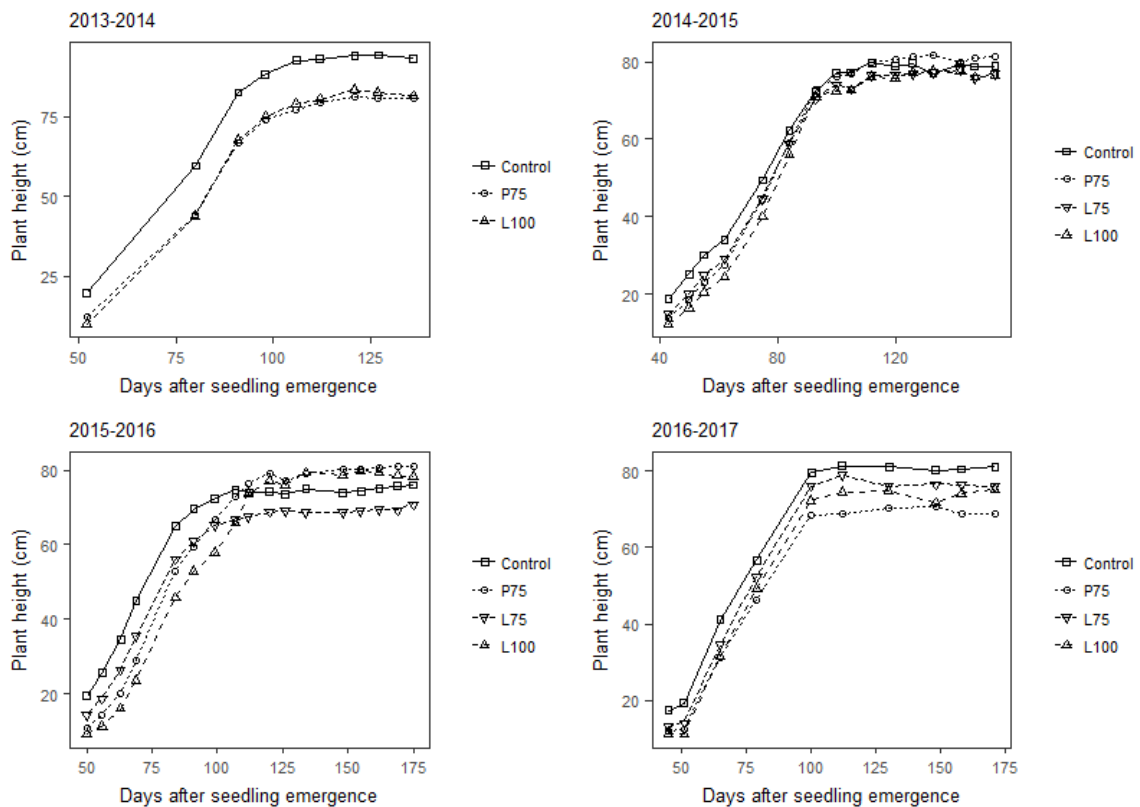


Figure 25. Growth patterns of plant height (cm) in undefoliated plots (Control), plots subjected to the treatment of 75% defoliation by plant (P75), 75% defoliation by leaf area (L75), and 100% defoliation (L100) in the artificial defoliation trials during 2013–2014, 2014–2015, 2015–2016, and 2016–2017.

Boll development was monitored for the entire seasons during 2013–2014, 2014–2015, and 2015–2016, and on four dates before harvest only during 2016–2017. Bolls first appeared around 80 DAE in the first three seasons (Figure 2). Except for L100 during 2013–2014, the first date of boll emergence was the same for all treatments. During 2013–2014, first bolls in L100 were observed one monitoring date later (9 days) than that in the other treatments. After boll initiation, boll number per plant increased gradually and peaked around 125–150 DAE before stabilising (2013–2014) or dropping slightly (2014–2015, 2015–2016) (Figure 26).

Compared with undefoliated plants, bolls appeared at a considerably slower rate in P75 during 2013–2014 and in L100 during 2015–2016, particularly during the late part of boll development (Figure 2). Delays in boll emergence relative to undefoliated plants were also observed in the other defoliated treatments during the two seasons, however, the amount of delays were much smaller. By contrast, no such delays were obvious in any defoliated treatments during 2014–2015. Over the four monitoring dates during 2016–2017, the largest reduction in boll number relative to undefoliated plants was seen in

L100 around 150 DAE. However, the gap in boll number between L100 and the control narrowed gradually over the remaining monitoring period. By 180 DAE, plants in L100 had more bolls than those in P75.

On the final assessment date, all treatments including the control had similar numbers of bolls in all four seasons (2013–2014: $F = 2.15$, $DF = 2, 6$, $P = 0.1980$; 2014–2015: $F = 0.08$, $DF = 3, 9$, $P = 0.9671$; 2015–2016: $F = 3.07$, $DF = 3, 9$, $P = 0.0836$; 2016–2017: $F = 0.57$, $DF = 3, 9$, $P = 0.0.6476$).

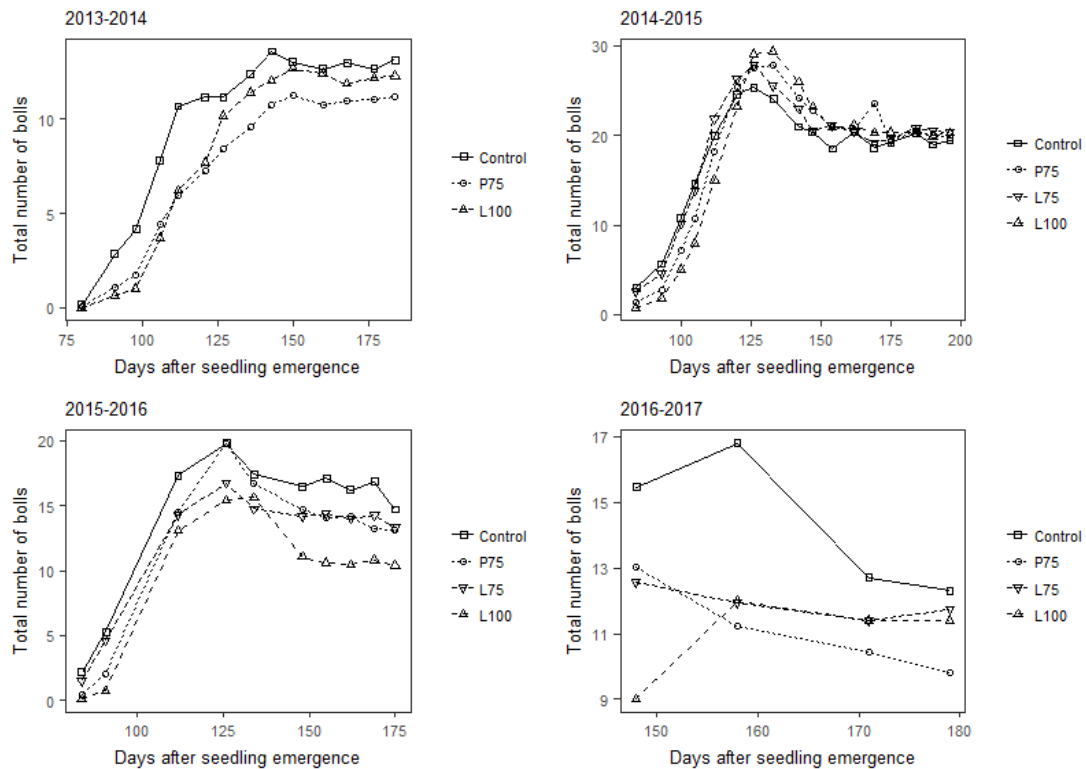


Figure 26. Growth patterns of total number of bolls (opened and un-opened) per plant in undefoliated plots (Control), plots subjected to the treatment of 75% defoliation by plant (P75), 75% defoliation by leaf area (L75), and 100% defoliation (L100) in the artificial defoliation trials during 2013–2014, 2014–2015, 2015–2016, and 2016–2017.

Fewer opened bolls were found in defoliated plants than in undefoliated plants on all monitoring dates during 2013–2014, 2015–2016 and 2016–2017 (Figure 27). The gap gradually widened during 2013–2014 and 2015–2016 but remained relatively constant during 2016–2017. Treatment differences in the number of opened bolls were smaller during 2014–2015 than during the other three seasons. There were noticeable differences in the number of opened bolls within different defoliated treatments during 2015–2016, with considerably higher number of opened bolls in P75 and L75 than in L100.

On the final assessment, plants in L100 had 60–64% less opened bolls than those in undefoliated plants during 2013–2014 and 2015–2016. A 49% reduction in opened bolls was also observed in P75 during 2013–2014. The reductions were significant in both seasons (2013–2014: $F = 14.14$, $DF = 2, 6$, $P = 0.0054$; 2015–2016: $F = 13.12$, $DF = 3, 9$, $P = 0.0012$). Defoliation did not affect the final number of opened bolls during 2014–2015 ($F = 0.07$, $DF = 3, 9$, $P = 0.9728$) and 2016–2017 ($F = 1.35$, $DF = 3, 9$, $P = 0.3196$).

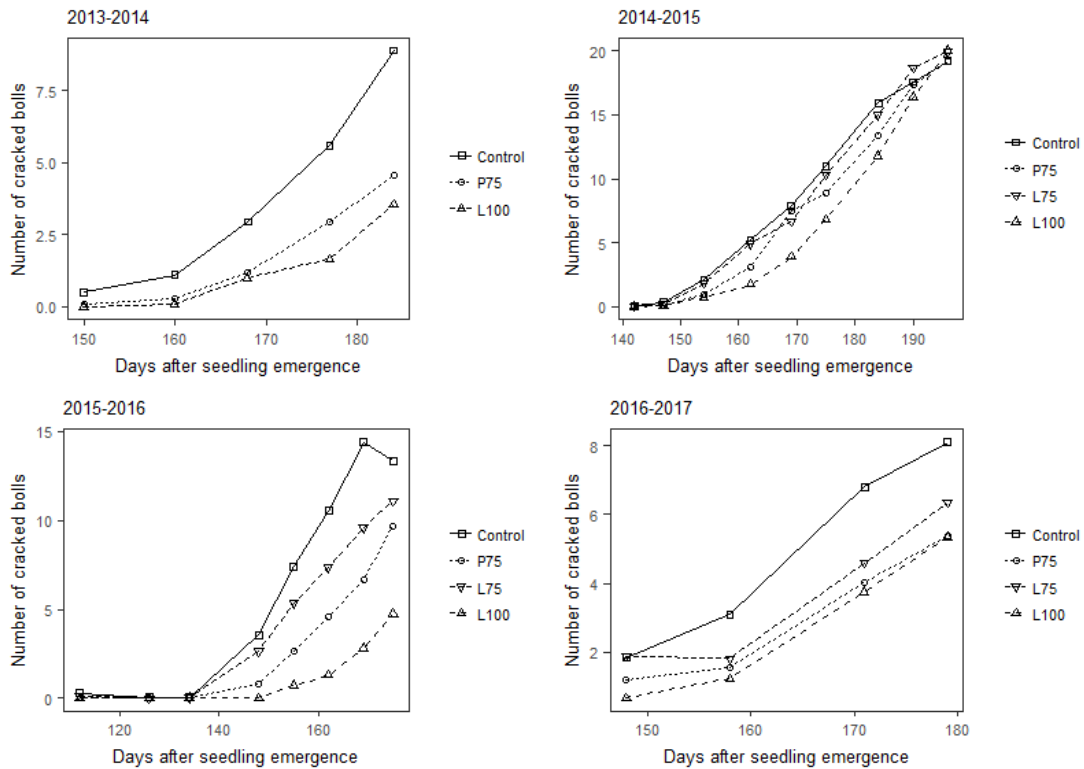


Figure 27. Growth patterns of opened bolls per plant in undefoliated plots (Control), plots subjected to the treatment of 75% defoliation by plant (P75), 75% defoliation by leaf area (L75), and 100% defoliation (L100) in the artificial defoliation trials during 2013–2014, 2014–2015, 2015–2016, and 2016–2017.

