Cotton
RESEARCH & DEVELOPMENT

Annual, Progress and Final Reports

Part 1 - Summary Details

REPORTS

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

CRDC Project Number: **UWS 3C**

Annual Report: ☐ Due 30-September

Progress Report: ☐ Due 31-January

Final Report: ☒ Due 30-September
(or within 3 months of completion of project)

Project Title: Evaluation of mineral oils for cotton IPM

Project Commencement Date: 01/07/2001 **Project Completion Date:** 30/6/2003

Research Program: A Insect Management

Part 2 – Contact Details

Administrator: Mr Gar Jones, Director of Research Services

Organisation: University of Western Sydney
Postal Address: Locked Bag 1797, Penrith South DC, NSW 1797
Ph: 02 45701259 **Fax:** 02 45701686 **E-mail:** g.jones@uws.edu.au

Principal Researcher: Professor Andrew Beattie
Organisation: Centre for Horticulture and Plant Sciences, UWS
Postal Address: Locked Bag 1797, Penrith South DC, NSW 1797
Ph: 02 45701287 **Fax:** 02 45701314 **E-mail:** a.beattie@uws.edu.au

Supervisor: Associate Professor Robert-Spooner-Heart, Director
Organisation: Centre for Horticulture and Plant Sciences, UWS
Postal Address: Locked Bag 1797, Penrith South DC, NSW 1797
Ph: 02 45701429 **Fax:** 02 45701314 **E-mail:** r.spooner-heart@uws.edu.au

Researcher 2 Dr Robert Mensah, Senior Research Scientist
Organisation: NSW Agriculture
Postal Address: Australian Cotton Research Institute, Myall Vale, Narrabri, NSW 2390
Ph: 02 67991525 **Fax:** 02 67991503 **E-mail:** robert.m@mv.pi.csiro.au

Signature of Research Provider Representative: ____________________

Part 3.3 – Final Reports

(The points below are to be used as a guideline when completing your final report. Postgraduates please note the instructions outlined at the end of this Section.)

1. Outline the background to the project.

This project was based on the results of extensive research on fruits, ornamentals, vegetables and cotton (in NSW) in which the effectiveness of petroleum-derived spray oils (PDSOs) on insect and mite pests has been unequivocally demonstrated. Oils kill susceptible pests through suffocation (e.g., mites, thrips, aphids and scales). They also influence the feeding and oviposition behaviour of some pests that are not generally susceptible to suffocation (e.g., *Helicoverpa armigera* and *H. punctigera*). This has led to behavioural effects on a very broad range of pests becoming much more important than suffocation, the traditionally accepted mode of action, of a much narrower range of pests. Contemporary PDSOs classed as either horticultural mineral oils or agricultural mineral oils are not toxic and pose no threat to human health or the environment. Their impact on natural enemies is generally negligible and arthropod resistance to PDSOs has not been empirically demonstrated in over 100 years of use.

In studies on cotton grown on 50 ha at Auscott, Narrabri, *Helicoverpa* oviposition on conventional cotton plants sprayed three times with 2% oil at 7–10 day intervals in November and December 2000 was 80% less than on unsprayed plants. The number of conventional sprays used in the oil treatments was 4 less than the number of conventional sprays applied in the conventional pesticide treatment. No phototoxicity was observed in the trial or on other plants sprayed 5 times with up to 10% oil. The effects of the sprays on *Helicoverpa* confirm earlier published studies in which the impact of oil sprays on oviposition in cotton and tomatoes.

The project is also linked to UWS PhD research on the impact of mineral oils with different distillation properties (*n*C21–*n*C24 products) on *Helicoverpa* oviposition behaviour under a range of environmental and other conditions. Collaborative work with Dr Nicolas Woods (University of Queensland) assessed the impact of oil on spray characteristics, particularly drift, under laboratory conditions, and the efficacy of spray deposition for sprays applied by a conventional groundrig, an air-assisted groundrig, and a helicopter.

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

2001–2002

1. Conduct first year of 2-year field trials determining the impact of selected mineral oils on key pests (*Helicoverpa*, thrips, sucking pests and mites) and their natural enemies, and phytotoxicity (cotton yields and quality).

   This work was undertaken at Narrabri and Moree.
2. Conduct laboratory and preliminary field studies with Dr N Woods (University of Queensland) to optimise spray application efficiency from groundrigs and aircraft.

   Only laboratory studies were completed and these were undertaken at University of Queensland, Gatton, in collaboration with Dr Woods and other C-PASS staff.
3. Evaluate behavioural impact of oil mixtures on selected pests in laboratory tests.

This work was not undertaken. Personnel recruitment difficulties and a resignation led us to give priority to field trials, and we also increased inputs into the field trials.

4. Conduct laboratory and field trials to determine the effects of mineral oil spray deposits on the feeding and oviposition behaviour of selected sucking pests.

This work was not undertaken. Personnel recruitment difficulties and a resignation led us to give priority to field trials.

2002–2003

1. Undertake second year of 2-year trials determining the impact of selected mineral oils on key pests and their natural enemies, and cotton yields and quality.

This work was undertaken at Moree.

2. For goundrigs, conduct extensive trials to determine relationships between oil concentration in sprays, spray volume, and spray efficacy against pests.

This work was undertaken at Moree but application efficacy was based on spray deposition rather than pest assessments. Emphasis was placed on evaluating using spray volumes acceptable to industry.

3. Undertake field groundrig evaluations of combined biological pesticide and mineral oil (+/– UV-screens and other additives) sprays for control of *Helicoverpa*.

This work was not undertaken. Evaluation of UV screens was hampered by legal action against UWS that was ultimately resolved without consequences for the university. Nevertheless, emphasis was placed on field trials with oil alone as difficulties with staff recruitment and a resignation made it impossible to explore the use environmentally acceptable sunscreens.

4. For aircraft, conduct trials to determine spray application efficacy for 2%–10% v/v sprays of selected mineral oil formulation.

This work was undertaken at Moree and was based on application of oil at 2 L/ha by helicopter.

5. In laboratory experiments determine the mode(s) of action of mineral oil sprays and deposits on sucking pests.

This work was partially completed for green mirid and analysis of data has not been completed. Emphasis was placed on field trials.

2003–2004

Funding was not provided for the following objectives in 2003-2004 when the project was funded, and drought and the low incidence of *Helicoverpa* at Narrabri and Moree in 2001-2002 and 2003-2004 led us not to seek funds for 2003-2004.

1. Review 2001–2003 results and identify outstanding issues for incorporation in final year field and laboratory experiments, and undertake these experiments.

2. Undertake final year trials for pre-crop closure groundrig applications of biological pesticide/mineral oil sprays.

3. Undertake field trials with aerially applied pre and post-crop closure biological pesticide/mineral oil sprays.

4. Assist with the preparation of registration submissions for mineral oils, relevant labels, and guides for use.
5. Ensure relevant data is prepared for publication in scientific and extension journals.

3. Detail the methodology and justify the methodology used.

Part A. Impact of Selected Mineral Oils on Key Pests and their Natural Enemies, and Phytotoxicity

Field trials in 2001-2002

Two sites were used for field trials in the 2001–2002 season.

Auscott, Narrabri. The study was conducted in field F20 in which cv. Delta Opal was planted at a density of 10–12 plants/m in rows 1 m apart. Four treatments were randomly allocated to each of 4 blocks. Each treatment plot comprised 24, 850 m long rows. Forty-eight row-wide buffers were established on both sides of the experimental area. The total experimental area was 32.64 ha (40.8 ha including the buffers). Each plot was divided into 4 equal subplots for most assessments.

Norwood, Moree. The study was conducted in field F9 in which cv. Sicot 80 was planted at a density of 6-8 plants/m in rows 1 m apart. Four treatments were randomly allocated to each of 4 blocks. Each treatment plot comprised 12, 220 m long rows. Twenty-four row-wide buffers were established on both sides of the experimental area. The total experimental area was 4.24 ha (5.3 ha including the buffers). Each plot was divided into 4 subplots for most assessments.

Treatments and spray volumes. Treatments included prophylactic sprays of two horticultural mineral oils (HMOs) (*n*C21 (SunSpray UltraFine, Sunoco, United States of America, and *n*C23 (70 SN, Caltex Australia, Sydney, New South Wales) and an *n*C24 agricultural mineral oil (AMO) (BioPest™, SACOA, Claremont, Western Australia), and a conventional threshold based pesticide treatment. All three oils were applied as prophylactic 2% v/v sprays [3 L oil/ha in sprays of 150 L/ha (30 μg oil/cm^2) by groundrig until crop closure, and at 0.6 L of oil/ha in sprays of 30 L/ha (6 μg oil/cm^2) by air after crop closure; see Tables 1 & 2] at 10 day intervals depending on weather conditions and irrigation schedules. Buffers of both experimental sites were sprayed with the *n*C24 AMO at 2% v/v.

Visual counts of Helicoverpa *and green mirid.* Visual assessments on each sampling date were based on whole plants in 4, 1-m lengths of row within the each replicate during the early part of the season. Mid season sampling was based on 2, 1-m lengths of row within each replicate. Late season sampling was based on a 1-m row length within each replicate. These assessments focused on *Helicoverpa* eggs (white and brown) and larvae (very small – small and medium – large), and green mirid nymphs and adults.

Mite populations. From each subplot 50 leaves were collected randomly and placed in a marked plastic bag. Samples were then taken to the Australian Cotton Research Institute, Narrabri, and processed according to procedures outlined by Deutscher & Wilson (1999).

D-vac assessments for thrips, jassids and predators. Populations of thrips, jassids and predators were assessed by using D-vac. From each treatment plot a 20-m long sweep was collected randomly. Each sample was then placed in marked plastic bag and stored in a refrigerator until counted.

Phytotoxicity and yield. Acute phytotoxicity in the form of 'burns', spotting or oil soaking was assessed visually on each sampling date. Yield was used to assess chronic phytotoxicity, and was based on harvested weight and percent lint. At Auscott, every treatment within the block was harvested separately. At Norwood, where the experimental area was smaller than at Auscott, it was necessary to harvest bolls from more than 1 block to fill a module, and 3 modules (= replicates) were filled from each treatment.

Field trial in 2002–2003

To overcome high variability in counts, which severely limited our ability to detect difference between treatments at both Auscott (Narrabri) and Norwood (Moree) in 2001-2002, we decided to focus on sampling more thoroughly at one site rather then two and chose Norwood on the basis of shorter row lengths than those at Auscott in Narrabri. We also sought to focus on applying oil at fixed rates (L oil/ha) and to apply sprays by helicopter where warranted and feasible for the entire season.

We chose field 9 at Norwood in which cv. Sicot 80 was planted at a density of 6–8 plants/m in rows 1 m apart. Four treatments were randomly allocated to each of 4 blocks, with the exception of an unsprayed control treatment that comprised two control plots. Each treatment plot comprised 12, 220-m long rows of cotton. The control plots were the same size as other plots. These plots were included in outer sides of Block 1 and Block 4. Twelve row-wide buffers were established both in northern and southern ends of the experimental site next to each control plot. The total experimental area was 4.77 ha (5.3 ha including the buffers). Each plot was divided into 4 equal subplots for most assessments.

Treatments and spray volumes. Treatments comprised of three deposits of an *n*C24 AMO (BioPest™, SACOA, Claremont, Western Australia) at 2, 4 and 6 L of oil/ha (these rates deposited 20, 40 and 60 μg oil/cm^2 of ground surface respectively), and conventional threshold-based pesticide treatment (see Table 3). Oil treatments were applied as prophylactic sprays at 10 days intervals depending on weather conditions and the irrigation schedule. The oil treatments were applied at 150 L of sprays/ha by groundrig and 30-60 L/ha by helicopter (see Table 3). Buffers were sprayed with the same AMO at the rate of 2 L/ha (20 μg oil/cm^2).

Visual counts of Helicoverpa*, green mirid, and aphids based on 20 plants within each of 4 replicate subplots.* Visual assessments were made weekly throughout the season on 20 plants within 4 subplots within each treatment replicate (80 plants per replicate or plot). Assessments were based on whole plants until branch formation. From this point central (apical) terminals (leaves, squares, and bolls) were assessed on each plant. All assessments were undertaken in the 5th, 6th and 7th rows of each treatment plot (replicate) to minimise the impact of spray drift on assessments. Care was taken to avoid interference on visual assessments by not counting the arthropods from the same of row from which D-vac samples were taken on the same day. This assessment focused on *Helicoverpa* eggs (white and brown) and larvae (very small, small and medium, and large), green mirid nymphs and adults, and aphids (colonies with < 10, or > 10, aphids).