Seasonal progression in the observed cumulative proportion of opened bolls for all treatments and seasons were well fitted by the Weibull distribution function (Figure 28). The fitted proportions explained $\geq 97\%$ of the variations in the observed proportions. Defoliated plants displayed varying degrees of delay in cotton maturity relative to undefoliated plants, as seen by the clear separations of the respective fitted curves. According to the fitted functions, delays of over 10 days were estimated for the timing of 60% opened bolls in plants in L100 during 2015–2016 (18 days), and 2013–2014 (12 days). The estimated delay for plants in L100 during 2014–2015 and 2016–2017 was 8 days. The estimated maximal delay for plants in P75 was 8 days during 2015–2016 and that for L75 6 days during 2016–2017. Estimated delays in the timing of 95% opened bolls were also observed in plants in L100, at 16 days during 2015–2016 and 11 days during 2013–2014. With respect to seasons, the longest delays were estimated for 2015–2016 and the shortest for 2014–2015.

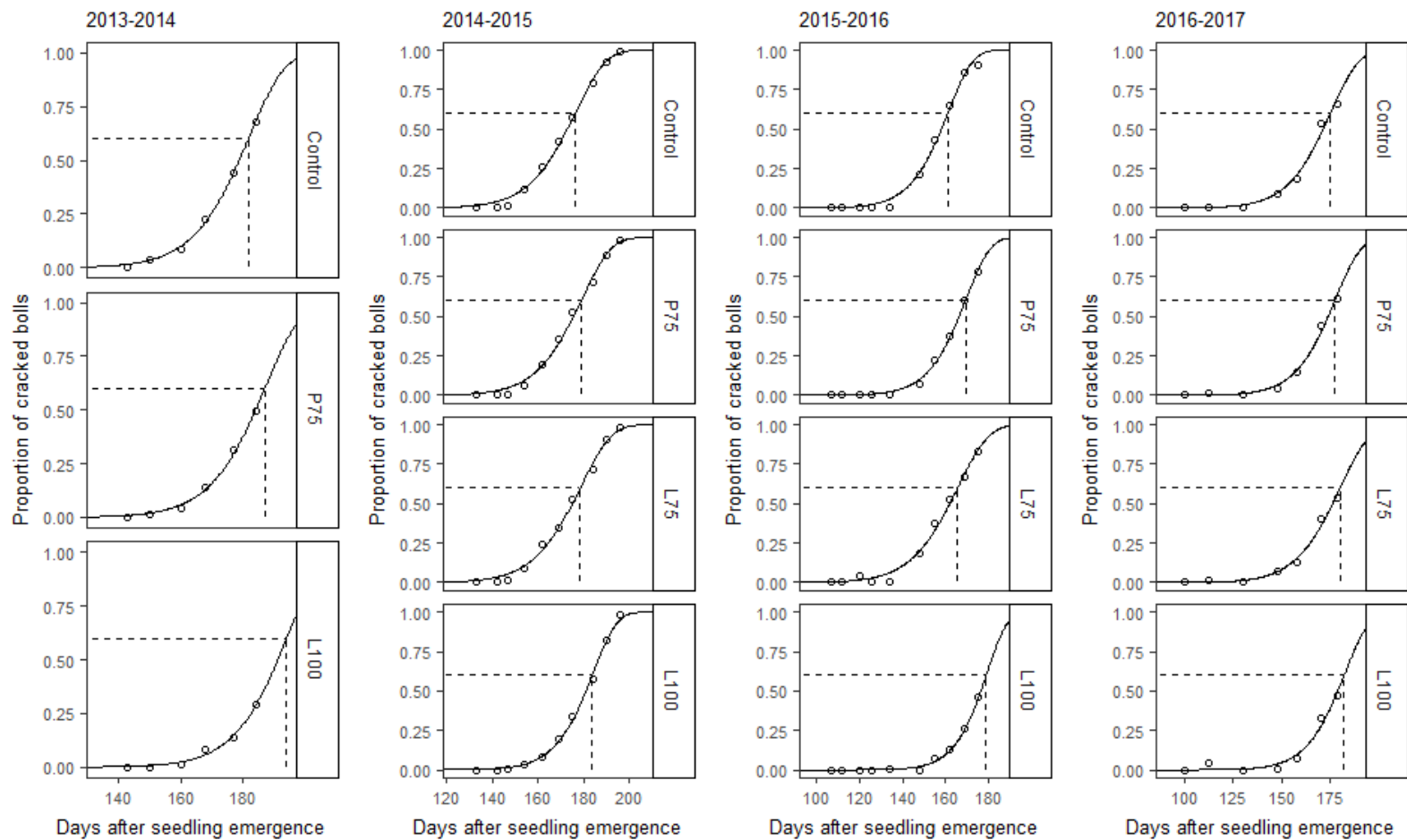


Figure 28. Observed (circles) and fitted (solid lines) accumulated proportions of opened bolls in undefoliated plots (Control), plots subjected to the treatment of 75% defoliation by plant (P75), 75% defoliation by leaf area (L75), and 100% defoliation (L100) in the artificial defoliation trials during 2013–2014, 2014–2015, 2015–2016, and 2016–2017. Dashed lines show the timings for 60% opened bolls.

Defoliation had a significant effect on lint yield (kg/ha) during 2013–2014 ($F = 8.39$, $DF = 2, 6$, $P = 0.0183$), 2015–2016 ($F = 5.89$, $DF = 3, 9$, $P = 0.0167$), and 2016–2017 ($F = 4.62$, $DF = 3, 9$, $P = 0.0321$). In all three seasons, yield in L100 was significantly lower than that in the control, with a reduction percentage of 16–31% (Figure 29). Significant yield reductions in P75 relative to the control were detected during 2013–2014 (24%) and 2015–2016 (16%). Yield in L75 was similar to that in the control in all four seasons.

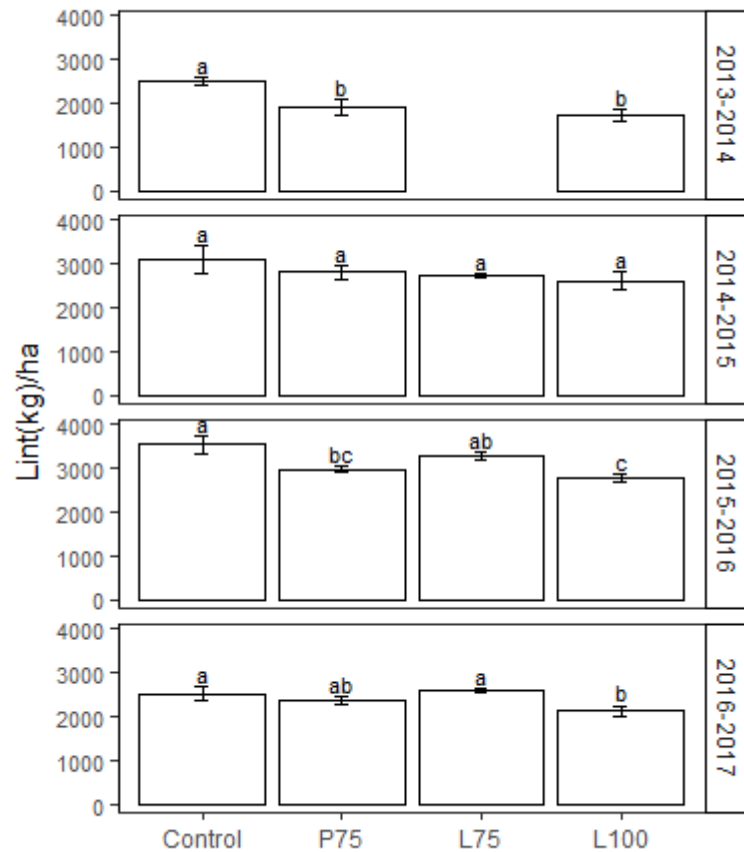


Figure 29. Lint yield (kg/ha) in undefoliated plots (Control), plots subjected to the treatment of 75% defoliation by plant (P75), 75% defoliation by leaf area (L75), and 100% defoliation (L100) in the artificial defoliation trials during 2013–2014, 2014–2015, 2015–2016, and 2016–2017. Bars within the same season labelled with different letters are significantly different by Fisher’s LSD tests following the detection of a significant treatment effects at $P = 0.05$ by ANOVA.

ii. Caged thrips damage experiment

To correlate the simulated thrips damage to actual numbers of thrips needed to cause clubbing and leaf area loss, a small greenhouse experiment was run with individually caged seedlings and introductions of field collected thrips at 0, 1, 5, or 10 thrips per cage per week. A summary of plant and thrips data at the final assessment date is presented in Figure 30.

A total of 116 thrips adults from five field collections were identified to species, of which 113 were tobacco thrips (*Thrips tabaci*) (97%) and 3 were western flower thrips (*Frankliniella occidentalis*) (3%). Before the first thrips introduction, 30–70% cotyledons were clubbed with no significant differences in the frequencies of clubbed cotyledons

among the four thrips introduction-rate treatments (0, 1, 5, 10 thrips per plant per week) ($P > 0.1$, Simulated Chisq Test, 1000 simulations).

True leaves first appeared at 13 DAE and clubbed true leaves one week later, or two weeks after the first thrips introduction. The highest percentages of clubbed true leaves were 32, 62, and 46% in plants receiving 1, 5, and 10 thrips per plant per week introductions respectively, all being reached on the final assessment date (41 DAE). Control plants remained club-free in true leaves during the experiment. On the final assessment date, there was a significant effect of thrips introduction rate on the proportion of clubbed true leaves ($F = 7.11$, $DF = 3, 12$, $P = 0.0053$). The effect was due to an absence of clubbed true leaves in the control plants, as no significant differences in the proportions were observed within the three thrips introduction-rate treatment ($P < 0.05$).

Final plant height differed significantly with thrips introduction rate ($F = 6.80$, $DF = 3, 12$, $P = 0.0062$) and the significant effect was due to the slightly shorter plants in the 5 thrips per plant per week treatment (19 cm) than that in the other three treatments (22–23 cm) ($P < 0.05$). Final leaf area were similar in plants of all thrips introduction rates including the control plants ($F = 2.34$, $DF = 3, 12$, $P = 0.1251$). Thrips densities at final assessment were 3.8, 59.4, 139.6, and 177.4 thrips per plant respectively in plants treated with 0 (control), 1, 5 and 10 thrips per plant per week introductions. Presence of thrips in control plants probably originated from thrips eggs laid inside cotyledons before the plants were caged.

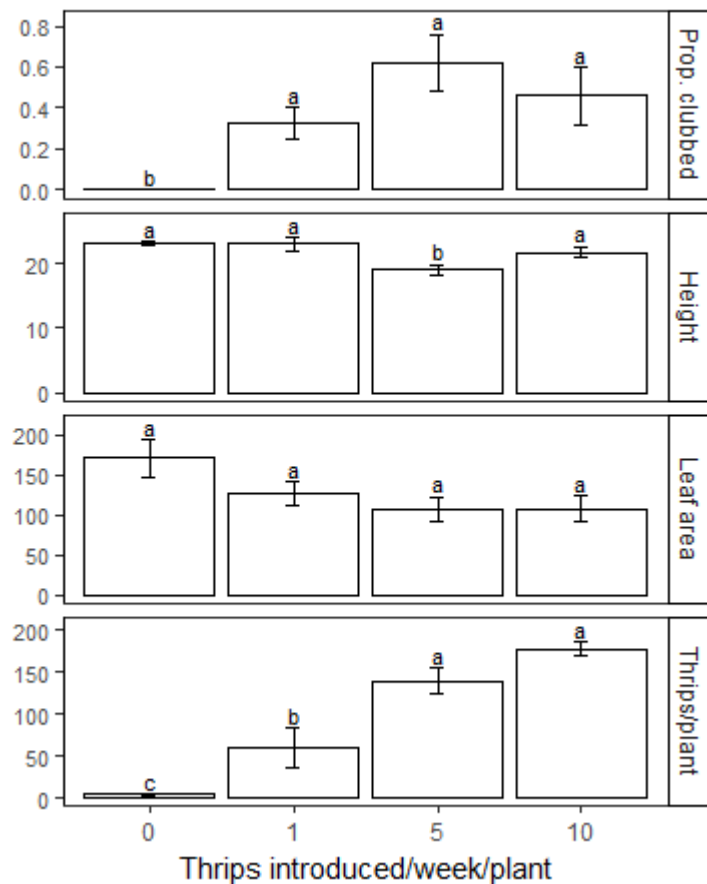


Figure 30. Proportion of clubbed true leaves, average plant height (cm), leaf area (cm²), and average number of thrips per plant on the final assessment in the laboratory thrips damage experiment.

The simulated thrips damage experiments did confirm previous research that severe defoliation such as removal of all true leaves at 2,4, and 6 node for either 100% or 75% of plants will delay maturity (60% bolls opened). The delays in maturity of the 100% defoliated treatment ranged from 8–18 days, 3–8 days in the 75% plant defoliation and 2–6 days in the 75% leaf defoliation. In all but one year the harvest date was after 95% maturity of the 100% defoliated treatment, in 2016–17 it was 3 and 6 days before expected 95% maturity for the control and 100% defoliated treatment. Yields were significantly reduced by defoliation in 3 of 4 years in the 100% defoliation, and 2 out of 4 years for the 70% by plant treatment. 75% leaf defoliation did not reduce yields.

e. Objective 5. Control options for mirids experiment

In both 2014–15 and 2015–16 a local agronomist informed the project team that green mirid (*Creontiades dilutus*) numbers had exceeded thresholds in a field they were monitoring but when systematically sampled the sites were well below threshold. In addition, the respective growers' were new to cotton and reluctant to leave an untreated area so no experiments were set up.

In 2016–17 a cotton crop near Griffith was identified as having high mirid numbers. An experimental protocol was agreed that allowed for a single strip of unsprayed cotton and replicated plots of Regent® (fipronil) + Canopy® oil and Canopy® oil only treatments. The farm manager was planning to spray immediately but the extensive pre-spray monitoring results indicated the crop was still well below threshold.

This monitoring took place on 12 December, the crop was at 6–8 node and from visual assessment of fifty-two 1-m row sections of cotton only a single mirid nymph and 8 apple dimpling bugs (*Campylomma liebknechti*) were observed. In addition fifty-two 5-m D-vac samples were made and 29 green mirid adults and 3 nymphs were captured averaging 0.1 mirids per metre row across the whole site.

The 'visual monitoring' threshold of 0.5 mirids per metre from flowering to 1 open boll in cool area is the most conservative of the mirid thresholds and was only just exceeded on 19 December in the edge plot designated for the unsprayed control based on four 5-m D-vac samples (Figure 31). Visual monitoring on 20 December was again less effective with no mirids and only 3 apple dimpling bugs observed from 52 m of cotton row assessed.

A third monitoring took place on 4 January when the crop was 14–15 node, approximately 53 cm high and first squares were on 11–13 node. Beatsheet monitoring of four 1-m beats per plot for each of the six replicates for the two treatments and the single control plot resulted in 19 adult mirids and 29 nymphs collected equating to approximately 0.9 mirids per metre across the site or in the designated treatment plots up to 2 mirids per metre in the designated control plot (Figure 32). Although mirid numbers had declined from the 19 December monitoring a decision to spray on 6 January was made.

The clumped and uneven distribution of mirids is evident by the mirid numbers on the three monitoring dates prior to any treatments being applied and it was expected that six replicates and a blocked design would balance mirid numbers between the two designated treatments (Figure 31 and 32).

Results from D-vac samples showed reductions in mirid numbers in all plots post-spray, with bigger reductions in the two sprayed treatments than in the control (Figure 31). Combined application of Regent® and Canopy® oil did not significantly improve the efficacy as compared with Canopy® oil alone. Results from the beatsheet samples (Figure 32) showed that mirid numbers had dropped to zero post-spray in all plots except those treated with Canopy® oil alone, where a small number of mirids remained. Statistical comparisons between unsprayed control and the two sprayed treatments were not possible as the unsprayed control was not replicated.

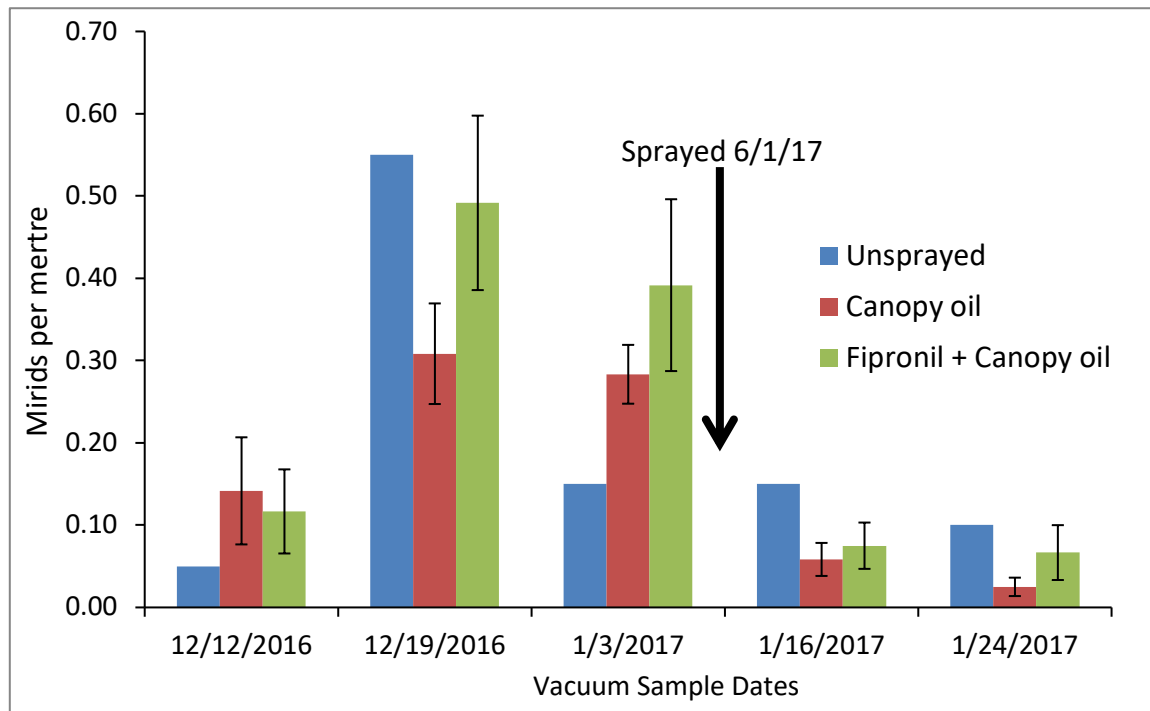


Figure 31. Mirid densities measured by D-vac sampling at dates before and after the spray application on 6 January 2017. Error bars indicate standard error on Canopy® oil and fipronil (Regent®)+ Canopy® oil treatments only n=6. Unsprayed treatment was unreplicated.

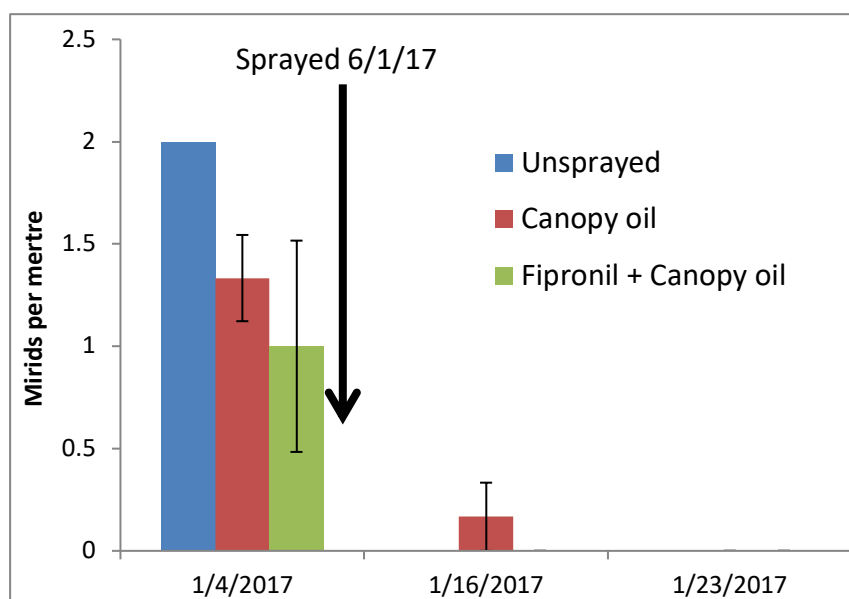


Figure 32. Mirid densities measured by beat sheet sampling at dates before and after the spray application on 6 January 2017. Error bars indicate standard error on Canopy[®] oil and fipronil (Regent[®]) + Canopy[®] oil treatments only n=6. Unsprayed treatment was unreplicated.

There were no observed differences in retention or boll positions between the two sprayed treatments. Commercial harvest and hand harvest found Canopy[®] oil on average yielded slightly lower than Regent[®] + Canopy[®] oil, however results were variable and the differences were not statistically significant (Figure 33). The unreplicated control had a lower yield than the sprayed treatments however not outside the range of error of the Canopy[®] oil treatment and this area included the edge of two bays so may have yielded lower due to its position. The crop was also affected by two instances of 2, 4-D spray drift in mid-January which caused substantial foliar damage.

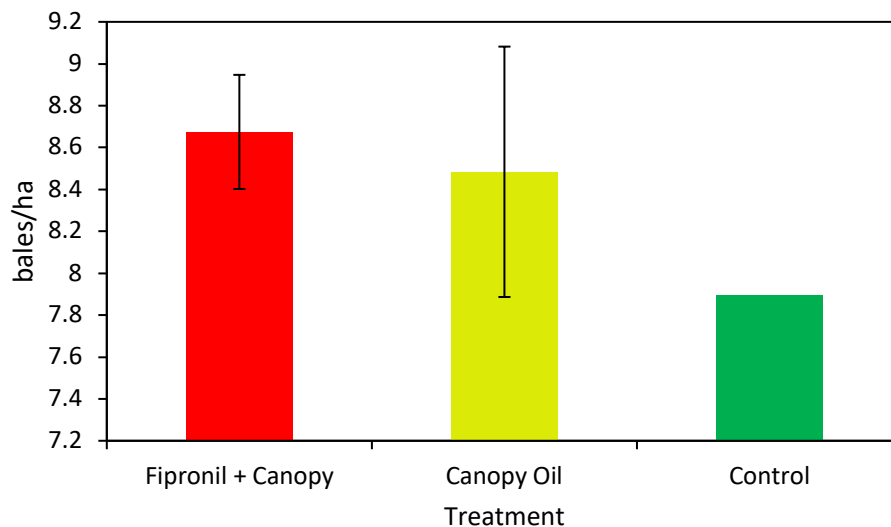


Figure 33. Yields measured from commercial harvest by continuous cotton picker/baler. Error bars indicate standard error on Canopy[®] oil and Regent[®] (fipronil) treatments only n=6. Unsprayed treatment was unreplicated.

f. Objective 6. Seasonal patterns of invertebrates in cotton fields

Seasonal patterns of pest and beneficial invertebrates were monitored with whole plant washes during establishment, and D-vac samples and with pit fall traps during mid and late season. Samples were taken from unsprayed Bt cotton, conventional cotton refuge and in some years from pigeon pea refuge. Where possible samples were collected from each of the four sites in each of the three cotton seasons during 2014–17. During cotton establishment plant washes were taken from 20 plants per block per site. Invertebrates were identified to morphological species groups and where possible to species. Subsets of pests and beneficials of importance in cotton are presented in graphs for each monitoring method for each year (Figures 34–51).

Plant wash samples

During establishment thrips were the most numerous cotton pests with numbers peaking in 2014 in November samples at 54 and 41.5 per plant averaged across the four monitoring sites respectively for Bt and Conventional cotton. Non-thrips cotton pests did not total more than 0.5 per plant, with leafhoppers being the next most numerous (Figure 34). At the same time

the beneficial invertebrates totalled on average less than 0.5 per plant with spiders and wasps being the most numerous (Figure 35). The peak in numbers of pests in 25 November 2014 samples from Conventional cotton refuges was mirrored with a similar peak in beneficial numbers for the same sample period.