Visual counts of Helicoverpa*, green mirid and aphids based on 1-m row lengths in each replicate.* Visual assessments were made weekly from mid (15 January 2003) to late (27 February 2003) season based on 2, 1-m lengths of row within the each replicate. Whole plants within the 1-m lengths row were assessed for this assessment. This assessment also focused on *Helicoverpa* eggs (white and brown) and larvae (very small – small and medium – large), green mirid nymphs and adults, and aphids (colonies with < 10, or > 10, aphids).

Mite populations. Mite populations were assessed on the same day visual counts were undertaken. From each subplot 10 leaves were collected randomly and placed in a marked plastic bag. Samples collected from two consecutive subplots were pooled together to get a single sample. Accordingly, two samples were obtained from each treatment plot. Samples were taken to the Australian Cotton Research Institute, Narrabri, and refrigerated. Mite populations were then estimated using CSIRO protocols (Deutscher & Wilson 1999).

D-vac assessments of thrips, jassids and beneficial arthropods. Populations of thrips, jassids, ladybirds, red and blue beetle, damsel bug, big-eyed bug, green lacewing and brown lacewing were assessed by D-vac sampling of 5-m long row lengths within each of the 4 subplots. On each occasion samples from the 1st and 2nd subplots, and from the 3rd and 4th subplots, were combined in single labelled sample bags to give 2 samples per replicate. Samples were taken to the laboratory and stored in a refrigerator until counted.

'Industry standard' visual counts of Helicoverpa*, green mirid, aphids and beneficial arthropods in 1-m row lengths throughout season*. Industry standard 1-m of row samples were collected twice weekly from each plot (replicate) by a consultant (Lindsay Tuart, Moree). *Helicoverpa*, green mirid, aphid, and beneficial arthropods populations were assessed.

Spray deposition (oil deposition and sprayer application efficacy. Spray application (deposition) efficiency was determined measuring oil deposits on leaves. FTIR (Fourier transform infra-red spectroscopy) was used for this purpose (see Johnson *et al*. 2002).

Phytotoxicity and yield. Acute phytotoxicity in the form of 'burns', spotting or oil soaking was assessed visually on each sampling date. Yield was used to assess chronic phytotoxicity. At the end of the season bolls from the eight central rows in each replicate were harvested with a cotton picker and weighed using a weigh cell. Yield data were also obtained from a conventionally managed 60-row plot adjacent to experimental site.

Data analysis. Counts before the first spray were analysed using ANOVA, GL model in SPSS 11.5 (SPSS 2003). Data for all other assessment dates were entered into the repeated measures analysis SPSS 11.5. In instances where there was no sampling time*treatment interaction data were averaged over time and the single analysis of variance was performed. However, if a significant sampling time*treatment interaction was detected analysis of variance was performed for each date separately. Prior to analysis data were checked for spherisity, normal distribution and homogeneity of variance and appropriate transformations (most frequently $\sqrt{(x + 0.5)}$) were applied. We used Ryan's Q test to determine differences between treatment means when the assumption of homogeneity of variance was met and Dunnett T3 test when the assumption was not met. When the F-test was significant and Ryan's Q-test showing no differences between treatment, LSD test was used to establish trends within data.

Table 1. Spray schedule at Auscott, Narrabri, in 2001-2002.

Date	Mineral oil treatments		Conventional pesticide treatment	Method of application and percent banding *
	Mineral oil (L/ha)	Conventional pesticides		
21/11/01	3			Groundrig as 30% band of 150 L/ha
5/12/01	3			Groundrig as 30% band of 150 L/ha
6/12/01			Affirm [1]	Groundrig as 30% band of 150 L/ha
17/12/01	3			Groundrig as 30% band of 150 L/ha
24/12/01			Affirm [1]	
27/12/01	3			Groundrig at 150 L/ha
4/01/02	3		Tracer [2]	Groundrig at 150 L/ha
14/01/02	0.6		Affirm [1]	Plane at 30 L/ha
15/01/02		Steward [3]	Steward[3]	Plane at 30 L/ha
24/01/02	0.6			Plane at 30 L/ha
6/02/02		Mustang [4]	Mustang [4]	Plane at 30 L/ha
18/02/02		Intrepid [5]	Intrepid [5]	Plane at 30 L/ha
21/02/02		Steward [3]	Steward [3]	Plane at 30 L/ha
6/03/02		Mustang [4]	Mustang [4]	Plane at 30 L/ha
12/03/02		Pirate [6] & Folidol[7]	Pirate [6] & Folidol [7]	Plane at 30 L/ha

* Rates (L/ha) are L of oil/ha of sprayed surface. Therefore, on 21 November, and on 5 and 17 December, 1 L of oil was applied per hectare of crop. Volumes of oil applied by plane were not adjusted for equivalent groundrig rates per hectare.

[1] Emamectin (Syngenta) insecticide/miticide for *Helicoverpa* spp. and mites at 550-700 mL/ha
[2] Spinosad (Dow) insecticide for *Helicoverpa* spp. at 600-800 mL/ha
[3] Indoxacarb 25:75 (Du Pont) insecticide for *Helicoverpa* spp. at 450-850 mL/ha
[4] Zeta-cypermethrine (FMC) insecticide for *Helicoverpa* spp. at 2-2.5 L/ha
[5] Chlorfenapyr (BASF) insecticide/miticide for *Helicoverpa* spp. at 1100 mL/ha
[6] Chlorpyrifos (Nufarm) insecticide/miticide for *Helicoverpa* spp. at 4-5 L/ha
[7] Parathion-methyl (Bayer) insecticide for *Helicoverpa* spp. and aphids and loopers at 1.6-3 L/ha

Table 2. Spray schedule at Norwood, Moree, in 2001–2002.

Date	Mineral oil treatments		Conventional pesticide treatment	Method of application and percent banding *
	Mineral oil (L/ha)	Conventional pesticides		
19/11/01	3		Affirm [1]	Groundrig as 40% band of 150 L/ha
4/12/01	3	Affirm [1]	Affirm [1]	Groundrig as 40% band of 150 L/ha
12/12/01	3			Groundrig as 40% band of 150 L/ha
22/12/01	3		Steward [2]	Groundrig as 60% band of 150 L/ha
29/12/01	3	Tracer [3]	Tracer[3]	Groundrig as 60% band of 150 L/ha
7/01/02	0.6			Helicopter at 30 L/ha
17/01/02	0.6		Tracer [3]	Helicopter at 30 L/ha
21/01/02		Delta Duo [4] Gemstar [5]	Delta Duo [4] Gemstar [5]	
28/01/02	0.6	Tracer [3]	Tracer [3]	Helicopter at 30 L/ha
5/02/02		Pegasus [6] Bulldock Duo [7] Gemstar [5]	Pegasus [6] Bulldock Duo [7] Gemstar [5]	
13/02/02		Bulldock Duo [7]	Bulldock Duo [7]	
22/02/02		Amitraz [8] Prowler [9]	Amitraz [8] Prowler [9]	

* Rates (L/ha) are L of oil/ha of sprayed surface. Therefore, on 19 November, and on 4 and 12 December, 1.2 L of oil was applied per hectare of crop, and on 22 December 1.8 L was applied per hectare of crop. Volumes of oil applied by plane were not adjusted for equivalent groundrig rates per hectare.

[1] Emamectin (Syngenta) insecticide/miticide for *Helicoverpa* spp. and mites at 550-700 mL/ha
[2] Indoxacarb 25:75 (Du Pont) insecticide for *Helicoverpa* spp. 450-850 at mL/ha
[3] Spinosad (Dow) insecticide for *Helicoverpa* spp. at 600-800 mL/ha
[4] Deltamethrin (Chemag) insecticide for *Helicoverpa* spp. at 500-700 mL/ha
[5] MPV (Bayer) biological insecticide for *Helicoverpa* spp. at 500 mL/ha
[6] Diafenthiuron (Syngenta) miticide for mites at 600-800 mL/ha
[7] betacyfluthrin (Bayer) insecticide for green mirid and jassids at 600 mL/ha
[8] Amitraz (Crop Care) insecticide for *Helicoverpa* spp. at 2 L/ha
[9] Prowler (Chemag) insecticide for *Helicoverpa* spp. at 4-5 L/ha

Table 3. Spray schedule at Norwood, Moree, in 2002–2003.

Date	*n*C24 mineral oil treatments		Conventional pesticides treatment	Method of application and percent banding *
	Oil (L/ha)	Conventional pesticides		
26/10/02		Chlorpyrifos [1] at 1.4 L/ha	Chlorpyrifos [1] at 1.4 L/ha	Groundrig as 50% band of 150 L/ha
6/11/02	2, 4 & 6	Gemstar [2] at 0.5L/ha	Gemstar [2] at 0.5 L/ha	Groundrig as 30% band of 150 L/ha
27/11/02	2, 4 & 6	Gemstar [2] at 0.25 L/ha	Gemstar [2] at 0.25 L/ha	Groundrig as 40% band of 150 L/ha
11/12/02	2, 4 & 6		Prodigy [3] at 1.7 L/ha	Helicopter at 60 L/ha for oil & 30 L/ha for Prodigy[3]
20/12/02	2, 4 & 6			Groundrig as 100% band of 150 L/ha
24/12/02			Steward [4] at 0.85 L/ha	Helicopter at 30 L/ha
30/12/02	2, 4 & 6		Affirm [5] at 0.7 L/ha	Helicopter at 60 L/ha
3/01/03			Affirm [5] at 0.7 L/ha	Helicopter at 30 L/ha
14/01/03	2, 4 & 6	Affirm [5] at 0.7 L/ha	Affirm [5] at 0.7 L/ha	Helicopter at 60 L/ha
24/01/03	2, 4 & 6			Helicopter at 60 L/ha
6/02/03	2, 4 & 6		Steward[4] at 0.85 L/ha	Helicopter at 60 L/ha for oil & 30 L/ha for Steward [4]

* Rates (L/ha) are L of oil/ha of sprayed surface. Therefore, on 6 November 0.6 L, 1.2 and 1.8 L of oil were applied per hectare of crop respectively for each oil treatment (2, 4 and 6 L/ha), and on 27 November 0.8 L, 1.6 L and 2.4 L of oil was applied per hectare of crop respectively for each oil treatment. Volumes of oil applied by helicopter were adjusted for equivalent groundrig rates per hectare.

[1] Chlorpyrifos (Dow AgroSci) for cutworms. Sprayed as pre-planting insecticide in all plots.
[2] MPV (Bayer) biological insecticide for *Helicoverpa* spp.
[3] Methoxyfenozide (Dow AgroSci) for *Helicoverpa* spp.
[4] Indoxacarb 25:75 (Du Pont) insecticide for *Helicoverpa* spp.
[5] Emamectin (Syngenta) insecticide/miticide for *Helicoverpa* spp. and mites

Part B. Spray Application Technology

Two issues were evaluated:

- the impact of oil on droplet spectra and consequently drift, and
- field evaluation of spray deposits for sprays applied by a hydraulic groundrigs with and without air assistance, and by helicopter.

Characteristics of droplets and drift were assessed in a wind tunnel laboratory at University of Queensland, Gatton. A range of nozzle types (flat fan, injet and hollow cone) and sizes were tested at the different pressures. Field evaluations were conducted at Norwood, Moree, using a Hardi Twin groundrig, a Hardi Auto-Track groundrig, and helicopter fitted with Micronair nozzles.

Laboratory evaluation of nozzle spectra and drift. We used an *n*C24 agricultural mineral oil (AMO) (BioPest™, SACOA, Claremont, Western Australia) with two concentrations of emulsifier (commercial formulation and an experimental formulation with 40% less emulsifier), and three types of Hardi nozzles

- flat fan ISO F110 nozzles with orifice sizes 0075, 015, 03 and 06,
- ISO injet air-inclusion nozzles with orifice sizes 015, 03 and 04, and
- and ceramic hollow cone nozzles 1299 with orifice sizes 12, 16 and 20.

A Malvern 200 laser diffraction analyser was used to measure droplet spectra in the wind tunnel. Three spray solutions were used: neat potable water, commercial AMO and the experimental AMO. Oil in water emulsions of the AMO were tested at 0.25%, 0.5%, 1%and 2% v/v aqueous emulsions. Three nozzles of each kind and size were used for each treatment (= 3 replicates). Parameters evaluated were:

- VMD = Volume Median Diameter (in µm) (50% of the spray volume is contained in droplets smaller than this size), and

- Span = an indication of the range of droplet sizes generated (90% volume diameter-10% volume diameter/VMD)
- Drift-prone droplets = percentage of droplets with the volume diameters less than 141 µm.