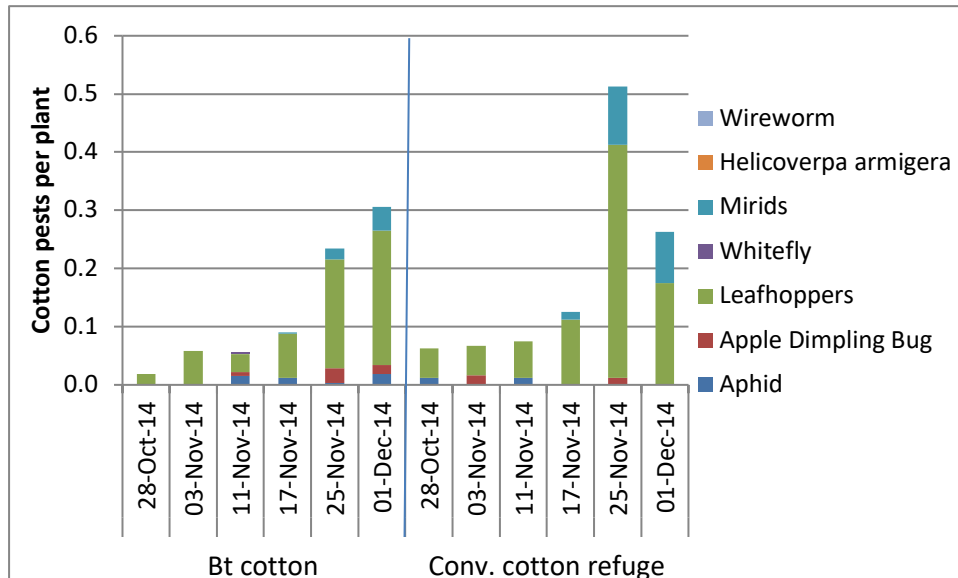


Figure 34 Cotton pests by functional group standardised per plant from whole plant wash samples taken from establishing cotton from unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2014.

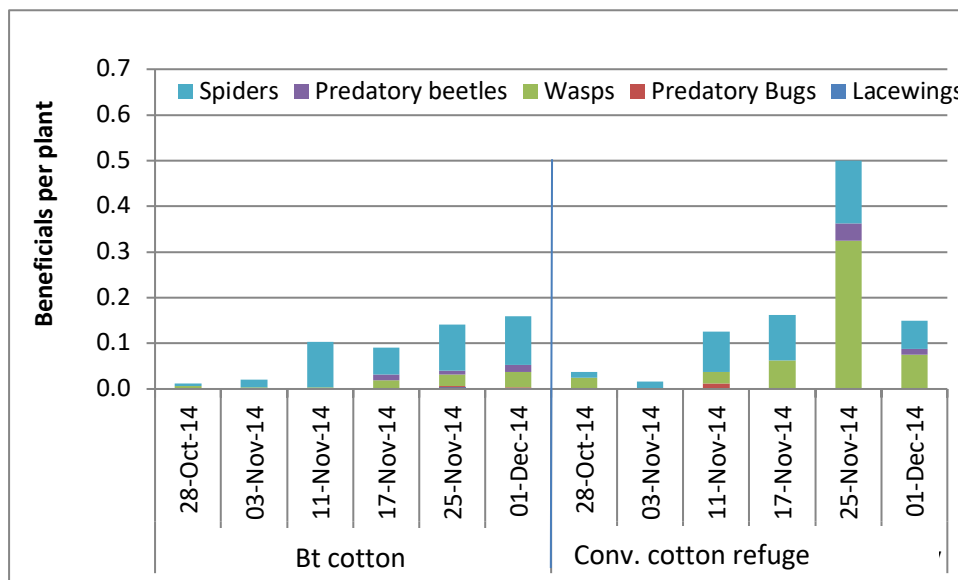


Figure 35 Beneficials by functional group standardised per plant from whole plant wash samples taken from establishing cotton from unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2014.

Cotton establishment in 2015 saw on average much smaller numbers of thrips with daily peaks of only 3.2 and 2.3 per plant in the 17 November 2015 sample and again leafhoppers were the next most numerous with a peak on 2 Dec 2015 of 0.38 leafhoppers per plant (Figure 36).

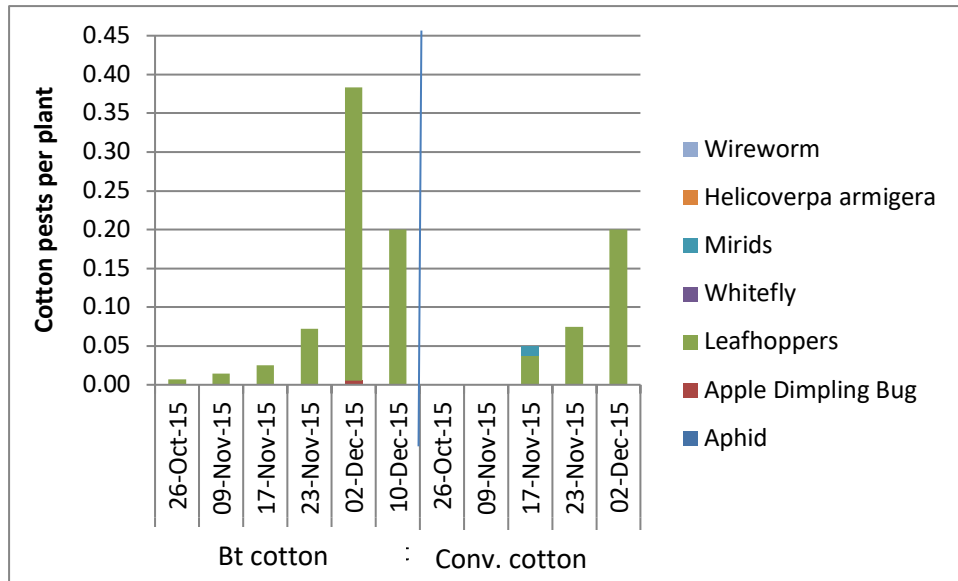


Figure 36 Cotton pests by functional group standardised per plant from whole plant wash samples taken from establishing cotton from unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2015

During cotton establishment in 2015 spiders and wasps were again the most numerous beneficials but this season predatory bugs and some predatory beetles were more numerous (Figure 37). Overall beneficial numbers were at a similar level to 2014 and 2016 (Figure 39).

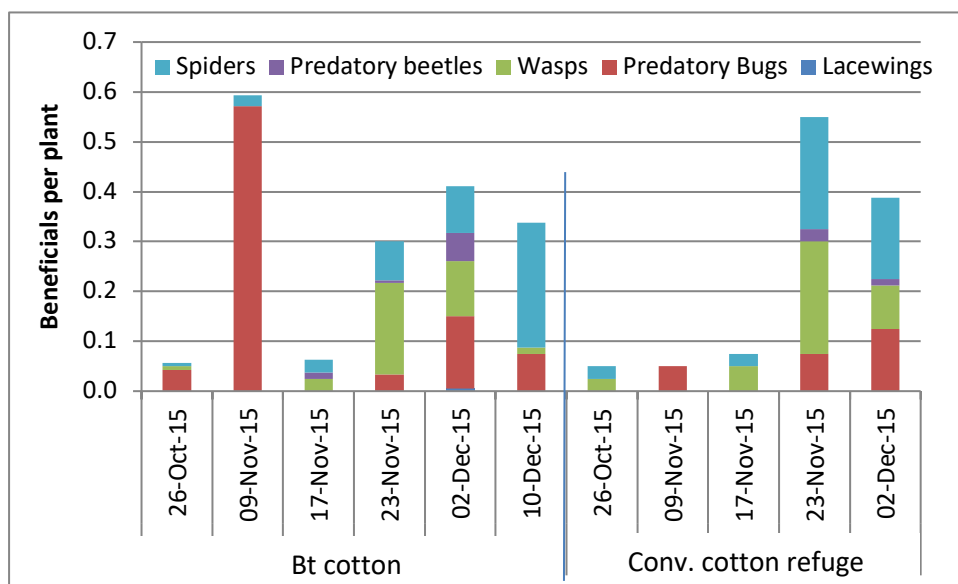


Figure 37 Beneficials by functional group standardised per plant from whole plant wash samples taken from establishing cotton from unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2015.

Thrips numbers in establishing cotton in 2016 were very low peaking at 0.46 per plant on 8 Dec 2016 when the cotton seedlings just passed the 6 node threshold level (Figure 38). *Helicoverpa armigera* egg numbers were collected from most sampling periods during cotton establishment and apple dimpling bug (*Campylomma liebknehti*) from December samples. Beneficial numbers were also low per plant with spiders and wasps present at all but the first monitoring period (Figure 39).

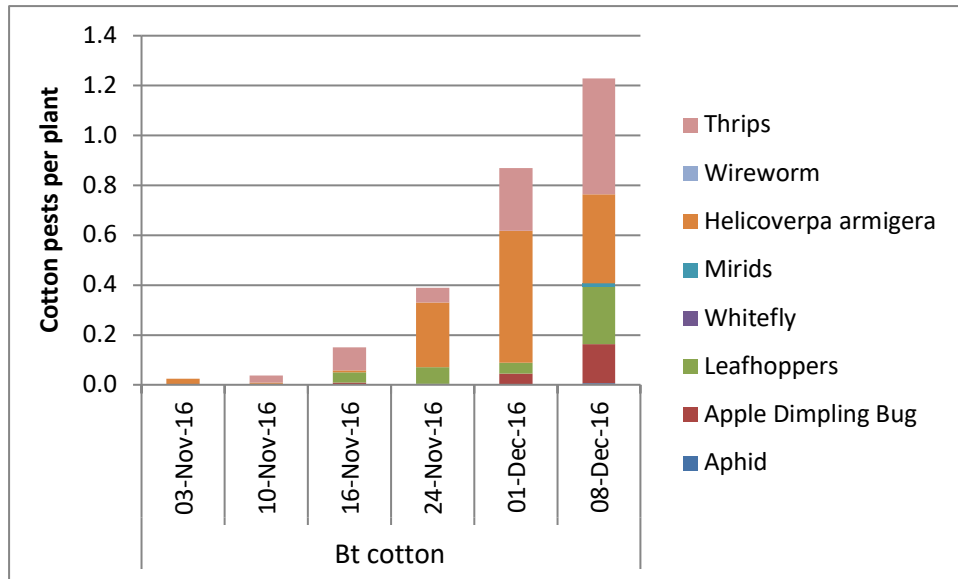


Figure 38 Cotton pests by functional group standardised per plant from whole plant wash samples taken from establishing cotton from unsprayed Bt cotton (74BRFD) from four sites in Whitton, Darlington Point and Coleambally areas in 2016.

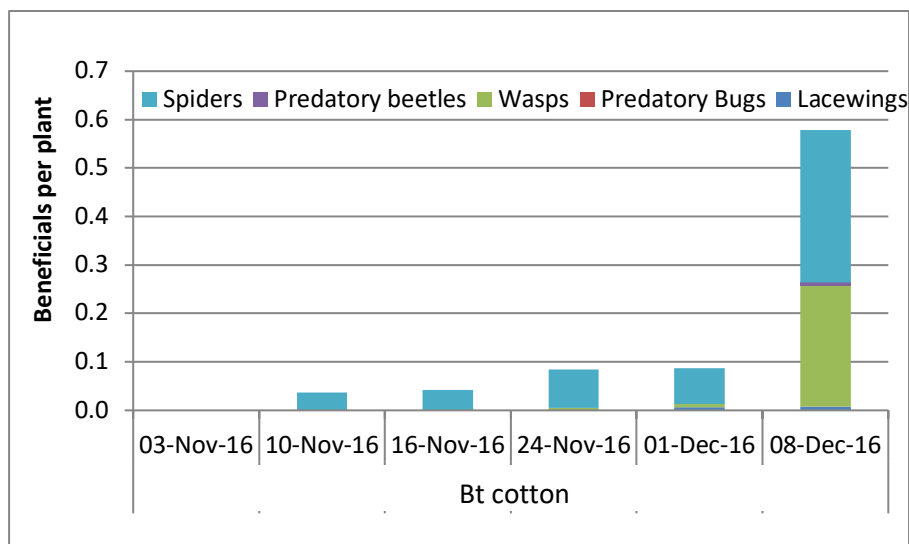


Figure 39 Beneficials by functional group standardised per plant from whole plant wash samples taken from establishing cotton from unsprayed Bt cotton (74BRFD) from four sites in Whitton, Darlington Point and Coleambally areas in 2016.

Pitfall samples

Pitfall traps collect insects that move across the soil surface and fall into the collecting vessel. These traps were left for a week at a time in transects in unsprayed Bt cotton and Conventional cotton refuges. Ants and flies were consistently the most common invertebrates collected in the traps. Thrips numbers reached at 56 and 74 per trap on 8 December 2014 but dropped to less than 5 in subsequent samples. Leafhoppers were consistently the most numerous cotton pests except for the 17 March 2015 collection in Bt cotton when whitefly numbers reached 21 per trap (Figure 40).

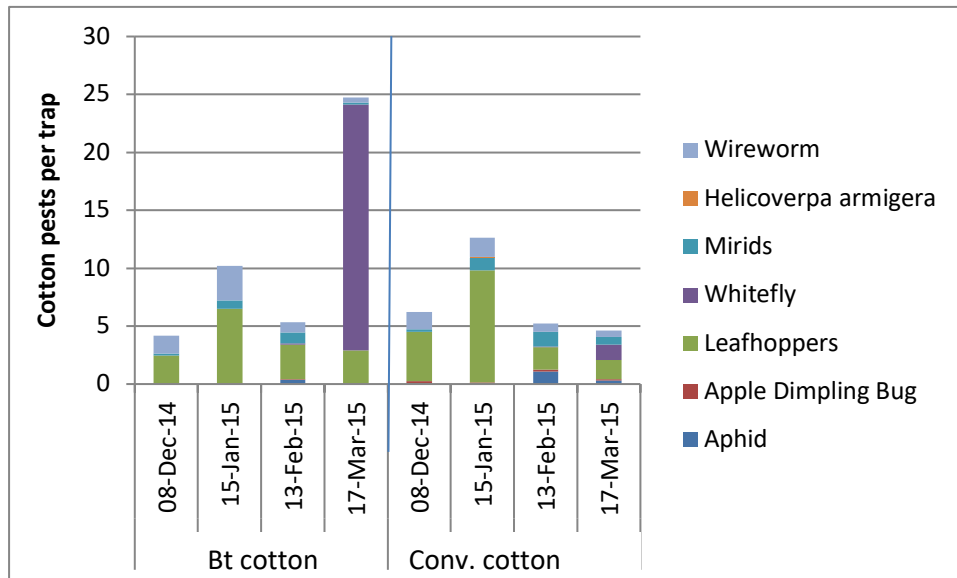


Figure 40 Cotton pests by functional group standardised per trap from periodic pitfall samples of 5 traps per block placed in cotton beds for 7-days in blocks of unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2014–15.

Slightly more beneficial invertebrates were collected from pitfall traps than pest invertebrates and like the plant wash samples during establishment, beneficial invertebrates were dominated by spiders and wasps, with some predatory beetles, mostly Staphylinids (Rove beetles) (Figure 41).

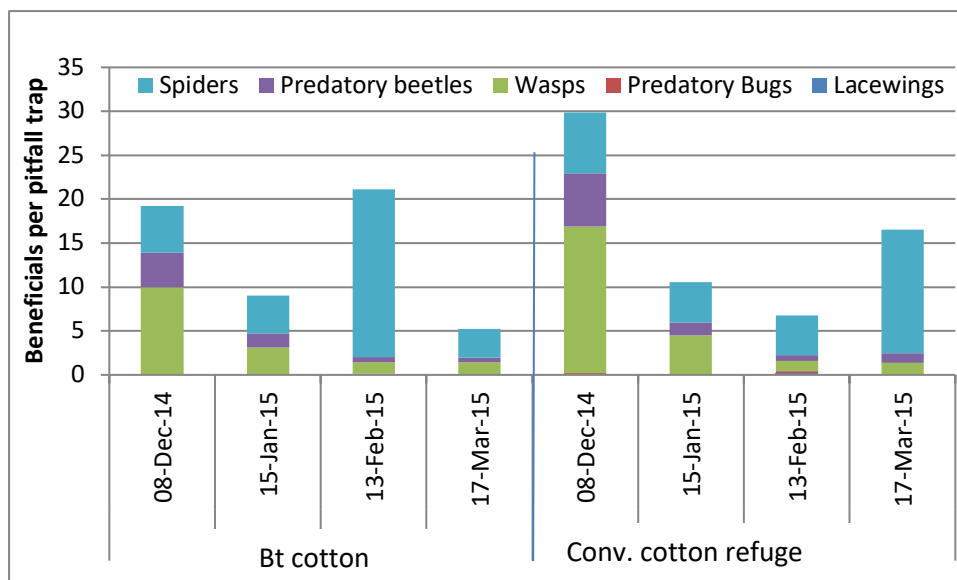


Figure 41 Beneficials by functional group standardised per trap from periodic pitfall samples of 5 traps per block placed in cotton beds for 7-days in blocks of unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2014–15.

Only two sets of pitfall samples were taken in 2016, mid and late season (Figure 42). Numbers of cotton pests were lower than in 2015 for similar periods, with whitefly appearing in all samples at relatively low numbers per trap, peaking in the Conventional cotton in January with 8 whitefly per trap. Thrips similarly peaked at 8 thrips per trap in the March Conventional cotton samples.

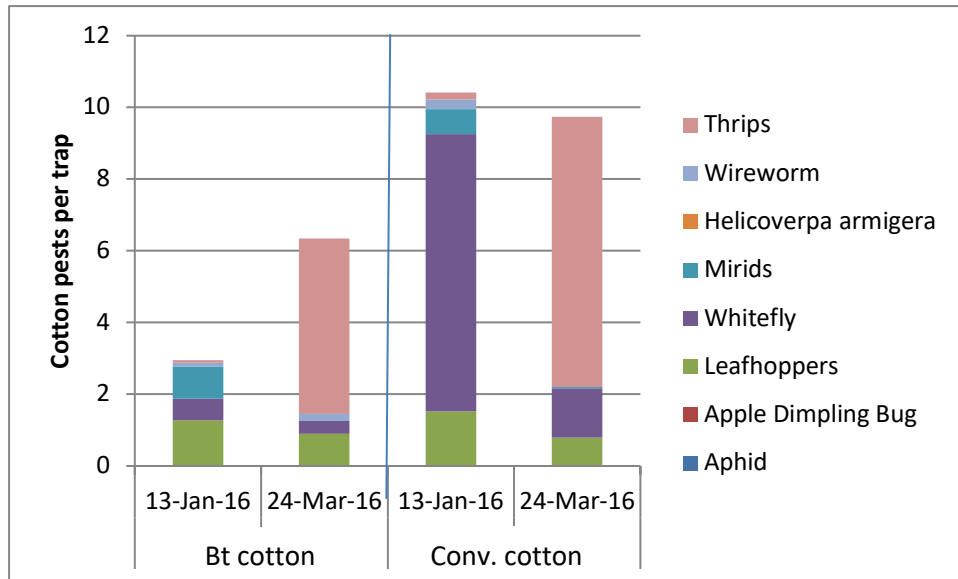


Figure 42 Cotton pests by functional group standardised per trap from periodic pitfall samples of 5 traps per block placed in cotton beds for 7-days in blocks of unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2016.

Beneficial invertebrates caught in pitfall traps in 2016 (Figure 43) were almost four times more numerous than for the same period in 2014 (Figure 41) and twice as numerous compared to 2017 (Figure 45). Predatory beetle numbers contributed most to the seasonal differences. Spiders, wasps and some predatory bugs making up the remainder of beneficials caught.

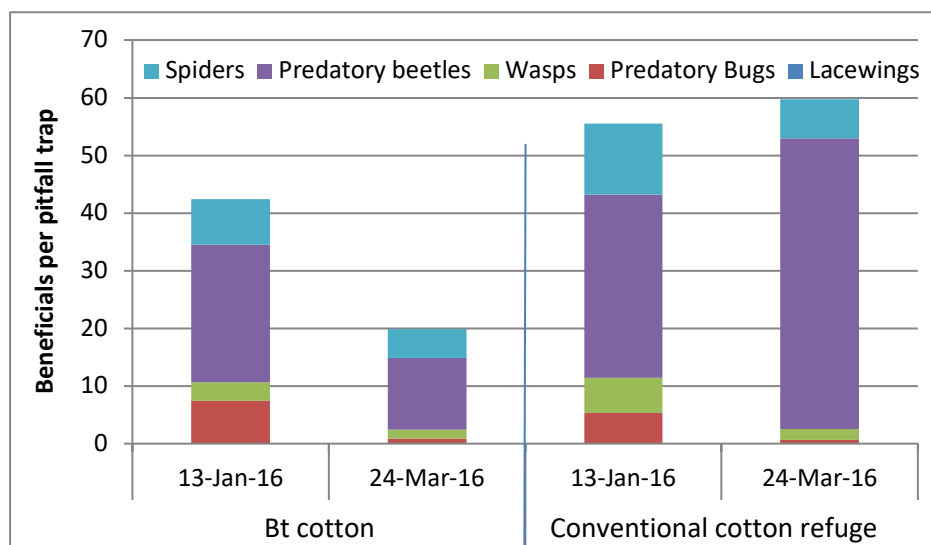


Figure 43 Beneficials by functional group standardised per trap from periodic pitfall samples of 5 traps per block placed in cotton beds for 7-days in blocks of unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2015–16.

Surprisingly in 2017 thrips numbers collected in the pitfall traps were higher than in the previous years, yet were lowest seen during establishment. The mid March 2017 sample averaged 24, 24 and 65 thrips per trap respectively for unsprayed Bt cotton, Conventional cotton refuges and pigeon pea refuges respectively. Similar to the plant wash samples at establishment, leafhoppers dominated the non-thrips cotton pests with a small number of mirids (Figure 44). The beneficials collected in pitfall traps in 2017 were dominated by spiders and wasps (Figure 45). Differences between Bt cotton, Conventional cotton refuges

and pigeon pea refuges were not consistent, although the Conventional cotton did tend to have greater numbers of pests and beneficials relative to the other sites on most sampling dates.

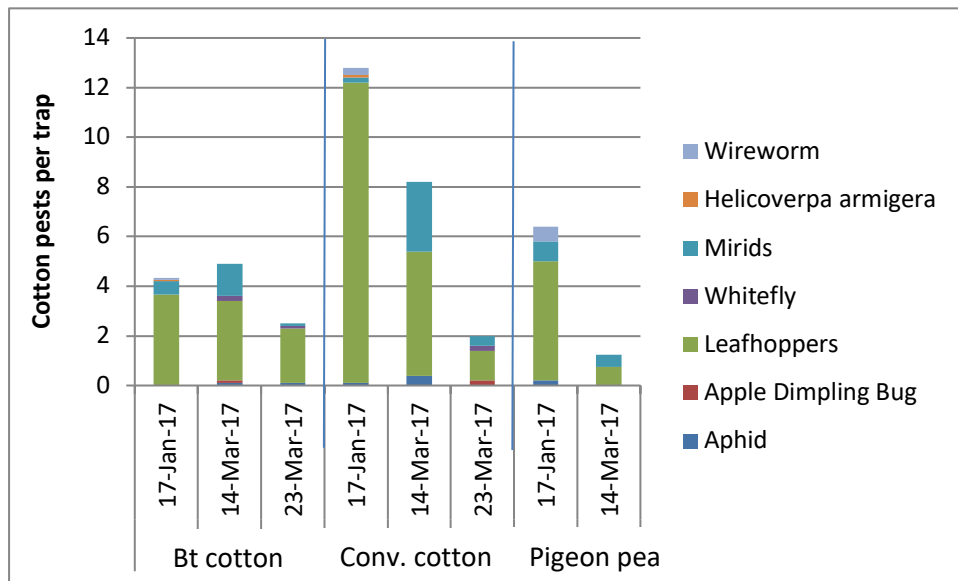


Figure 44 Cotton pests by functional group standardised per trap from periodic pitfall samples of 5 traps per block placed in cotton beds for 7-days in blocks of unsprayed Bt cotton (74BRFD), Conventional cotton (71RRFD) refuges and pigeon pea refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2017.