For each test, a single nozzle was placed in the wind tunnel at a height of the 35 cm above ground level. Spray drift was determined by attaching 4 cotton strings to the frame of the tunnel 2 m downwind from the nozzle at heights of 5, 15, 25 and 30 cm above ground level. A fluorescence dye (Helios 0.1g/L) was added to the treatment (water or AMO). The solution was sprayed for 10 s at a wind speed of 4.5 m/s. After spraying, the cotton strings were collected and the dye was extracted with a solvent (ethyl digol). Colour intensity of solutions was then measured with a Perkin Elmer LS2 spectrofluorimeter.

Field evaluation of spray deposit and coverage. The experiment was performed in field 14 (planted with cv Sicot 80) at Norwood on 17 December 2003. The design was a modified completely randomised block with 8 sampling blocks across the sprayer swaths. Each groundrig treatment was applied in 4 x 24 m swaths to a single plot comprising 96 rows of cotton (= 96 m). Treatments applied by helicopter were applied in 8 x 18 m swaths to a single plot comprising 124 rows of cotton (= 124 m). Each sampling block was 20 x 20 m. Five 5 diagonally positioned samples were taken for assessments of leaf coverage using water sensitive paper, and 3 leaf samples were picked for oil deposit analysis.

Oil was applied at 2 L/ha in each of 6 treatments based on sprayer type and spray volume:
- Hardi Twin at 75 L of spray/ha
- Hardi Twin at 150 L of spray/ha
- Hardi Auto-Track at 75 L/ha
- Hardi Auto-Track at 150 L/ha
- Helicopter at 30 L/ha
- Helicopter at 60 L/ha

In order to achieve the required volume of spray per hectare following nozzles and pressures were used for groundrigs as follows. The Hardi Twin was fitted with Hardi ISO 02 nozzles (yellow coded) and operated at 390 kPa to deliver 75 L/ha, and with 48 Hardi ISO 04 nozzles (red coded) at the same pressure to deliver 150 L/ha. The Hardi Auto-Track was fitted with 72 Hardi ISO 015 nozzles (green coded) and operated at 310 kPa to deliver 75 L/ha, and with 72 Hardi ISO 03 nozzles (blue coded) at the same pressure to deliver 150 L/ha. Sprays were applied at 15 km/h in all groundrig treatments. The helicopters sprays were applied at two Micronairs settings.

Relative oil deposition (µg/cm^2) was assessed using FTIR spectroscopy (Johnson *et al*. 2002). A total of 48 samples were analysed from each treatment. Each sample comprised 5 leaves. Samples were taken from 3 plants, each randomly chosen but reasonably equally spaced across the diagonal of each sampling block. Separate samples were taken from the upper and from the middle part of the canopy.

Droplet density and coverage was determined using water sensitive paper (WSP). In this instance samples were taken from 5 plants, each randomly chosen but reasonably equally spaced across the diagonal of each sampling block. WSP was attached to upper and lower leaf surface in upper and middle part of the canopy (4 WSP/plant and 20 WSP/sampling block). The total number of WSP samples per treatment was therefore 160 (Figure 2). WSP were analysed using Swath Kit, and the density of droplets per cm^2 and percent area covered were determined.

Part C. UV Sunscreens, and Impact of Oil Deposits on Sucking Pests in Laboratory Studies

Evaluation of UV screens was hampered by legal action against UWS that was ultimately resolved without consequences for the university. Nevertheless, emphasis was placed on field trials with oil alone as difficulties with staff recruitment and a resignation made it impossible to explore the use environmentally acceptable sunscreens.

Laboratory studies on sucking pests were hampered by problems encountered with staff recruitment and continuity. Partial studies were undertaken on green mirid but complex analysis of the data has not been completed. We also chose to focus on field trials.

4. Detail and discuss the results including the statistical analysis of results.

Part A. Impact of Selected Mineral Oils on Key Pests and their Natural Enemies, and Phytotoxicity

Field trials in 2001-2002 (Auscott, Narrabri, and Norwood, Moree)

Helicoverpa thresholds in all treatments, including the unsprayed control, did not reach industry thresholds (2 larvae/m of row from planting to flowering; 5 brown eggs or 2 larvae/m of row from flowering to one open boll; 3 larvae/m of row or 1 medium or 1 large larvae/m of row from 1 open boll to harvest, and 5 larvae or 2 medium or large larvae after 15% of bolls open) at any point in the season at either Auscott (Narrabri) or at Norwood (Moree). Mite and aphid numbers in samples were too low to warrant counting.

Auscott, Narrabri. From late November 2001 to late January 2002, 7 oil sprays and 1 pesticide spray were applied to each oil treatment (Table 1). Over the same interval, 5 pesticide sprays were applied to the conventional pesticide treatment (4 more than in the oil treatments). Conventional pesticides were applied to all treatments from February.

Visual counts of Helicoverpa. There were no differences between treatments for eggs and larvae before the first spray. Subsequently, there were significant time*treatment interactions ($F_{15, 45} = 2.15$, $p = 0.024$) for eggs but separate analyses for each date showed no differences between treatments (Table 4). For larvae there were no significant time*treatment interactions ($F_{15, 45} = 0.87$, $p = 0.545$) and analysis of averaged data over the time showed no significant difference between treatments ($F_{3, 9} = 0.201$, $p = 0.893$) (Table 5).

Visual counts of green mirid. There were no significant time*treatment interactions ($F_{15, 45} = 0.961$, $p = 0.509$) or differences between treatments ($F_{3, 9} = 1.056$, $p = 0.415$) (Table 6).

D-vac assessments of thrips. There were no significant time*treatment interactions ($F_{6.57, 19.72} = 0.970$, $p = 0.476$) or differences between treatments ($F_{3, 9} = 0.54$ $p = 0.668$) (Table 7).

D-vac assessments of jassids. There was a significant sampling time*treatment interaction ($F_{3.10, 9.31} = 4.152$, $p = 0.040$). ANOVA for each sampling date revealed that the significant differences between treatments occurred on 23 January 2002 ($F_{3, 9} = 9.57$, $p = 0.004$). Ryan's

Q test showed that the conventional pesticide treatment was significantly more effective than any of the oil treatments. There were no differences between the oil treatments (Table 8).

Beneficial arthropods. Counts were either too low or too variable to analyse.

Phytotoxicity and yield. No acute symptoms (burns) of phytotoxicity were observed. There were no differences in yield (chronic phytotoxicity) between treatments ($F_{3,\ 9}$ = 0.712, p = 0.569) (Table 14).

Norwood, Moree. From late 19 November 2001 to late January 2002, 8 oil sprays and 5 pesticide sprays were applied were applied to each oil treatment (Table 2). Over the same interval, 8 pesticide sprays were applied to the conventional pesticide treatment (3 more than in the oil treatments). Conventional pesticides were applied to all treatments from February.

Visual counts of Helicoverpa. There were no differences between treatment for eggs and larvae before the first spray. Subsequently, there were no significant time*treatment interactions ($F_{6.45,\ 3.54}$ = 1.168, p = 0.364) or differences between treatments ($F_{3,\ 9}$ = 1.518, p = 0.275) (Table 9) for eggs. For larvae, there were no significant time*treatment interactions ($F_{6.69,\ 20.06}$ = 0.793, p=0.597) and analysis of averaged data over the time showed no significant differences between treatments ($F_{3,\ 9}$ = 2.413, p = 0.134) (Table 10).

Visual counts of green mirid. There were no significant time*treatment interactions ($F_{5.44,\ 16.31}$ = 0.612, p = 0.704) or differences between treatments ($F_{3,\ 9}$ = 0.957, p = 0.454) (Table 11).

D-vac assessments of thrips. There were no significant time*treatment interactions ($F_{18,\ 54}$ = 1.088, p = 0.389) nor differences between treatments ($F_{3,\ 9}$ = 0.588, p = 0.638) (Table 12).

D-vac assessments of jassids. There were no significant time*treatment interactions ($F_{6,\ 18.03}$ = 0.427, p = 0.851) or differences between treatments ($F_{3,\ 9}$ = 0.204, p = 0.891) (Table 13).

Beneficial arthropods. Counts were either too low or too variable to analyse.

Phytotoxicity and yield. No acute symptoms (burns) of phytotoxicity were observed but there were significant differences between treatments for yield (chronic phytotoxicity) ($F_{3,\ 6}$ = 7.44, p = 0.019) and Ryan's Q test showed that yield in the *n*C23 oil treatment was significantly lower than in any other treatment. There were no differences between other treatments for yield (Table 14).

Table 4. Visual 1-m of row counts of *Helicoverpa* spp. eggs at Auscott, Narrabri, in 2001–2002. Data represent treatment means (± SEM).

Treatment	***Helicoverpa* spp. eggs**	**Sampling date**							**Average**
		2001				**2002**			
		20/11 (pre-treatment)	04/12	17/12	27/12	03/01	11/01	23/01	
***n*C21 oil**	White	0.13	1.00	0.81	0.19	0.50	0.56	1.63	0.73
		(0.09)	(0.41)	(0.26)	(0.14)	(0.13)	(0.29)	(0.32)	(0.13)
	Brown	0.06	0.25	0.31	0	0	0	0.63	0.15
		(0.06)	(0.19)	(0.15)	(-)	(-)	(-)	(0.32)	(0.05)
	Total	0.19	1.25	1.13	0.19	0.50	0.56	2.25	0.88
		(0.10)	(0.50)	(0.35)	(0.14)	(0.13)	(0.29)	(0.59)	(0.14)
***n*C23 oil**	White	0.44	0.63	1.69	0.31	0.44	0.31	1.50	0.81
		(0.16)	(0.20)	(0.69)	(0.18)	(0.27)	(0.15)	(0.80)	(0.18)
	Brown	0.19	0.25	0.63	0.31	0	0	0.25	0.27
		(0.10)	(0.14)	(0.38)	(0.19)	(-)	(-)	(0.25)	(0.09))
	Total	0.63	0.88	2.31	0.63	0.44	0.31	1.75	1.08
		(0.24)	(0.30)	(0.80)	(0.24)	(0.27)	(0.15)	(1.01)	(0.16)
***n*C24 oil**	White	0.38	2.50	0.25	0.56	0.19	0.31	1.25	0.77
		(0.15)	(0.47)	(0.14)	(0.18)	(0.10)	(0.18)	(0.49)	(0.19)
	Brown	0.06	0.63	0.19	0.13	0.25	0.06	0.13	0.19
		(0.06)	(0.20)	(0.10)	(0.09)	(0.11)	(0.06)	(0.13)	(0.07)
	Total	0.44	3.13	0.44	0.69	0.44	0.38	1.37	0.96
		(0.18)	(0.57)	(0.16)	(0.24)	(0.18)	(0.18)	(0.56)	(0.20)
Conventional pesticides	White	0.13	1.13	0.31	0.19	0.56	0.63	1.25	0.60
		(0.09)	(0.31)	(0.20)	(0.10)	(0.18)	(0.20)	(0.59)	(0.13)
	Brown	0.25	0.38	0.25	0.19	0	0.19	0	0.19
		(0.19)	(0.20)	(0.11)	(0.14)	(-)	(0.14)	(-)	(0.08)
	Total	0.38	1.50	0.56	0.37	0.56	0.81	1.25	0.79
		(0.26)	(0.34)	(0.24)	(0.15)	(0.18)	(0.31)	(0.59)	(0.15)

Table 5. Visual 1-m of row counts of *Helicoverpa* spp. larvae at Auscott, Narrabri, in 2001-2002. Data represent treatment means (± SEM).

Treatment	***Helicoverpa* spp. larvae**	**Sampling date**							**Average**
		2001				**2002**			
		20/11 (pre-treatment)	04/12	17/12	27/12	03/01	11/01	23/01	
***n*C21 oil**	Very small – small	0.06	0.25	0	0.06	0.50	0.13	0.25	0.13
		(0.06)	(0.11)	(-)	(0.06)	(0.27)	(0.09)	(0.16)	(0.04)
	Medium – large	0.06	0	0.06	0.06	0.06	0	0	0.06
		(0.06)	(-)	(0.06)	(0.06)	(0.06)	(-)	(-)	(0.03)
	Total larvae	0.13	0.25	0.06	0.13	0.56	0.13	0.25	0.19
		(0.09)	(0.11)	(0.06)	(0.09)	(0.30)	(0.09)	(0.16)	(0.06)
***n*C23 oil**	Very small – small	0.63	0.13	0.19	0.13	0.25	0.38	0.13	0.27
		(0.15)	(0.13)	(0.10)	(0.13)	(0.11)	(0.15)	(0.13)	(0.13)
	Medium – large	0	0.06	0.13	0	0.25	0.25	0	0.04
		(-)	(0.06)	(0.09)	(-)	(0.25)	(0.11)	(-)	(0.02)
	Total	0.63	0.19	0.31	0.13	0.50	0.63	0.13	0.29
		(0.15)	(0.14)	(0.15)	(0.13)	(0.32)	(0.15)	(0.13)	(0.12)
***n*C24 oil**	Very small – small	0.38	0.50	0.13	0.13	0.13	0.06	0	0.15
		(0.15)	(0.24)	(0.09)	(0.09)	(0.09)	(0.06)	(-)	(0.07)
	Medium – large	0	0.06	0	0	0.06	0.38	0.13	0.15
		(-)	(0.06)	(-)	(-)	(0.06)	(0.15)	(0.13)	(0.07)
	Total	0.38	0.56	0.13	0.13	0.19	0.44	0.13	0.27
		(0.15)	(0.24)	(0.09)	(0.09)	(0.10)	(0.18)	(0.13)	(0.08)
Conventional pesticides	Very small – small	0.19	0.56	0.06	0.13	0.63	0.06	0.13	0.29
		(0.10)	(0.16)	(0.06)	(0.09)	(0.20)	(0.06)	(0.13)	(0.09)
	Medium – large	0.13	0	0	0	0	0	0	0
		(0.09)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
		0.31	0.56	006	0.13	0.63	0.06	0.13	0.27
	Total	(0.12)	(0.16)	(0.06)	(0.09)	(0.20)	(0.06)	(0.13)	(0.10)

Table 6. Visual 1-m of row counts of green mirid at Auscott, Narrabri, in 2001-2002. Data represent treatment means (± SEM).

Treatments	**Sampling date**							**Average**
	2001				**2002**			
	20/11 (pre-treatment)	04/12	17/12	27/12	03/01/02	11/01/02	23/01/02	
***n*C21**	0.13	0.06	0	0.13	0.13	0.13	0.50	0.16
	(0.07)	(0.06)	(-)	(0.07)	(0.13)	(0.07)	(0.29)	(0.07)
***n*C23**	0.13	0	0.19	0.50	0	0	0.38	0.18
	(0.13)	(-)	(0.11)	(0.20)	(-)	(-)	(0.23)	(0.03)
***n*C24**	0	0	0.13	0.56	0.19	0.13	0.38	0.22
	(-)	(-)	(0.13)	(0.16)	(0.12)	(0.13)	(0.24)	(0.06)
Conventional pesticides	0.06	0	0.19	0.19	0.25	0	0.25	0.14
	(0.06)	(-)	(0.12)	(0.12)	(0.25)	(-)	(0.14)	(0.04)

Table 7. Thrips counts in D-vac samples at Auscott, Narrabri, in 2001–2002. Data represent treatment means (± SEM).

Treatment	**Sampling date**					**Average**
	2001			**2002**		
	23/11	04/12	17/12	03/01	23/01	
***n*C21 oil**	19.50	7.75	10.50	1.25	17.75	11.25
	(5.89)	(0.85)	(5.24)	(0.63)	(4.11)	(1.23)
***n*C23 oil**	18.50	5.50	6.00	0.50	27.00	11.50
	(6.59)	1.94)	(1.41)	(0.50)	(9.70)	(2.94)
***n*C24 oil**	11.75	5.00	7.25	2.25	25.75	10.40
	(6.41)	(2.12)	(1.31)	(1.03)	(3.97)	(2.00)
Conventional pesticides	14.50	9.75	8.50	0	41.75	14.90
	(8.37)	(1.84)	(3.01)	(-)	(11.58)	(3.21)

Table 8. Jassid counts in D-vac samples at Auscott, Narrabri, in 2001–2002. Data represent treatment means (± SEM).

Treatment	**Sampling date**					**Average**
	2001			**2002**		
	23/11	04/12	17/12	03/01	23/01	
***n*C21 oil**	19.00	192.75	190.00	97.25	1160.00 ^{a}	331.80
	(4.18)	(21.74)	(36.25)	(14.93)	(300.69)	(75.24)
***n*C23 oil**	12.00	193.25	138.25	89.25	1343.75 ^{a}	355.30
	(2.48)	(20.41)	(12.43)	(25.00)	(269.41)	(44.82)
***n*C24 oil**	14.50	182.25	140.50	95.00	1039.50 ^{a}	294.35
	(7.60)	(50.64)	(8.11)	(17.01)	(353.61)	(74.37)
Conventional pesticide	14.25	167.50	159.75	94.00	95.50	106.20
	(5.15)	(21.33)	(22.49)	(14.22)	(19.04) ^{b}	(8.62)

Means followed by different letters in columns were significantly different at $p < 0.05$. Ryan's Q test was used.

Table 9. Visual 1-m of row counts of *Helicoverpa* spp. eggs at Norwood, Moree, in 2001-2002. Data represent treatment means (± SEM).

Treatment	*Helicoverpa* spp. eggs	Sampling date								Average
		2001					2002			
		19/11 (pre-treatment)	03/12	11/12	20/12	28/12	04/01	16/01	25/01	
***n*C21 oil**	White	0.17 (0.11)	0.56 (0.27)	0.88 (0.30)	0.75 (0.39)	0.31 (0.15)	0.75 (0.31)	0.13 (0.13)	3.25 (2.29)	1.14 (0.30)
	Brown	0 (-)	0.25 (0.14)	0.56 (0.16)	0.25 (0.11)	0.06 (0.06)	0.13 (0.13)	0.13 (0.13)	1.75 (0.63)	0.29 (0.12)
	Total	0.17 (0.11)	0.81 (0.41)	1.44 (0.32)	1.00 (0.38)	0.38 (0.15)	0.88 (0.40)	0.25 (0.16)	5.00 (0.42)	1.43 (0.34)
***n*C23 oil**	White	0.25 (0.13)	1.13 (0.33)	1.31 (0.36)	0.44 (0.16)	0.38 (0.15)	0.25 (0.16)	0 (-)	3.00 (1.08)	1.11 (0.24)
	Brown	0 (-)	0.13 (0.09)	0.38 (0.18)	0 (-)	0.25 (0.14)	0 (-)	0 (-)	1.75 (0.85)	0.36 (0.09)
	Total	0.25 (0.13)	1.25 (0.38)	1.69 (0.44)	0.44 (0.16)	0.63 (0.18)	0.25 (0.16)	0 (-)	4.75 (1.70)	1.46 (0.26)
***n*C24 oil**	White	0.17 (0.11)	1.38 (0.41)	0.31 (0.15)	0.19 (0.10)	0.69 (0.22)	0.63 (0.32)	0.25 (0.16)	1.75 (0.85)	0.58 (0.18)
	Brown	0 (-)	0.31 (0.12)	0.13 (0.09)	0.13 (0.08)	0.19 (0.10)	0 (-)	0 (-)	1.50 (0.65)	0.39 (0.11)
	Total	0.17 (0.11)	1.69 (0.50)	0.44 (0.16)	0.31 (0.12)	0.88 (0.24)	0.63 (0.32)	0.25 (0.16)	3.25 (0.31)	1.07 (0.28)
Conventional pesticides	White	0.08 (0.08)	1.06 (0.36)	1.13 (0.41)	0.50 (0.32)	0.75 (0.23)	0.38 (0.26)	0.13 (0.13)	0.75 (0.48)	0.82 (0.34)
	Brown	0 (-)	0.63 (0.29)	0.13 (0.08)	0.25 (0.14)	0.25 (0.14)	0 (-)	0 (-)	1.50 (0.65)	0.32 (0.12)
	Total	0.08 (0.08)	1.69 (0.55)	1.25 (0.43)	0.75 (0.35)	1.00 (0.29)	0.38 (0.26)	0.13 (0.13)	2.25 (1.03)	1.14 (0.39)

Table 10. Visual 1-m of row counts of *Helicoverpa* spp. larvae at Norwood, Moree, in 2001-2002. Data represent treatment means (± SEM).

Treatment	*Helicoverpa* spp. larvae	Sampling date								Average
		2001					2002			
		19/11 (pre-treatment)	03/12	11/12	20/12	28/12	04/01	16/01	25/01	
***n*C21**	Very small - small	0.50 (0.26)	0.06 (0.06)	0 (-)	0.13 (0.13)	0.06 (0.06)	0.13 (0.13)	0 (-)	0 (-)	0.14 (0.09)
	Medium - large	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0.50 (0.50)	0.07 (0.07)
	Total	0.50 (0.26)	0.06 (0.06)	0 (-)	0.13 (0.13)	0.06 (0.06)	0.13 (0.13)	0 (-)	(0.50 (0.50)	0.21 (0.04)
***n*C23**	Very small – small	0.08 (0.08)	0.62 (0.27)	0.13 (0.09)	0 (-)	0.38 (0.15)	0 (-)	0 (-)	0.75 (0.48)	0.21 (0.09)
	Medium - large	0 (-)	0 (-)	0 (-)	0.06 (0.06)	0 (-)	0 (-)	0 (-)	0.25 (0.25)	0.04 (0.04)
	Total	0.08 (0.08)	0.62 (0.27)	0.13 (0.09)	0.06 (0.06)	0.38 (0.15)	0 (-)	0 (-)	1.00 (0.58)	0.25 (0.09)
***n*C24**	Very small – small	0.08 (0.08)	0.50 (0.20)	0.13 (0.13)	0 (-)	0.31 (0.18)	0.13 (0.13)	0.13 (0.13)	0.50 (0.29)	0.21 (0.09)
	Medium - large	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)
	Total	0.08 (0.08)	0.50 (0.20)	0.13 (0.13)	0 (-)	0.31 (0.18)	0.13 (0.13)	0.13 (0.13)	0.50 (0.29)	0.21 (0.09)
Conventional pesticides	Very small – small	0.17 (0.11)	0.38 (0.13)	0.19 (0.14)	0.06 (0.06)	0.19 (0.10)	0.50 (0.19)	0 (-)	0.75 (0.75)	0.36 (0.21)
	Medium - large	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0 (-)	0.25 (0.25)	0.04 (0.04)
	Total	0.17 (0.11)	0.38 (0.13)	0.19 (0.14)	0.06 (0.06)	0.19 (0.10)	0.50 (0.19)	0 (-)	1.00 (0.71)	0.39 (0.21)

Table 11. Visual 1-m of row counts of green mirid at Norwood, Moree, in 2001-2002. Data represent treatment means (± SEM).

Treatment	**Sampling date**						**Average**
	2001				**2002**		
	19/11 (pre-treatment)	03/12	20/12	28/12	04/01	16/01	
***n*C21**	0 (-)	0.25 (0.14)	0.44 (0.25)	0.31 (0.15)	0 (-)	0.75 (0.31)	0.25 (0.06)
***n*C23**	0 (-)	0.13 (0.09)	0.38 (0.13)	0.50 (0.13)	0.25 (0.16)	0.50 (0.27)	0.35 (0.08)
***n*C24**	0 (-)	0.38 (0.20)	0.69 (0.22)	0.81 (0.29)	0.63 (0.26)	0.88 (0.58)	0.60 (0.16)
Conventional pesticides	0 (-)	0.44 (0.18)	0.38 (0.26)	0.06 (0.06)	0.25 (0.25)	0.50 (0.19)	0.38 (0.15)

Table 12. Thrips counts in D-vac samples at Norwood, Moree, in 2001–2002. Data represent treatment means (± SEM).