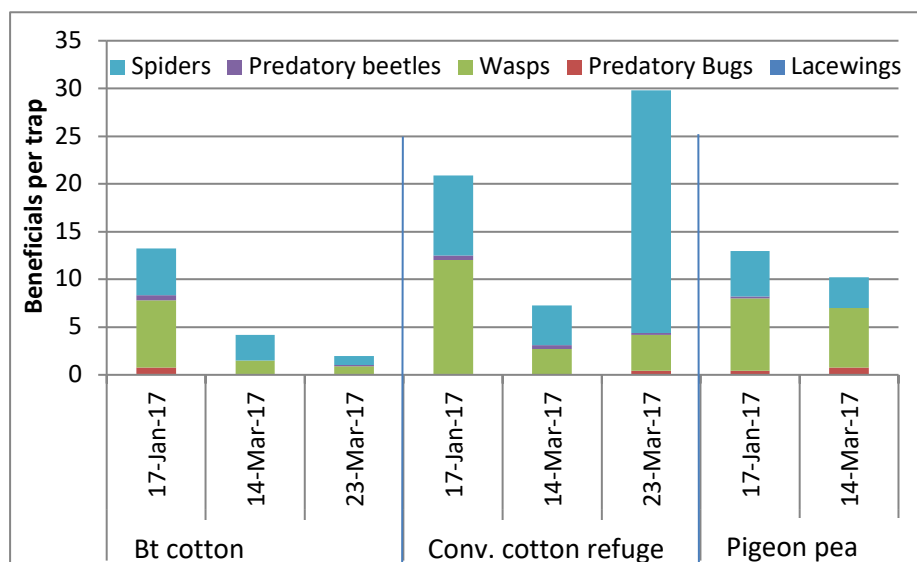


Figure 45 Beneficials by functional group standardised per trap from periodic pitfall samples of 5 traps per block placed in cotton beds for 7-days in blocks of unsprayed Bt cotton (74BRFD), Conventional cotton (71RRFD) refuges and pigeon pea refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2017.

D-vac samples

D-vac's can be a quick way to sample invertebrates from plants. Five 4 m D-vac samples were taken per block from each of the four monitoring sites and average data standardised per metre. In 2014 an incorrect technique was used for the December- January samples so data has been omitted. Of the late season samples cotton pest numbers per metre ranged from approximately 8–16 pests per metre not including thrips. Whitefly and leafhoppers were consistently present, peaking at 6 and 7 per metre respectively for the Bt and Conventional cotton for both insects on 19 Feb 2015 (Figure 46).

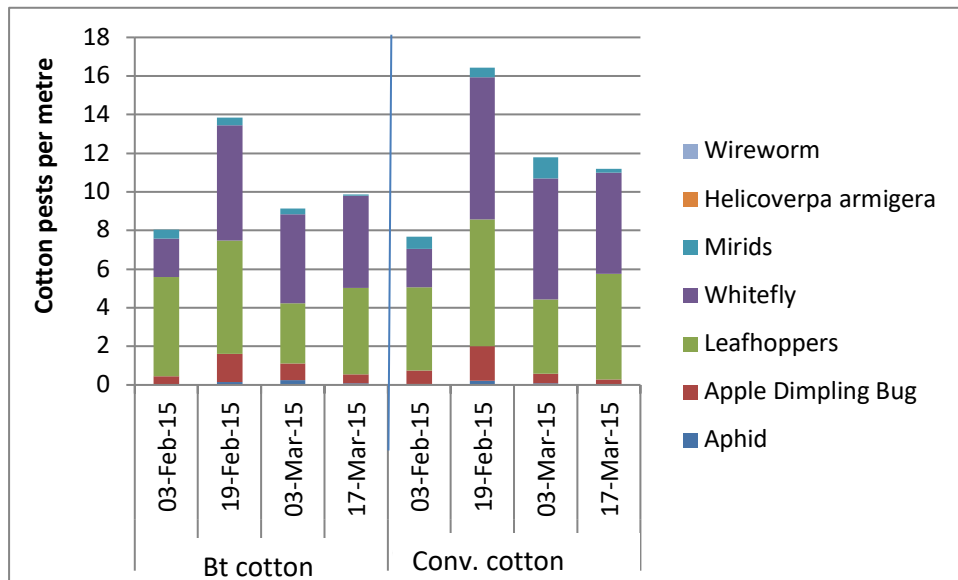


Figure 46 Cotton pests by functional group standardised per metre row from five 4 m D-vac samples taken periodically from unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2015.

Beneficials numbers were around 2 per metre in all four sample periods, with spiders and wasps dominating the numbers (Figure 47).

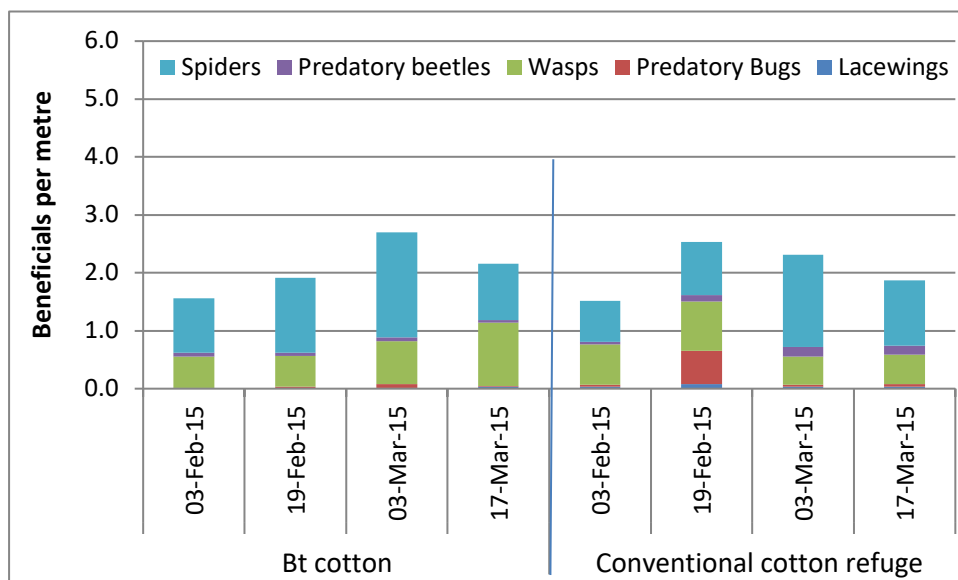


Figure 47 Beneficials by functional group standardised per metre row from five 4 m D-vac samples taken periodically from unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2015.

From December 2015 to February 2016 cotton pest numbers from D-vac samples were similar to pitfall and plant wash samples, consistently seeing 2–7 leafhoppers per metre (Figure 48). The biggest difference from the February and March 2015 D-vac samples was the large spike in whitefly numbers, particularly in the Conventional cotton refuge, with an average of 75 whitefly per metre on 17 March 2016. Whitefly were not sampled from the pigeon pea refuge. Surprisingly few *Helicoverpa armigera* were sampled from either refuge crop. Apple dimpling bugs were present in later season samples at about 1–2 bugs per metre. Beneficial numbers were approximately 1 per metre for each sample period, with little difference between the Bt and cotton or pigeon pea refuges (Figure 49). In the D-vac samples the predatory beetle samples consisted of Red and Blue beetles (*Dicranolalus bellulus*) and various lady beetle (Coccinellid) species.

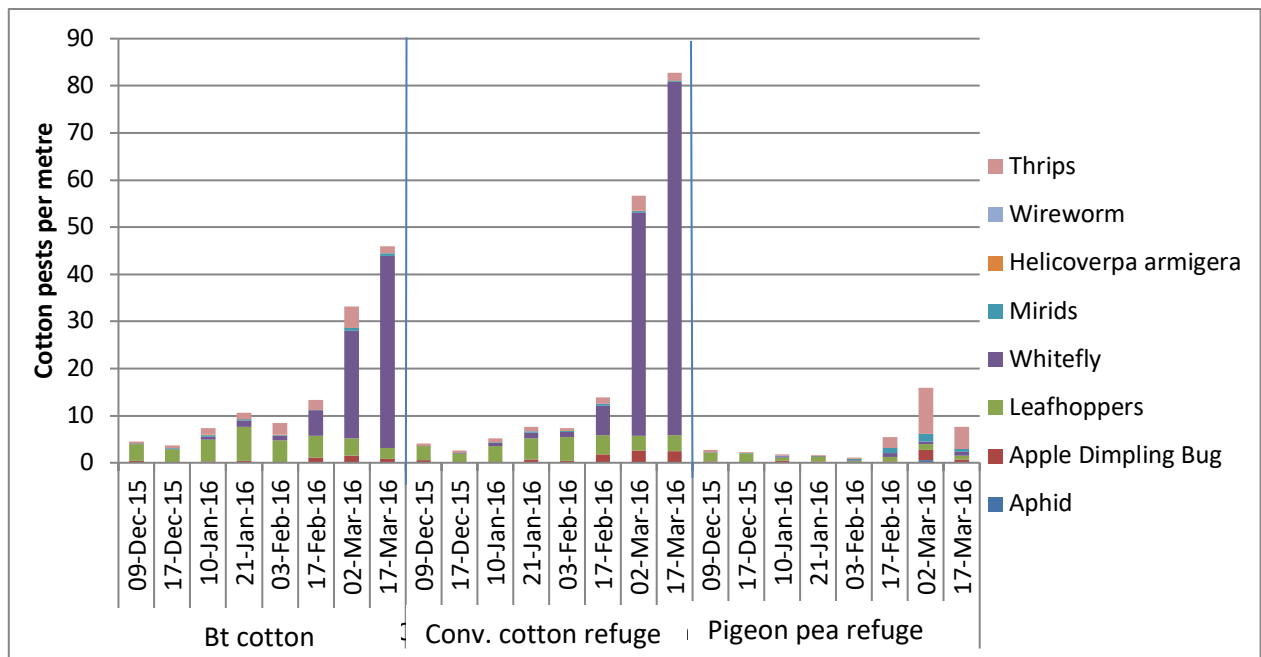


Figure 48. Cotton pests by functional group standardised per metre row from five 4 m D-vac samples taken periodically from unsprayed Bt cotton (74BRFD), Conventional cotton (71RRFD) refuges and pigeon pea refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2015–16.

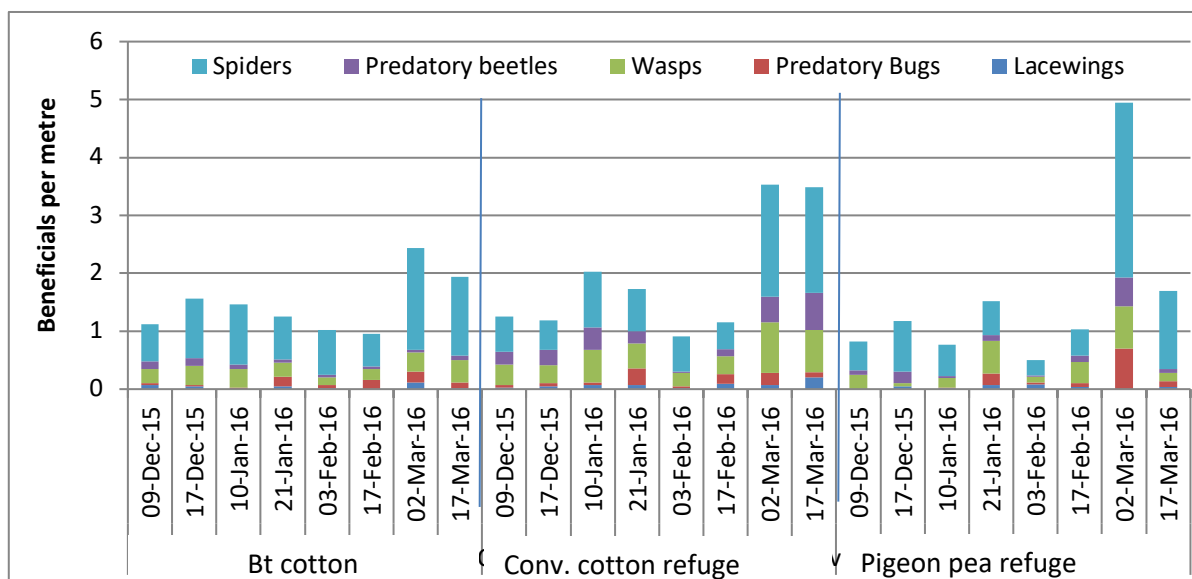


Figure 49 Beneficials by functional group standardised per metre row from five 4 m D-vac samples taken periodically from unsprayed Bt cotton (74BRFD), Conventional cotton (71RRFD) refuges and pigeon pea refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2015–16.