Treatments	**Sampling date**								**Average**
	2001					**2002**			
	19/11 (pre-treatment)	03/12	11/12	20/12	28/12	04/01	16/01	25/01	
***n*C21**	15.50 (7.31)	26.50 (6.02)	18.00 (2.35)	37.25 (7.64)	21.25 (4.55)	18.00 (3.87)	27.75 (4.94)	12.25 (3.64)	23.00 (1.27)
***n*C23**	21.75 (6.27)	28.25 (4.50)	25.50 (9.61)	52.00 (6.48)	16.00 (1.08)	13.5 (2.10)	29.00 (3.08)	9.75 (1.65)	24.85 (1.27)
***n*C24**	26.75 (11.14)	28.25 (2.17)	26.75 (5.07)	55.00 (14.65)	16.50 (3.86)	13.5 (2.72)	18.75 (3.47)	11.75 (2.59)	24.36 (1.52)
Conventional pesticides	25.25 (8.06)	41.00 (7.14)	27.50 (9.74)	50.25 (4.71)	10.25 (1.60)	18.75 (3.77)	24.5 (4.27)	10.25 (3.61)	26.07 (2.68)

Table 13. Jassid counts in D-vac samples at Norwood, Moree, in 2001–2002. Data represent treatment means (± SEM).

Treatment	**Sampling date**								**Average**
	2001					**2002**			
	19/11 (pre-treatment)	03/12	11/12	20/12	28/12	04/01	16/01	25/01	
***n*C21**	9.00 (6.67)	67.50 (4.43)	54.75 (11.15)	57.75 (3.75)	24.25 (5.76)	32.25 (7.17)	22.50 (3.30)	9.25 (5.44)	38.32 (3.13)
***n*C23**	10.50 (4.21)	64.25 (6.36)	60.00 (30.55)	62.75 (4.70)	19.50 (2.96)	33.50 (2.40)	15.50 (3.80)	0.75 (0.48)	36.61 (4.27)
***n*C24**	18.00 (7.20)	53.50 (4.57)	65.00 (30.75)	62.50 (9.70)	18.75 (3.20)	27.00 (6.76)	24.00 (4.71)	4.50 (4.50)	36.46 (5.25)
Conventional pesticides	18.00 (7.96)	68.00 (6.89)	69.25 (28.79)	66.25 (3.50)	22.25 (4.97)	33.25 (7.47)	16.50 (2.36)	4.00 (3.67)	39.93 (4.95)

Table 14. Treatment yields at Auscott (Narrabri) and Norwood (Moree) in 2001–2002. Data represent treatment means (± SEM).

Treatment	Yield (bales/acre or hectare) *			
	Auscott		Norwood	
	ac	ha	ac	ha
n**C21**	3.56^{a} (0.12)	8.80	3.80^{a} (0.08)	9.39
n**C23**	3.55^{a} (0.23)	8.77	3.19^{b} (0.14)	7.88
n**C24**	3.43^{a} (0.25)	8.48	3.83^{a} (0.21)	9.46
Conventional pesticides	3.70^{a} (0.16)	9.14	3.90^{a} (0.06)	9.64

* Means in columns followed different letter in columns were significantly different at $p < 0.05$. Ryan's Q test was used.

Field trial in 2002-2003 (Norwood, Moree)

Helicoverpa thresholds in all treatments, including the unsprayed control, did not reach industry thresholds (2 larvae/m of row from planting to flowering; 5 brown eggs or 2 larvae/m of row from flowering to one open boll; 3 larvae/m of row or 1 medium or 1 large larvae/m of row from 1 open boll to harvest, and 5 larvae or 2 medium or large larvae after 15% of bolls open) at any point in the season. Mite and aphid populations were too low to count.

Visual counts of Helicoverpa *based on 20 plants within each of 4 replicate subplots*. For eggs, there were no significant time*treatment interactions ($F_{44, 594} = 1.258$, $p = 0.128$) but there were significant differences between treatments ($F_{4, 10} = 3.736$, $p = 0.041$) as although Ryan's Q test did not detect significant differences between treatments ($p = 0.157$) when the LSD test was used egg numbers in all sprayed treatments were significantly lower than in the untreated control (Table 15). For larvae, there were no significant time*treatment interactions ($F_{48, 648} = 0.838$, $p = 0.774$), and when data were averaged over time there were no significant differences between treatments ($F_{4, 10} = 2.792$, $p = 0.086$) (Table 16).

Visual counts of Helicoverpa *in 1-m row lengths (mid to late season)*. For eggs, there was no significant time*treatment interaction ($F_{16, 72} = 1.008$, $p = 0.458$) but there were significant differences between treatments ($F_{4, 10} = 5.794$, $p = 0.011$) as Ryan's Q test detected significant differences between the 2 L/ha oil treatment and control but there were no significant differences between other treatments. However, LSD test showed that numbers in all sprayed treatments were significantly lower than in the untreated control (Table 17). For larvae, there were no significant time*treatment interactions ($F_{20, 90} = 1.300$, $p = 0.200$) and averaged data over the time showed no significant differences between treatments ($F_{4, 10} = 1.343$, $p = 0.320$) (Table 18).

'Industry standard' visual counts of Helicoverpa *in 1-m row lengths throughout season*. For eggs, there were no significant time*treatment interactions ($F_{36, 90} = 0.798$, $p = 0.774$) nor there were significant differences between treatments ($F_{4, 10} = 1.724$, $p = 0.221$) (Table 19). For larvae, there were no significant time*treatment interactions ($F_{8.20, 20.49} = 0.840$, $p = 0.581$) and for data averaged over the time there were no significant differences between treatments ($F_{4, 10} = 2.248$, $p = 0.136$) (Table 20).

Visual counts of green mirid based on 20 plants within each of 4 replicate subplots. There were no significant time*treatment interactions ($F_{48, 648} = 1.041$, $p = 0.400$) and no significant differences between treatments ($F_{4, 10} = 2.073$, $p = 0.160$) (Table 21).

Visual counts of green mirid in 1-m row lengths (mid to late season). There were no significant time*treatment interactions ($F_{31.65, 427.23} = 1.041$, $p = 0.408$) and no significant differences between treatments ($F_{4, 10} = 2.073$, $p = 0.160$) (Table 22).

Green mirid in D-vac samples. There were no significant time*treatment interactions ($F_{36, 162} = 0.741$, $p < 0.001$) and there were no significant differences between treatments ($F_{4,10} = 1.262$, $p = 0.321$) (Table 23).

Thrips. There were no significant time*treatment interactions ($F_{13.65, 95.56} = 1.152$, $p = 0.325$) and no significant differences between treatments ($F_{4, 10} = 2.034$, $p = 0.165$) (Table 24).

Jassids. There were significant time*treatment interactions ($F_{19.58, 88.117} = 3.818$, $p < 0.001$) and analyses for each sampling date indicated significant differences occurred between treatments on the last sampling date, 4 February 2003. Ryan's Q test subsequently showed that numbers in the 2 L and 6 L oil/ha treatments were significantly lower than in the conventional pesticide treatment but differences between the oil treatments and the unsprayed control were not significant (Table 25).

Beneficial arthropods. There were no statistically significant differences between treatments in total numbers of ladybird beetles ($F_{4, 28} = 0.825$, $p = 0.520$), damsel bugs ($F_{4, 28} = 0.220$, $p = 0.925$), big-eyed bugs ($F_{4, 28} = 1.971$, $p = 0.126$) or brown lacewings ($F_{4, 28} = 0.506$, $p = 0.732$) over the season.

There were significant differences in the total number of green lacewings ($F_{4, 28} = 4.107$, $p = 0.010$). Oil at 4 L/ha significantly reduced numbers but oil at 6 L/ha did not, even though numbers in the latter oil treatment and in the conventional treatment appeared relatively low compared to the control and 2 L oil/ha treatment (Table 26).

As numbers of red and blue beetle were high throughout the season analyses were undertaken separately for each sample date. As there was no significant time*treatment interactions ($F_{11.18, 78.25} = 1.317$, $p = 0.245$) data were averaged for the season. Subsequent analysis indicated significant differences between treatment ($F_{4, 28} = 4.308$, $p = 0.008$) and Ryan's Q test showed that beetle numbers in the 6 L oil/ha treatment and the conventional pesticide treatment were significantly lower than in the 4 L oil/ha treatment, but not lower than in the 2 L oil/ha and unsprayed control treatments (Table 27).

Yield. No acute symptoms (burns) of phytotoxicity were observed and there were no significant differences between treatments in yield ($F_{4, 10} = 0.591$, $p = 0.677$) (Table 28). A shortage of water affected yields in all treatments.

Table 15. Counts of *Helicoverpa* spp. eggs on 80 (4 × 20) whole plants or terminals per replicate at Norwood in 2002–2003. Data represent treatment means (± SEM).

TTreatment	***Helicoverpa* spp. eggs**	**Sampling date**												**Average**
		2002						**2003**						
		18/11	25/11	03/12	13/12	19/12	23/12	08/01	14/01	21/01	28/01	04/02	17/02	
***n*C24 at 2 L/ha**	White	0.75 (0.27)	0.19 (0.10)	0.13 (0.90)	0.19 (0.14)	0.13 (0.09)	0.31 (0.15)	0.06 (0.06)	0 (-)	0.06 (0.06)	0.50 (0.22)	0.13 (0.09)	0.13 (0.09)	0.21 (0.30)
	Brown	0.06 (0.06)	0.13 (0.09)	0.06 (0.06)	0 (-)	0 (-)	0.25 (0.14)	0 (-)	0 (-)	0.06 (0.06)	0.06 (0.06)	0 (-)	0.13 (0.09)	0.74 (0.01)
	Total	0.81 (0.28)	0.31 (0.12)	0.19 (0.10)	0.19 (0.14)	0.13 (0.09)	0.56 (0.18)	0.6 (0.06)	0 (-)	0.13 (0.09)	0.56 (0.22)	0.13 (0.09)	0.25 (0.11)	0.28 ^{a} (0.03)
***n*C24 at 4 L/ha**	White	0.25 (0.14)	0.56 (0.13)	0.13 (0.09)	0.06 (0.06)	0.06 (0.06)	0.25 (0.11)	0.13 (0.09)	0.06 (0.06)	0.38 (0.20)	0.56 (0.22)	0.25 (0.14)	0.13 (0.09)	0.23 (0.03)
	Brown	0.19 (0.10)	0.13 (0.09)	0 (-)	0.06 (0.06)	0 (-)	0.13 (0.13)	0 (-)	0 (-)	0 (-)	0.06 (0.06)	0 (-)	0 (-)	0.73 (0.01)
	Total	0.44 (0.18)	0.69 (0.15)	0.13 (0.09)	0.13 (0.09)	0.06 (0.06)	0.38 (0.15)	0.13 (0.09)	0.06 (0.06)	0.38 (0.20)	0.63 (0.22)	0.25 (0.14)	0.13 (0.09)	0.28 ^{a} (0.03)
***n*C24 at 6 L/ha**	White	0.06 (0.06)	0.19 (0.10)	0.06 (0.06)	0.06 (0.06)	0.13 (0.09)	0.44 (0.20)	0.06 (0.06)	0 (-)	0.19 (0.10)	0.50 (0.22)	0.44 (0.18)	0.13 (0.09)	0.19 (0.03)
	Brown	0.19 (0.14)	0.13 (0.09)	0 (-)	0 (-)	0 (-)	0.13 (0.09)	0 (-)	0 (-)	0 (-)	0 (-)	0.13 (0.13)	0.19 (0.14)	0.74 (0.01)
	Total	0.25 (0.14)	0.31 (0.12)	0.06 (0.06)	0.06 (0.06)	0.13 (0.09)	0.56 (0.20)	0.06 (0.06)	0 (-)	0.19 (0.10)	0.50 (0.22)	0.56 (0.18)	0.31 (0.20)	0.25 ^{a} (0.04)
Conventional pesticides	White	0.19 (0.10)	0.56 (0.13)	0.13 (0.09)	0.06 (0.06)	0.25 (0.11)	0.06 (0.06)	0.06 (0.06)	0 (-)	0.25 (0.11)	0.44 (0.18)	0.13 (0.09)	0.19 (0.10)	0.19 (0.03)
	Brown	0.13 (0.09)	0.13 (0.09)	0.13 (0.09)	0 (-)	0.06 (0.06)	0.06 (0.06)	0.06 (0.06)	0 (-)	0 (-)	0.06 (0.06)	0 (-)	0.06 (0.06)	0.74 (0.01)
	Total	0.31 (0.15)	0.69 (0.18)	0.25 (0.11)	0.06 (0.06)	0.31 (0.11)	0.13 (0.09)	0.13 (0.09)	0 (-)	0.25 (0.11)	0.50 (0.18)	0.13 (0.09)	0.25 (0.14)	0.25 ^{a} (0.04)
Control	White	0.25 (0.16)	0.38 (0.18)	0.38 (0.18)	0.13 (0.13)	0 (-)	0.13 (0.13)	0.50 (0.19)	0.25 (0.16)	0.50 (0.27)	0.88 (0.30)	0.25 (0.16)	0.13 (0.13)	0.31 (0.03)
	Brown	0.13 (0.13)	0.13 (0.13)	0 (-)	0 (-)	0.25 (0.16)	0 (-)	0.13 (0.13)	0.13 (0.13)	0.13 (0.13)	0.13 (0.13)	0 (-)	0.13 (0.13)	0.76 (0.02)
	Total	0.38 (0.18)	0.50 (0.27)	0.38 (0.18)	0.13 (0.13)	0.25 (0.16)	0.13 (0.13)	0.63 (0.18)	0.50 (0.38)	0.63 (0.38)	1.00 (0.33)	0.25 (0.16)	0.25 (0.16)	0.42 ^{b} (0.06)

Means followed by different letters in columns were significantly different at $p \leq 0.05$. The LSD test was used.

Table 16. Counts of *Helicoverpa* spp. larvae on 80 (4 × 20) whole plants or terminals per replicate at Norwood in 2002–2003. Data represent treatment means (± SEM).

Treatment	***Helicoverpa* spp. larvae**	**Sampling date**													**Average**
		2002						**2003**							
		18/11	25/11	03/12	13/12	19/12	23/12	08/01	14/01	21/01	28/01	04/02	11/02	17/02	
***n*C24 at 2 L/ha**	Very small – small	0.25 (0.11)	0.63 (0.18)	0.31 (0.12)	0.06 (0.06)	0.25 (0.11)	0.19 (0.10)	0.06 (0.06)	0.44 (0.13)	0 (-)	0.06 (0.06)	0.50 (0.16)	0.31 (0.15)	0 (-)	0.24 (0.02)
	Medium – large	0.06 (0.06)	0.13 (0.09)	0.06 (0.06)	0.25 (0.14)	0.13 (0.09)	0.06 (0.06)	0.13 (0.09)	0.19 (0.14)	0.19 (0.14)	0 (-)	0.06 (0.06)	0.38 (0.13)	0 (-)	0.13 (0.02)
	Total	0.31 (0.12)	0.75 (0.17)	0.38 (0.13)	0.31 (0.15)	0.38 (0.13)	0.25 (0.11)	0.19 (0.10)	0.63 (0.15)	0.19 (0.14)	0.06 (0.06)	0.56 (0.16)	0.69 (0.15)	0 (-)	0.39 (0.03)
***n*C24 at 4 L/ha**	Very small – small	0.25 (0.11)	0.56 (0.18)	0.25 (0.11)	0.13 (0.09)	0.19 (0.10)	0.13 (0.09)	0.13 (0.09)	0.19 (0.14)	0.06 (0.06)	0 (-)	0.81 (0.21)	0.13 (0.09)	0.06 (0.06)	0.22 (0.03)
	Medium – large	0 (-)	0.06 (0.06)	0.13 (0.09)	0.06 (0.06)	0 (-)	0.13 (0.09)	0 (-)	0 (-)	0 (-)	0 (-)	0.13 (0.13)	0.19 (0.10)	0 (-)	0.05 (0.01)
	Total	0.25 (0.11)	0.63 (0.18)	0.38 (0.15)	0.19 (0.10)	0.19 (0.10)	0.25 (0.11)	0.13 (0.09)	0.19 (0.14)	0.06 (0.06)	0 (-)	0.94 (0.25)	0.31 (0.12)	0.06 (0.06)	0.30 (0.04)
***n*C24 at 6 L/ha**	Very small – small	0.31 (0.12)	0.81 (0.26)	0.25 (0.11)	0.06 (0.06)	0 (-)	0.06 (0.06)	0.06 (0.06)	0.19 (0.10)	0 (-)	0 (-)	0.50 (0.20)	0.13 (0.09)	0.06 (0.06)	0.19 (0.03)
	Medium – large	0 (-)	0.13 (0.09)	0.13 (0.13)	0 (-)	0.06 (0.06)	0.13 (0.09))	0.06 (0.06)	0 (-)	0.13 (0.09)	0 (-)	0 (-)	0.31 (0.12)	0 (-)	0.07 (0.02)
	Total	0.31 (0.12)	0.94 (0.12)	0.28 (0.15)	0.06 (0.06)	0.06 (0.06)	0.19 (0.10)	0.13 (0.09)	0.19 (0.10)	0.13 (0.09)	0 (-)	0.50 (0.20)	0.44 (0.16)	0.06 (0.06)	0.28 (0.03)
Conventional pesticides	Very small – small	0.25 (0.11)	0.75 (0.17)	0.31 (0.15)	0 (-)	0 (-)	0.19 (0.10)	0.06 (0.06)	0.56 (0.18)	0.06 (0.06)	0 (-)	0.69 (0.22)	0.31 (0.15)	0 (-)	0.25 (0.02)
	Medium – large	0 (-)	0.06 (0.06)	0 (-)	0.06 (0.06)	0 (-)	0.06 (0.06)	0 (-)	0 (-)	0 (-)	0 (-)	0.06 (0.06)	0.31 (0.12)	0 (-)	0.04 (0.01)
	Total	0.25 (0.11)	0.81 (0.19)	0.31 (0.15)	0.06 (0.06)	0 (-)	0.25 (0.11)	0.06 (0.06)	0.56 (0.18)	0.06 (0.06)	0 (-)	0.75 (0.23)	0.63 (0.20)	0 (-)	0.31 (0.03)
Control	Very small – small	0.63 (0.26)	0.25 (0.16)	0.38 (0.18)	0 (-)	0 (-)	0.25 (0.16)	0.25 (0.16)	0.25 (0.16)	0.13 (0.13)	0 (-)	0.63 (0.32)	0.38 (0.18)	0.13 (0.13)	0.25 (0.05)
	Medium – large	0 (-)	0.25 (0.16)	0.13 (0.13)	0.13 (0.13)	0 (-)	0 (-)	0.13 (0.13)	0 (-)	0 (-)	0 (-)	0.13 (0.13)	0.25 (016)	0.13 (0.13)	0.09 (0.03)
	Total	0.63 (0.26)	0.50 (0.19)	0.50 (0.19)	0.13 (0.13)	0 (-)	0.25 (0.16)	0.38 (0.18)	0.25 (0.16)	0.13 (0.13)	0 (-)	0.75 (0.41)	0.63 (0.26)	0.25 (0.16)	0.36 (0.7)

Table 17. Counts of *Helicoverpa* spp. eggs in 2, 1-m row lengths per replicate at Norwood in 2002-2003. Data represent treatment means (± SEM).

Treatment	***Helicoverpa* spp. eggs**	**Sampling date**					**Average ***
		2003					
		22/01	29/01	12/02	18/02	27/02	
***n*C24 at 2 L/ha**	White	0.63	0.13	0.38	0.50	0.38	0.40
		(0.38)	(0.13)	(0.26)	(0.27)	(0.18)	(0.13)
	Brown	0	0	0	0	0	0
		(-)	(-)	(-)	(-)	(-)	(-)
	Total	0.63	0.13	0.38	0.50	0.38	0.40 $^{\mathrm{AB,\ a}}$
		(0.38)	(0.13)	(0.26)	(0.27)	(0.18)	(0.13)
***n*C24 at 4 L/ha**	White	0.63	0.38	0.75	1.25	0.63	0.73
		(0.32)	(0.26)	(0.41)	(0.41)	(0.26)	(0.11)
	Brown	0.13	0	0	0	0	0.03
		(0.13)	(-)	(-)	(-)	(-)	(0.03)
	Total	0.75	0.38	0.75	1.25	0.63	0.75 $^{\mathrm{BC,\ a}}$
		(0.41)	(0.26)	(0.41)	(0.41)	(0.26)	(0.13)
***n*C24 at 6 L/ha**	White	0.38	0.50	0.38	1.63	0.63	0.70
		(0.18)	(0.33)	(0.18)	(0.53)	(0.50)	(0.16)
	Brown	0	0	0	0.25	0	0.05
		(-)	(-)	(-)	(0.16)	(-)	(0.03)
	Total	0.38	0.50	0.38	1.88	0.63	0.75 $^{\mathrm{BC,\ a}}$
		(0.18)	(0.33)	(0.18)	(0.58)	(0.50)	(0.19)
Conventional pesticide	White	0.38	0.13	0.63	1.75	0	0.58
		(0.18)	(0.13)	(0.38)	(0.45)	(-)	(0.08)
	Brown	0	0	0.13	0.13	0.13	0.08
		(-)	(-)	(0.13)	(0.13)	(0.13)	(0.04)
	Total	0.38	0.13	0.75	1.88	0.13	0.65 $^{\mathrm{BC,\ a}}$
		(0.18)	(0.13)	(0.49)	(0.48)	(0.13)	(0.11)
Control	White	1.00	0.75	1.50	1.75	0.50	1.10
		(0.41)	(0.48)	(0.87)	(0.48)	(0.29)	(0.10)
	Brown	0	0.25	0	0.75	0	0.20
		(-)	(0.25)	(-)	(0.48)	(-)	(0.11)
	Total	1.00	1.00	1.50	2.50	0.50	1.30 $^{\mathrm{C,\ b}}$
		(0.41)	(0.58)	(0.87)	(0.65)	(0.29)	(0.19)

* Means followed a different letter (uppercase for Ryan's Q test and lowercase for LSD test) within the column differed significantly at $p < 0.05$.

Table 18. Visual counts of *Helicoverpa* spp. larvae in 2, 1-m row lengths per replicate at Norwood in 2002-2003. Data represent treatment means (± SEM).

Treatment	***Helicoverpa* spp. larvae**	**Sampling date**						**Average**
		2003						
		15/01	22/01	29/01	12/02	18/02	27/02	
***n*C24 at 2 L/ha**	Very small - small	0.13	0.50	0.38	0.25	0	0.38	0.27
		(0.13)	(0.19)	(0.18)	(0.16)	(-)	(0.18)	(0.05)
	Medium - large	0	0.13	0	0	0	0	0.02
		(-)	(0.13)	(-)	(-)	(-)	(-)	(0.02)
	Total	0.13	0.63	0.38	0.25	0	0.38	0.29
		(0.13)	(0.26)	(0.18)	(0.16)	(-)	(0.18)	(0.06)
***n*C24 at 4 L/ha**	Very small - small	0.50	0	0.63	0.25	0	0.38	0.29
		(0.27)	(-)	(0.38)	(0.16)	(-)	(0.18)	(0.10)
	Medium - large	0	0.13	0	0	0	0.13	0.04
		(-)	(0.13)	(-)	(-)	(-)	(0.13)	(0.03)
	Total	0.50	0.13	0.63	0.25	0	0.50	0.33
		(0.27)	(0.13)	(0.38)	(0.16)	(-)	(0.18)	(0.04)
***n*C24 at 6 L/ha**	Very small - small	0.50	0.25	0.75	0.13	0	0.75	0.40
		(0.38)	(0.16)	(0.37)	(0.13)	(-)	(0.37)	(0.12)
	Medium - large	0.13	0.13	0.13	0.25	0	0.13	0.13
		(0.13)	(0.13)	(0.13)	(0.16)	(-)	(0.13)	(0.04)
	Total	0.63	0.38	0.88	0.38	0	0.88	0.52
		(0.38)	(0.18)	(0.40)	(0.26)	(-)	(0.35)	(0.13)
Conventional pesticides	Very small - small	0.13	0	0.25	0.25	0	1.00	0.27
		(0.13)	(-)	(0.16)	(0.16)	(-)	(0.27)	(0.04)
	Medium - large	0.13	0.38	0	0	0.13	0.38	0.17
		(0.13)	(0.26)	(-)	(-)	(0.13)	(0.26)	(0.06)
	Total	0.25	0.38	0.25	0.25	0.13	1.38	0.44
		(0.16)	(0.26)	(0.16)	(0.16)	(0.13)	(0.38)	(0.09)
Control	Very small - small	0.75	0.25	0.25	0.50	0	0.75	0.42
		(0.25)	(0.25)	(0.25)	(0.29)	(-)	(0.25)	(0.14)
	Medium - large	0.50	0.25	0	0.50	0	0	0.21
		(0.29)	(0.25)	(-)	(0.29)	(-)	(-)	(0.10)
	Total	1.25	0.50	0.25	1.00	0	0.75	0.63
		(0.25)	(0.29)	(0.25)	(0.58)	(-)	(0.25)	(0.08)

Table 19. ‘Industry standard’ (1-m of row per replicate) counts of *Helicoverpa* spp. eggs at Norwood in 2002-2003. Data represent treatment means (± SEM).