In 2016–17 whitefly numbers did not increase as they did in 2015–16, and thrips numbers were slightly lower relative to the previous year in the D-vac samples (Figure 50). *Helicoverpa armigera* eggs were collected in most samples, although the numbers were below 0.5 per metre. Ironically they were slightly more numerous in the Bt plots than the refuge sites. Spiders and wasps were again the most numerous beneficials sampled and averaged in both the Bt cotton and Conventional cotton refuge around 2 per metre each monitoring date (Figure 51).

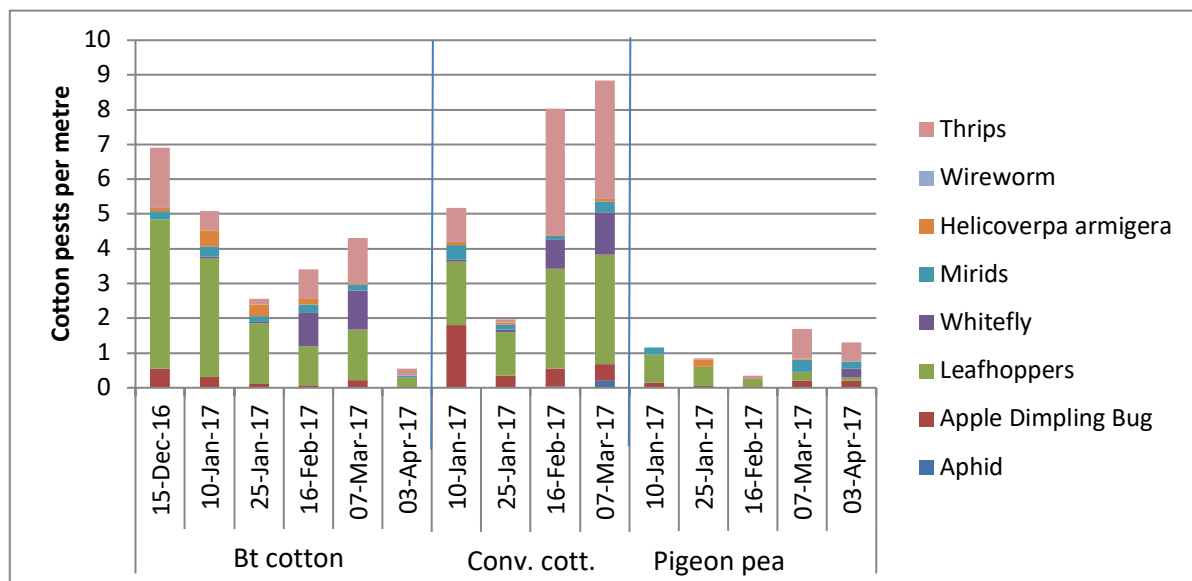


Figure 50. Cotton pests by functional group standardised per metre row from five 4 m D-vac samples taken periodically from unsprayed Bt cotton (74BRFD), Conventional cotton (71RRFD) refuges and pigeon pea refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2017.

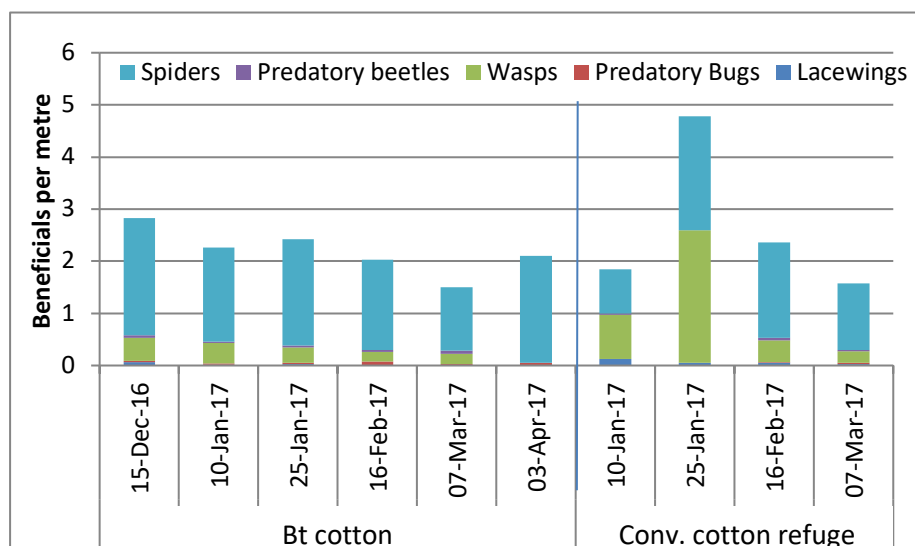


Figure 51 Beneficials by functional group standardised per metre row from five 4 m D-vac samples taken periodically from unsprayed Bt cotton (74BRFD) and Conventional cotton (71RRFD) refuges from four sites in Whitton, Darlington Point and Coleambally areas in 2017.

The seasonal patterns for cotton invertebrate pests and beneficials observed over three southern cropping seasons were not dramatically different from what is expected in cotton grown in other regions. Both pests and beneficials colonised the cotton from seedling emergence, with thrips being by far the most numerous pest and their numbers being the most variable between seasons. Leafhoppers were consistently present at relatively steady numbers, as were mirids, although at much smaller numbers. Whitefly were highly variable with a particularly high numbers in summer of 2016. The relative absence of *Helicoverpa armigera* from the refuge collections is of concern. There were a complex fauna of spiders and wasps that consistently dominated the beneficial fauna. The relative importance of the wasps is not clear given most were not identified to species but only to parasitoid families, hence likely to be highly host specific. The spiders however are generalist predators and were likely to be feeding on at least some stages of all the pests observed.

g. Objective 7. OZCOT model validation

For ten of our experiments, from three trial sites we have planting, key agronomy and some phenology data to assist in validating the OZCOT model.

Outcomes

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

Monitoring data and experiments over three years have increased understanding of invertebrate populations in southern grown cotton and provided some data to give growers and consultants more confidence that cotton industry IPM information and recommendations are relevant for southern grown cotton:

- a. Thrips community identified at cotton establishment, mid and late season identified from plant washes, pit falls and D-vac samples and similar to reported in more northern grown cotton.
 - i. *Frankliniella occidentalis* found as a minor but increasing component of the establishment thrips community
 - ii. *Frankliniella occidentalis* found to be more locally abundant near Whitton than at sites near Darlington Point or Coleambally.
- b. Six commercial scale experiments conducted to validate thrips threshold for southern grown cotton
 - i. Foliar insecticides generally reduce thrips numbers temporarily
 - ii. Controlling for thrips did not significantly reduce yields relative to not controlling thrips although there was a trend to lower yields relative to the sprayed treatment plots.
- c. Commercial scale experiment conducted to evaluate seed and in furrow treatment efficacy for thrips control
 - i. In-furrow application of phorate reduced thrips numbers for 21 days whereas thiomethoxam seed treatment reduced thrips for only 7 days after emergence relative to the untreated control.

- d. Two small plot experiments conducted to evaluate alternative insecticides for controlling thrips
 - i. Spinatoram, cyantraniliprole, flonicamid and sulfoxaflor all reduced larval thrips numbers relative to the unsprayed control and the latter three adult thrips numbers after the 2nd spray application.
 - ii. Thrips numbers were low and patchy in the second experiment and results were not significant
- e. Four seasons of simulated thrips experiments conducted to identify level of defoliation leading to maturity delays and yield penalties.
 - i. Defoliation led to decreased final plant height in two of four years
 - ii. At the final assessment date, close to harvest, boll numbers were similar in all four years but numbers of open bolls were smaller in 100% defoliated treatments in two years and in 100% defoliation of 75% of plants in one year but trended lower in three years.
 - iii. 100% defoliation led to delays in maturity (60% opened bolls) in all four years with delays 12, 8, 18 and 8 days respectively. Maximum delays found in the 100% defoliation of 75% of plants was 8 days and 6 days for 75% of each leaf defoliated.
 - iv. The longest delays were experienced in 2015–2016
 - v. There was a yield deficit from 100% defoliation in three out of four years, and for 100% defoliation of 75% of plants in two out of four years.
 - vi. There was no yield deficit seen in the defoliation of 75% of each leaf in the three years assessed.
- f. Developed an individual cotton plant in a single pot bioassay protocol to quantify thrips population to cotton seedling damage.
 - i. Introduction of 1, 5, and 10 thrips per week onto cotton seedlings did result in significant differences in final thrips numbers at 41 days after emergence compared to no thrips introductions; 5 and 10 thrips per week resulted in statistically equivalent final numbers.
 - ii. There was no thrips damage, distortion or clubbing in the control pots and no significant difference between the rate of thrips introductions and level of damage observed, plant height or leaf area. Although there was a trend towards smaller leaf area for seedlings with thrips.
- g. A commercial scale experiment conducted to validate mirid threshold
 - i. Without a replicated control it is not possible to confirm a validation of the mirid threshold but we can say that the Canopy® oil treatment was
- h. Seasonal patterns of invertebrates collected from cotton at establishment via plant washes, from D-vac samples in mid and late season and with pitfall traps in untreated Bt cotton, conventional cotton refuge and in some pigeon pea refuges.
 - i. Data collected from experimental plots will assist with validation of the OZCOT model.

- j. Co-convened annual southern cotton research review for researchers working in southern cotton region, interested local consultants, industry representatives and growers to report, plan and discuss research relevant to southern cotton.
- k. Participated in IREC meetings, field days and farm walks
- l. Helped convene and contribute to 2017 REFCOM in Griffith.

6. Please describe any:-

- a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.); N/A
- b) other information developed from research (eg discoveries in methodology, equipment design, etc.);
- c) and no changes required to intellectual property register

Conclusion

7. 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?

The overall objective of this project was determining the applicability of IPM recommendations developed for northern cotton to southern production areas, which has a shorter growing season and higher solar radiation, with a focus on establishment pests, specifically thrips. None of the data collected suggested that pest dynamics in the south are grossly different from the north and that the current IPM recommendations are applicable to southern conditions.

Thrips species composition was similar to the north with *Thrips tabaci* being the most dominant species followed by *Franklinella schultzei* and *Thrips imago*. *Frankliniella occidentalis* was only a minor component of the thrips community during cotton establishment in the first two seasons of monitoring but, it did however increase in third year at approximately a quarter of the adults and almost a third of nymphs monitored. If spraying for thrips becomes routine in cotton it is likely that the proportion of *F. occidentalis* will increase and could become a more significant establishment pest, however it could also ensure that mite predators are still within the system and reduce mite outbreaks.

Commercial scale thrips threshold experiments were able to confirm that seed treatments of thiomethoxam reduced thrips nymph numbers for only one week after emergence, phorate reduced thrips nymph numbers for 3 weeks after seedling emergence. Commercial scale experiments with foliar insecticides for thrips control did not support a reduced thrips threshold for southern grown cotton. Within field variability potentially masked thrips treatment effects but we saw no significant yield effects from thrips treatments relative to each other or not treating for thrips at all.

The simulated thrips damage experiments did confirm previous research that severe defoliation such as removal of all true leaves at 2,4, and 6 node for either 100% or 75% of plants can delay maturity (60% bolls opened) and in 50–75% of years reduce yield. This is more frequent than the estimate of delays or yield reduction in one year in two for cool areas (CPMG 2017). Whereas removal of 75% of each true leaf at 2,4, and 6 node stage, a more realistic simulation of severe thrips damage did not reduce yield and saw a small delay in

maturity (2–6 days). Small cage experiments with 0,1,5 and 10 thrips introduced per week for five weeks onto cotton seedlings did generate some leaf distortion or clubbing in the cotton plants with added thrips. The damage was not however co-related to thrips density, which varied between 2–30 adult thrips per plant and 38–208 thrips nymphs per plant, six weeks after emergence.