Treatment	***Helicoverpa* spp. eggs**	**Average of two pre-treatment counts**	**Sampling date**									**Average**
			2002				**2003**					
			8/11	26/11	20/12	31/12	10/01	15/01	18/01	25/01	28/01	
***n*C24 at 2 L/ha**	White	2.25 (0.60)	1.25 (0.25)	0.75 (0.48)	2.00 (0.41)	1.25 (0.75)	1.50 (0.87)	1.00 (0.41)	2.00 (0.71)	1.75 (0.75)	0.75 (0.25)	1.36 (0.24)
	Brown	1.00 (0.20)	1.00 (0.41)	0.25 (0.25)	0.75 (0.75)	0 (-)	2.00 (1.08)	0 (-)	0.75 (0.48)	0.75 (0.48)	0 (-)	0.61 (0.17)
	Total	3.25 (0.60)	2.25 (0.25)	1.00 (0.58)	2.75 (0.48)	1.25 (0.75)	3.50 (0.65)	1.00 (0.41)	2.75 (0.85)	2.50 (0.96)	0.75 (0.25)	1.97 (0.17)
***n*C24 at 4 L/ha**	White	2.5 (0.54)	0 (-)	0.25 (0.25)	1.50 (0.65)	1.00 (0.58)	1.25 (0.48)	0.75 (0.25)	2.00 (0.41)	1.75 (0.63)	1.25 (0.48)	1.08 (0.12)
	Brown	2.38 (0.31)	1.75 (0.63)	0 (-)	1.00 (0.58)	0 (-)	2.50 (0.65)	0 (-)	0.50 (0.29)	0 (-)	0.25 (0.25)	0.67 (0.18)
	Total	4.88 (0.75)	1.75 (0.63)	0.25 (0.25)	2.50 (0.65)	1.00 (0.58)	3.75 (0.75)	0.75 (0.25)	2.50 (0.50)	1.75 (0.63)	1.50 (0.29)	1.75 (0.26)
***n*C24 at 6 L/ha**	White	1.6 (0.66)	0.50 (0.50)	2.50 (0.65)	2.50 (0.19)	0.25 (0.25)	1.75 (0.25)	1.00 (0.58)	2.50 (0.65)	1.25 (0.95)	1.75 (0.63)	1.56 (0.24)
	Brown	0.88 (0.13)	1.25 (0.48)	0 (-)	1.75 (1.44)	0.50 (0.50)	1.75 (0.48)	0.25 (0.25)	0.75 (0.48)	0.25 (0.25)	0.25 (0.25)	0.75 (0.16)
	Total	2.50 (0.74)	1.75 (0.25)	2.50 (0.65)	4.25 (1.38)	0.75 (0.48)	3.50 (0.50)	1.25 (0.48)	3.25 (0.75)	1.50 (0.87)	2.00 (0.41)	2.31 (0.17)
Conventional pesticides	White	1.5 (0.54)	1.00 (0.41)	1.25 (0.48)	2.00 (0.71)	1.00 (0.71)	0.75 (0.48)	0.75 (0.75)	1.25 (0.25)	0.75 (0.48)	0.25 (0.25)	1.00 (0.14)
	Brown	1.88 (0.59)	0.50 (0.50)	0 (-)	1.25 (0.48)	0.25 (0.25)	1.50 (0.50)	0 (-)	1.00 (0.71)	0 (-)	0 (-)	0.50 (0.13)
	Total	3.38 (0.38)	1.50 (0.29)	1.25 (0.48)	3.25 (0.25)	1.25 (0.63)	2.25 (0.25)	0.75 (0.75)	2.25 (0.95)	0.75 (0.48)	0.25 (0.25)	1.50 (0.26)
Control	White	2.5 (1.50)	0 (-)	0 (-)	3.00 (1.00)	0.50 (0.50)	1.50 (0.50)	1.00 (1.00)	2.50 (0.50)	2.00 (0.00)	0.50 (0.50)	1.22 (0.22)
	Brown	1.00 (0.00)	1.50 (0.50)	0.50 (0.50)	0.50 (0.50)	0 (-)	0.50 (0.50)	0.50 (0.50)	1.00 (0.00)	0 (-)	0 (-)	0.50 (0.06)
	Total	3.50 (1.50)	1.50 (0.50)	0.50 (0.50)	3.50 (0.50)	0.50 (0.50)	2.00 (0.00)	1.50 (1.50)	3.50 (0.50)	2.00 (0.00)	0.50 (0.50)	1.72 (0.28)

Table 20. ‘Industry standard’ (1-m of row per replicate) counts of *Helicoverpa* spp. larvae at Norwood in 2002-2003. Data represent treatment means (± SEM).

Treatment	***Helicoverpa* spp. larvae**	**Average of two pre-treatment counts**	**Sampling dates**											**Average**
			2002									**2003**		
			8/11	15/11	19/11	22/11	26/11	29/11	3/12	27/12	31/12	03/01	10/01	
***n*C24 at 2 L/ha**	Very small - small	-	-	-	2.00 (1.41)	1.00 (0.58)	.075 (0.25)	1.00 (0.58)	1.00 (0.41)	0.50 (0.29)	0.50 (0.29)	0 (-)	1.50 (0.50)	0.92 (0.22)
	Medium - large	-	-	-	0 (-)	0 (-)	0 (-)	0.75 (0.48)	1.00 (0.41)	0.25 (0.25)	0.75 (0.25)	0.75 (0.25)	0.75 (0.48)	0.47 (0.13)
	Total	1.25 (0.25)	2.25 (1.11)	3.75 (3.75)	2.00 (1.41)	1.00 (0.58)	0.75 (0.25)	1.75 (0.63)	2.00 (0.71)	0.75 (0.48)	1.25 (0.25)	0.75 (0.25)	2.25 (0.63)	1.68 (0.45)
***n*C24 at 4 L/ha**	Very small - small	-	-	-	0.25 (0.25)	2.25 (0.85)	0.50 (0.50)	0 (-)	0.25 (0.25)	0 (-)	1.00 (0.71)	0 (-)	1.25 (0.48)	0.61 (0.22)
	Medium - large	-	-	-	0 (-)	1.25 (1.25)	0.50 (0.50)	0 (-)	0.25 (0.25)	0 (-)	0 (-)	0.50 (0.29)	0.50 (0.29)	0.33 (0.26)
	Total	0.88 (0.31)	2.00 (0.82)	2.25 (1.32)	0.25 (0.25)	3.50 (0.65)	1.00 (0.58)	0 (-)	0.50 (0.29)	0 (-)	1.00 (0.71)	0.50 (0.29)	1.75 (0.25)	1.16 (0.08)
***n*C24 at 6 L/ha**	Very small - small	-	-	-	1.00 (0.58)	0.50 (0.50)	0.75 (0.48)	0.50 (0.50)	0 (-)	0.25 (0.25)	0.50 (0.29)	0.75 (0.48)	0.25 (0.25)	0.50 (0.15)
	Medium - large	-	-	-	0 (-)	0 (-)	0 (-)	0.75 (0.48)	0 (-)	0.50 (0.29)	0.50 (0.29)	0.50 (0.29)	0.50 (0.29)	0.31 (0.09)
	Total	0.63 (0.47)	0.75 (0.25)	1.00 (1.00)	1.00 (0.58)	0.50 (0.50)	0.75 (0.48)	1.25 (0.48)	0 (-)	0.75 (0.25)	1.00 (0.41)	1.25 (0.25)	0.75 (0.48)	0.82 (0.23)
Conventional pesticides	Very small - small	-	-	-	1.00 (0.71)	0.75 (0.25)	1.00 (0.41)	0.50 (0.29)	0 (-)	0.75 (0.25)	1.00 (0.41)	0.75 (0.48)	0.25 (0.25)	0.67 (0.08)
	Medium - large	-	-	-	0 (-)	0 (-)	0.25 (0.25)	0 (-)	0 (-)	0 (-)	0 (-)	0.75 (0.25)	0.75 (0.25)	0.19 (0.07)
	Total	0.13 (0.13)	0 (-)	1.25 (0.95)	1.00 (0.71)	0.75 (0.25)	1.25 (0.48)	0.50 (0.29)	0 (-)	0.75 (0.25)	1.00 (0.41)	1.50 (0.29)	1.00 (0.41)	0.82 (0.10)
Control	Very small - small	-	-	-	0.50 (0.50)	0 (-)	1.00 (0.00)	0 (-)	0 (-)	0.50 (0.50)	1.00 (1.00))	1.00 (1.00)	0 (-)	0.44 (0.33)
	Medium - large	-	-	-	0 (-)	0 (-)	0 (-)	0 (-)	0.50 (0.50)	0 (-)	0.50 (0.50)	0.50 (0.50)	0 (-)	0.17 (0.06)
	Total	0.25 (0.25)	2.00 (1.00)	0 (-)	0.50 (0.50)	0 (-)	1.00 (0.00)	0 (-)	0.50 (0.50)	0.50 (0.50)	1.50 (1.50)	1.50 (0.50)	0 (-)	0.68 (0.32)

Table 21. Visual counts of green mirid on 80 (4 × 20) whole plants or terminals per replicate at Norwood in 2002–2003. Data represent treatment means (± SEM).

Treatment	Sampling date													Average
	2002						2003							
	18/11	25/11	03/12	13/12	19/12	23/12	08/01	14/01	21/01	28/01	04/02	11/02	17/02	
***n*C24 at 2 L/ha**	0.50 (0.27)	0.50 (0.16)	1.69 (0.28)	0.56 (0.22)	1.38 (0.35)	0.88 (0.18)	0 (-)	0.38 (0.18)	0 (-)	0.63 (0.22)	1.38 (0.36)	0.75 (0.17)	0.75 (0.25)	0.72 (0.07)
***n*C24 at 4 L/ha**	0.44 (0.18)	0.75 (0.17)	1.38 (0.39)	0.81 (0.28)	0.81 (0.19)	0.63 (0.26)	0.06 (0.06)	0.19 (0.14)	0.06 (0.06)	0.50 (0.22	1.56 (0.35)	0.75 (0.21)	1.00 (0.30)	0.69 (0.06)
***n*C24 at 6 L/ha**	0.13 (0.09)	0.50 (0.13)	1.81 (0.40)	0.63 (0.31)	0.63 (0.22)	0.44 (0.13)	0.13 (0.09)	0.56 (0.30)	0.13 (0.09)	0.56 (0.18)	1.56 (0.34)	0.63 (0.15)	1.31 (0.30)	0.69 (0.07)
Conventional pesticides	0.38 (0.18)	0.56 (0.18)	1.06 (0.19)	0.56 (0.22)	0.50 (0.16)	1.00 (0.24)	0.13 (0.09)	0.06 (0.06)	0.19 (0.14)	0.63 (0.20)	0.81 (0.25)	0.44 (0.16)	1.06 (0.46)	0.57 (0.07)
Control	0.38 (0.26)	0.25 (0.16)	1.63 (0.65)	0.75 (0.31)	0.63 (0.26)	1.13 (0.35)	0 (-)	0.25 (0.16)	0.25 (0.16)	1.00 (0.38)	1.88 (0.35)	0.25 (0.25)	1.75 (0.73)	0.78 (0.09)

Table 22. Visual counts of green mirid in 2, 1-m row lengths per replicate at Norwood in 2002-2003. Data represent treatment means (± SEM).

Treatment	**Sampling date**						**Average**
	2003						
	15/01	22/01	29/01	12/02	18/02	27/02	
***n*C24 at 2 L/ha**	0.25	0.13	0.63	0.75	1.88	1.75	0.90
	(0.16)	(0.13)	(0.38)	(0.41)	(0.52)	(0.37)	(0.18)
***n*C24 at 4 L/ha**	0.25	0.38	1.00	0.63	3.00	1.50	1.13
	(0.16)	(0.26)	(0.42)	(0.26)	(0.82)	(0.53)	(0.19)
***n*C24 at 6 L/ha**	0	0.13	1.25	0.38	2.38	1.25	0.90
	(-)	(0.13)	(0.37)	(0.26)	(0.53)	(0.37)	(0.16)
Conventional pesticides	0.25	0.13	0.75	0.75	3.25	1.75	1.15
	(0.16)	(0.13)	(0.35)	(0.25)	(0.84)	(0.45)	(0.14)
Control	0	0.75	1.75	2.00	4.50	1.15	1.75
	(-)	(0.48)	(1.03)	(0.71)	(0.96)	(0.50)	(0.17)

Table 23. Green mirid counts from D-vac samples at Norwood in 2002–2003. Data represent treatment means (± SEM).