Although we could not really confirm or reject the mirid threshold it does appear that Canopy® oil does reduce mirid numbers and adding fipronil did not greatly improve efficacy. Further experiments are recommended to evaluate Canopy® oil efficacy on mirids and potentially demonstrate a softer control option, particularly in the horticultural-intensive areas where bees are commonly used hence vulnerable to fipronil poisoning.

The seasonal patterns for cotton invertebrate pests and beneficials observed over three southern cropping seasons are not dramatically different from what is expected in cotton grown in other regions. Both pests and beneficials colonised the cotton from emergence, with thrips being by far the most numerous pest and numbers the most variable between seasons. Leafhoppers were consistently present at relatively steady numbers, as were mirids, although at much smaller numbers. Whitefly were highly variable with a particularly high numbers in summer of 2016. The relative absence of *Helicoverpa armigera* from the refuge collections is of concern. There were a complex fauna of spiders and wasps that consistently dominated the beneficial fauna. The relative importance of the wasps is not clear given most are not identified to species but are from parasitoid families hence likely to be highly specific. The spiders however are generalist predators and likely to be feeding on stages of all the pests observed.

Acknowledgements

This project has been co-invested by CRDC and NSW DPI.

We greatly appreciate the input from Drs Lewis Wilson, Simone Heimona and Mike Bange (CSIRO), Dr Robert Mensah (NSW DPI), Kieran O’Keeffe (Cotton Info) on project design and methods. We are particularly appreciative of the input and co-operation of James Hill, the IREC demonstration farm committee, Coleambally demonstration farm committee, the Stott family and farm staff, Matt Watson, Matt and James Toscan, Ben Witham, Ross Askins, Nick Donnelon, and Darrell Fiddler. Specific thanks to Dupont and Caltex for supplying insecticides for the trial, Jorian Millyard (CSD) for the trailer scales for weighing modules and trial seed for 2014/15 trials, Warrick Stillard (CSIRO) and team for hand ginning trial samples from the 2014/15 and 2015/16 trials, the Southern Cotton and RivCott Gins for providing machine harvest module weights.

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Extension Opportunities

8. Detail a plan for the activities or other steps that may be taken:

(a) Steps taken:

Specific publications included in section below.

- i. Discussion and reports were made to the Irrigation Research and Extension Council (IREC) before and during project implementation;
- ii. Field day presentations: 22 January 2015: at Point Farms (~60 farmers and consultants) and 24 February 2017, at Point Farms (~60 attendees). – presentation and handouts provided;
- iii. CCA meeting: Griffith 13 May 2015: McDougall, S CCA presentation and handout for proceedings;
- iv. Experiment reports published in NSW DPI's annual Southern cropping results publication;
- v. Convened the inaugural Southern Valley Cotton R&D forum at Yanco Agricultural Institute in August 2015 and then annually since. Reported and discussed project proposal, results and research plans;
- vi. Presented 2 oral presentations at the Cotton R&D Conference, Toowoomba, 8-10th September 2015;
- vii. Poster at NSW DPI, Yanco Agricultural Institute Open day, 30th October 2015
- viii. Cotton infor IPM Training days – contributed a session: New farmers and advisors IPM training day, IREC 17 Dec 2015 [~18 advisors attended], 2016 IPM roadshow, Huddersfield 21 November 2016, 2017 IPM Training course, Griffith 19 September 2017;
- ix. Official Opening of the IREC Demonstration site at Whitton 5th April 2016. Presentation of cotton thrips trial results [150 attendees];
- x. Article in Spotlight on Cotton R&D, Summer 2016-17, May 2017
- xi. Article IREC Farmers' Newsletter, No. 196 Summer 2016
- xii. REFCOM presentations x3, Griffith 21 March 2017, (~30 researchers, growers, consultants and cotton industry attendees)

(b) Future steps:

- i. Trial reports from 2016–17 thrips threshold and species, and seasonal patterns to be published in Southern Cropping Results 2018
- ii. Summary project report to be submitted to the IREC's Farmers' Newsletter
- iii. Project summary report to be made at Southern Cotton R&D forum planned for Yanco Agricultural Institute, August 2018
- iv. Submission of journal paper on thrips species in southern cotton;
- v. Submission of journal paper on seasonal patterns of invertebrate pests and beneficials

(c) for future research.

Due to the large numbers of new cotton growers and agronomists in the southern region, there is a large body of previous cotton invertebrate pest and beneficial research and recommendations that are not known, understood or adopted in the south. There is a perception that due to the shorter production window that industry thresholds are too high and that beneficials are probably not that important hence a culture of resorting to insecticides appears to be growing. This project team did not develop the necessary trust or a large enough 'foot print' in the south with the crop consultants and new growers to effectively challenge growing insecticide use. Hence it is critical to have an articulate respected researcher who is knowledgeable on invertebrate pests and beneficials working actively in the southern production area and solely focused on cotton. The researcher needs to pro-actively engage with local agronomists to better understand invertebrate pest and beneficial dynamics in southern cotton, and where possible, demonstrate and educate on current best practice crop protection.

Further validation of the mirid thresholds is required, and collaborative work with the cotton establishment project on on early boll development and retention. The results from the laboratory-based evaluation of thrips damage on cotton seedlings should be further explored given it raises doubts to the applicability of the 100% defoliation treatments to cotton threshold decisions, and expected maturity delays or yield penalty frequency.

The small numbers of *Helicoverpa armigera* collected in the refuge crops warrents futher surveys of refuges to gauge the effectiveness of the refuges to produce susceptible moths, as part of the resistance management strategy for the Bt cotton.

The basis of this is detailed in the new submission to CRDC for "Southern Cotton Crop Protection" project, although this proposal is weighted towards the cotton pathology and the appointment of a plant pathologist in the Crop Protection Specialist role. The project will explore the research question: *Does having regionally based technical crop protection expertise improve IPDM outcomes?* by actively engaging with crop consultants and reviewing crops where they are experiencing high pest pressure as case studies. These case studies aim to better understand the drivers involved in leading to high pest pressure in the specific by reviewing the crop history, surrounds and management practices. If possible crop protection data will be included in the Southern Database instigated in DAN1701 which ideally will give us good data on current practices and how they change over time.

The specifically entomological objective of the project is to understand early season insecticide applications impact on later season pests in southern cotton. Cotton fields with early season insecticides will be monitored for late season pests and conversely cotton fields with late season pest problems will have reverse case histories conducted to identify likely pest population drivers for the outbreak.

To actively link this southern based crop protection project to cotton entomologists working out of ACRI, in the northern production area, to build both expertise and credibility, one objective is to run replicates of IPM efficacy evaluations in the south. This will also provide southern data to northern research and again build confidence that cotton industry recommendations are relevant for the southern production areas as well as the north.

9. A. List the publications arising from the research project and/or a publication plan.

- Mo, J, McDougall, S, and S. Munro. 2015. Simulating early season thrips damage in cotton in southern NSW pp 118-121 In: *Southern cropping region trial results 2014* NSW DPI
- Mo, J, McDougall, S, Munro, S, and M. Stevens. 2015. New insecticides for thrips control in cotton. pp 122-124 In: *Southern cropping region trial results 2014* NSW DPI
- Summary of project for IREC website: *CRDC Thrips IPM Project* <http://irec.org.au/research/>
- Mo, J, Munro, S, McDougall, S, Beaumont, S, Stevens M. (2016) *Southern cotton seedling thrips species composition*. Southern NSW research results 2015 NSW DPI 183-186
- McDougall, S, Mo, J, Munro, S, Munn, L, and Beaumont, S. (2016) *Seed or planting treatments impact on thrips- commercial scale trials* Southern NSW research results 2015 NSW DPI 187-189
- McDougall, S, Mo, J, Munro, S, Munn, L, Beaumont, S, and Stevens, M. (2015) *Thrips threshold validation – commercial-scale trials* Southern NSW research results 2015 NSW DPI 190-195
- Spotlight article contribution: (December 2016) *Cotton can compensate in the south* Spotlight on Cotton R&D, Summer 2016-17, pp 12
- McDougall, S, Beaumont, S, Mo, J, Ryan, A, Munro, S, Stevens, M. (2017) *Validating thrips thresholds for southern cotton* IREC Farmers' Newsletter, No. 196 Summer 2016, pp 12-15
- McDougall, S, Mo, J, Beaumont, S, Ryan, A, Stevens, M. (2017) *Thrips threshold validation – commercial-scale trials 2015-16* Southern NSW research results 2017 NSW DPI, pp.182-186
- Beaumont, S, McDougall, S, Mo, J, Munro, S, Ryan, A. (2017) *New chemicals for thrips control in cotton 2015-16 trial* Southern NSW research results 2017 NSW DPI, pp.187-190
- Mo J., S. McDougall, M.M. Stevens, S. Beaumont, S. Munro *Effects of seedling defoliation on growth and yield in southern New South Wales* (in final stages of preparation for journal submission)

B. Have you developed any online resources and what is the website address? No

Part 4 – Final Report Executive Summary

The cotton industry in southern NSW has expanded from negligible areas less than a decade ago to 70,680 ha harvested in 2014, 44,201 ha in 2016, and predictions of 90,000 ha in the 2017/18 season, with plantings into Victoria. Three gins have opened in the south; one each at Whitton (2012), Carathool (2014) and Hay (2015). Since cotton production first moved to the south, growers have reported having to control thrips during establishment, and mirids and occasionally green vegetable bug (GVB) mid season.

The overall objective of this project was determining the applicability of IPM recommendations developed for northern cotton to southern production areas, with the shorter growing season and higher solar radiation with a focus on establishment pests, specifically thrips. None of the data collected suggested that pest dynamics in the south are grossly different from the north and that the current IPM recommendations are applicable to southern conditions.

Thrips species composition was similar to the north with *Thrips tabaci* being the most dominant species followed by *Franklinella schultzei* and *Thrips imagis*. *Frankliniella occidentalis* was only a minor component of the thrips community during cotton establishment in the first two seasons of monitoring but, it did however increase in third year at approximately a quarter of the adults and almost a third of nymphs monitored. If spraying for thrips becomes routine in cotton it is likely that the proportion of *F. occidentalis* will increase and could become a more significant establishment pest, however it could also ensure that mite predators are still within the system and reduce mite outbreaks.

Commercial scale thrips threshold experiments were able to confirm that seed treatments of thiomethoxam reduced thrips nymph numbers for only one week after emergence, phorate reduced thrips nymph numbers for 3 weeks after seedling emergence. Commercial scale experiments with foliar insecticides for thrips control did not support a reduced thrips threshold for southern grown cotton. Within field variability potentially masked thrips treatment effects but we saw no significant yield effects from thrips treatments relative to each other or not treating for thrips at all.

The simulated thrips damage experiments did confirm previous research that severe defoliation such as removal of all true leaves at 2,4, and 6 node for either 100% or 75% of plants can delay maturity (60% bolls opened) and in 50–75% of years reduce yield. This is more frequent than the estimate of delays or yield reduction in one year in two for cool areas (CPMG 2017). Whereas removal of 75% of each true leaf at 2,4, and 6 node stage, a more realistic simulation of severe thrips damage did not reduce yield and saw a small delay in maturity (2–6 days). Small cage experiments with 0,1,5 and 10 thrips introduced per week for five weeks onto cotton seedlings did generate some leaf distortion or clubbing in the cotton plants with added thrips. The damage was not however co-related to thrips density, which varied between 2–30 adult thrips per plant and 38–208 thrips nymphs per plant, six weeks after emergence.

Although we could not really confirm or reject the mirid threshold it does appear that Canopy® oil does reduce mirid numbers and adding fipronil did not greatly improve efficacy. Further experiments are recommended to evaluate Canopy® oil efficacy on mirids and potentially demonstrate a softer control option, particularly in the horticultural-intensive areas where bees are commonly used hence vulnerable to fipronil poisoning.