Treatment	**Sampling date**										**Average**
	2002					**2003**					
	18/11	25/11	03/12	13/12	19/12	08/01	14/01	21/01	28/01	04/02	
***n*C24 at 2 L/ha**	0.88	1.88	3.00	1.13	1.75	0.75	1.25	0	0.50	0.63	1.18
	(0.61)	(0.77)	(0.71)	(0.48)	(0.45)	(0.37)	(0.41)	(-)	(0.33)	(0.26)	(0.24)
***n*C24 at 4 L/ha**	0.38	1.38	2.50	0.25	1.88	0.38	1.88	0.13	0.63	0.75	1.01
	(0.18)	(1.10)	(0.98)	(0.16)	(0.52)	(0.18)	(0.77)	(0.13)	(0.18)	(0.25)	(0.23)
***n*C24 at 6 L/ha**	0.38	0.88	2.38	1.00	1.00	0.50	1.13	0	0.50	0.63	0.84
	(0.38)	(0.61)	(0.98)	(0.33)	(0.38)	(0.27)	(0.48)	(-)	(0.27)	(0.49)	(0.17)
Conventional pesticides	0.13	1.15	3.25	1.00	1.25	0.13	1.50	0	0.75	0.13	0.96
	(0.13)	(0.46)	(0.94)	(0.27)	(0.31)	(0.13)	(0.38)	(-)	(0.37)	(0.13)	(0.16)
Control	1.00	1.25	3.75	0.75	1.25	1.25	0.75	0.25	1.50	2.50	1.43
	(0.58)	(0.95)	(1.11)	(0.48)	(0.25)	(0.48)	(0.75)	(0.25)	(0.29)	(1.04)	(0.22)

Table 24. Thrips counts from D-vac samples at Norwood in 2002–2003. Data represent treatment means (± SEM).

Treatment	**Sampling date**										**Average**
	2002					**2003**					
	18/11	25/11	03/12	13/12	19/12	08/01	14/01	21/01	28/01	04/02	
***n*C24 at 2 L/ha**	30.50	10.13	16.75	17.00	58.63	82.13	187.00	261.63	247.25	267.50	117.85
	(8.00)	(1.96)	(2.20)	(2.62)	(4.65)	(11.44)	(18.03)	(32.36)	(20.85)	(16.18)	(5.74)
***n*C24 at 4 L/ha**	27.25	11.25	17.25	17.25	52.50	78.75	194.00	247.13	229.13	297.50	117.20
	(4.13)	(1.47)	(2.88)	(2.14)	(4.56)	(12.94)	(18.31)	(28.60)	(28.41)	(29.18)	(6.27)
***n*C24 at 6 L/ha**	29.63	10.50	19.00	19.00	61.63	83.50	220.13	230.88	233.13	261.25	116.86
	(6.89)	(2.05)	(2.90)	(3.06)	(7.21)	(11.03)	(8.52)	(26.27)	(7.83)	(22.60)	(3.89)
Conventional pesticides	31.00	14.88	20.25	16.88	59.13	70.63	199.13	226.13	192.25	293.38	112.36
	(5.07)	(2.70)	(3.62)	(3.06)	(6.30)	(10.34)	(14.66)	(15.33)	(5.29)	(25.47)	(4.03)
Control	23.50	11.25	17.00	17.75	41.00	83.50	207.75	172.50.	185.00	224.00	98.33
	(7.19)	(2.75)	(1.35)	(5.99)	(5.55)	(6.96)	(38.94)	(14.15)	(20.79)	(32.41)	(3.51)

Table 25. Jassid counts from D-vac samples at Norwood in 2002–2003. Data represent treatment means (± SEM).

Treatment	**Sampling date**										**Average**
	2002					**2003**					
	18/11	25/11	03/12	13/12	19/12	08/01	14/01	21/01	28/01	04/02	
***n*C24 at 2 L/ha**	11.38 (1.02)	21.38 (2.50)	43.25 (5.46)	32.88 (3.48)	98.50 (7.62)	48.25 (6.08)	42.88 (5.24)	26.75 (2.25)	20.63 (5.09)	30.75 ^{a} (1.58)	37.66 (2.02)
***n*C24 at 4 L/ha**	18.88 (2.39)	22.63 (2.33)	40.13 (3.88)	28.38 (2.82)	79.75 (6.74)	53.00 (9.66)	38.00 (7.82)	25.75 (4.96)	16.63 (2.82)	45.38 ^{ab} (6.51)	36.85 (2.58)
***n*C24 at 6 L/ha**	13.38 (2.98)	24.00 (2.80)	38.63 (5.45)	35.50 (2.49)	95.13 (6.86)	29.00 (4.94)	30.50 (2.43)	25.00 (5.15)	15.25 (1.73)	33.25 ^{a} (4.33)	33.56 (5.09)
Conventional pesticides	14.63 (1.90)	22.88 (3.11)	38.13 (4.77)	35.13 (2.52)	90.75 (7.83)	48.88 (9.14)	49.25 (2.72)	24.88 (5.39)	15.13 (1.66)	50.38 ^{b} (4.74)	39.00 (2.25)
Control	14.50 (4.84)	20.75 (3.47)	35.25 (4.71)	33.00 (6.67)	59.00 (7.14)	71.75 (7.24)	61.00 (6.28)	19.50 (6.12)	16.50 (2.22)	48.50 ^{ab} (7.71)	37.98 (2.41)

Table 26. Ladybird, big-eyed bug, damsel bug, green lacewing and brown lacewing counts from D-vac samples at Norwood in 2002–2003. Data represent treatment means (± SEM).

Treatment	**Ladybird beetles**	**Big-eyed bug**	**Damsel bug**	**Green lacewing**	**Brown lace wing**
***n*C24 at 2 L/ha**	6.25 (0.92)	6.13 (0.72)	1.13 (0.44)	3.63 ^{a} (0.56)	1.50 (0.50)
***n*C24 4 at L/ha**	4.62 (1.19)	8.25 (1.22)	1.50 (0.65)	1.25 ^{b} (0.37)	2.00 (0.73)
***n*C24 at 6 L/ha**	6.50 (1.72)	7.38 (1.07)	1.25 (0.37)	1.75 ^{a} (0.56)	0.88 (0.44)
Conventional pesticides	7.00 (1.34)	7.00 (0.93)	1.00 (0.33)	2.13 ^{a} (0.69)	1.25 (0.65)
Control	8.00 (2.41)	12.00 (3.58)	1.50 (0.65)	3.15 ^{a} (0.65)	1.50 (0.65)

* For green lacewing, means followed by different letters in columns were significantly different at $p \leq 0.05$. The LSD test was used.

Table 27. Red and blue beetle counts from D-vac samples at Norwood in 2002–2003. Data represent treatment means (± SEM).

Treatment	**Sampling date**										**Average ***
	2002					**2003**					
	18/11	25/11	03/12	13/12	19/12	08/01	14/01	21/01	28/01	04/02	
***n*C24 at 2 L/ha**	3.38 (0.53)	5.25 (0.59)	8.00 (1.04)	7.75 (1.18)	19.38 (5.71)	5.63 (1.60)	6.00 (0.78)	2.75 (0.80)	1.63 (0.38)	2.13 (0.77)	6.19 ^{ab} (0.63)
***n*C24 at 4 L/ha**	6.63 (1.03)	6.00 (0.89)	9.50 (2.36)	6.00 (1.40)	11.75 (2.74)	16.50 (10.62)	12.00 (6.92)	2.25 (0.94)	1.63 (0.73)	2.25 (0.56)	7.45 ^{a} (1.18)
***n*C24 at 6 L/ha**	5.63 (1.36)	6.50 (1.44)	8.13 (1.42)	9.75 (1.87)	8.25 (0.77)	4.25 (0.96)	3.38 (0.60)	1.50 (0.65)	0.88 (0.88)	1.38 (0.38)	4.96 ^{b} (0.40)
Conventional pesticides	3.75 (0.86)	4.25 (1.19)	8.38 (1.16)	5.50 (0.78)	11.00 (1.41)	4.13 (1.01)	5.88 (0.61)	1.25 (0.62)	1.00 (0.42)	2.38 (0.50)	4.75 ^{b} (0.49)
Control	3.25 (1.11)	9.50 (2.40)	7.75 (1.11)	10.50 (3.40)	5.25 (1.38)	10.75 (3.04)	10.50 (4.63)	1.25 (0.63)	1.00 (0.71)	5.25 (0.63)	6.50 ^{ab} (1.19)

* Means followed by different letters in columns were significantly different at $p \leq 0.05$. The LSD test was used.?

Table 28. Treatment yields at Norwood in 2002-2003. Data represent treatment means (± SEM).

Treatment	Yield (bales/ha)
***n*C24 at 2 L/ha**	5.57 (0.28)
***n*C24 at 4 L/ha**	5.57 (0.09)
***n*C24 at 6 L/ha**	5.38 (0.30)
Conventional pesticides	5.32 (0.27)
Control	5.01 (0.36)

Part B: Spray Application Technology

Laboratory ***e****valuation of nozzle spectra and drift***.** Analysis of droplet spectra measurements indicated complex relationships between nozzle size, pressure, emulsifier concentration in oil, and oil concentration in water. Many significant interactions were derived for volume median diameter (VMD), span and percentage of droplets with diameter less than 141 μm (drift-prone droplets). It was clear that the impact of nozzle size could only be compared at the same pressure and that the impact of oil on droplet spectra is related to nozzle size and/or operating pressure. However, there were no interactions between oil concentration in water and emulsifier concentration in oil. Initial results are summarised in Tables 29, 30 and 31 and only data for 0.25% and 2% are presented.

Orifice size and the pressure influenced the impact of oil on droplet spectra of flat fan nozzles (Table 29). There was no significant impact on the droplets produced by 0075 nozzles (the smallest orifice size). The impact on droplets produced by 015 nozzles increased with increasing pressure. Significantly higher VMD, and reduced percentage of drift-prone droplets, was recorded for 03 and 06 orifices. These nozzles produced medium to coarse spray. Increase of VMD was about 10% and reduction of drift prone droplets was 20-40%. Increased oil concentration sometimes had significant impact but emulsifier concentration had no impact.

Oil significantly reduced VMD of droplets produced by injet nozzles by about 10% (Table 30). Influence was more pronounced for nozzles with the smaller orifice (015) than for those with a larger orifice (04). The impact of oil increased with increasing pressure (there was no significant impact on VMD for 04 orifice nozzle at 300 kPa but the impact was significant at 600 kPa). The percentage of drift-prone droplets was very low (1-4%) and addition of oil increased that percentage for up to 1% (an increase of about 40%) but may have limited practical consequences. Increasing oil concentration produced significantly greater reductions of VMD for 015 nozzles at 300 kPa and emulsifier concentration in oil had no impact.

Oil significantly increased VMD and reduced the percentage of drift-prone droplets from hollow cone nozzles (Table 31). However, the impact of oil fell as the nozzle orifice and pressure increased. Oil reduced the percentage of drift-prone droplets for nozzles with orifice size 12 by approximately 50 % at 400 kPa but only 5 % at 1200 kPa. It seems that the potential of using oil for spray drift reduction of hollow cone nozzles is very high since this type of nozzle produced higher levels of drift than other nozzle types tested. Increasing oil concentration had significant impacts for orifice size 15 nozzles at 400 and 800 kPa. Emulsifier concentration in oil had no impact.

Results for the spray drift experiments are presented in Table 32. Values presented are relative values that represent colour intensity measured by the spectrofluorimeter.

For flat fan nozzles there was no reduction of drift for 0075 and 015 nozzles, which produced very fine and fine spray at all measured heights (Table 32). However, reduction in drift was significant for 03 nozzles at 5 cm and 15 cm above ground level. Reduction in drift was about 60% at 5 cm and 20% at 15 cm.

Spray drift from injet nozzles was very low compared to drift from the other nozzle types tested. Oil significantly reduced drift for 015 nozzles, at all measured heights, by as much as 60%, and by 30% for 03 nozzles at 5 cm and 25 cm above ground level.

For hollow cone nozzles the addition of oil resulted in a significant reduction of spray drift for both orifice sizes at all heights. Hollow cones produced high and similar levels of spray drift at all measured heights above ground level, while most drift from flat fan nozzles occurred at lowest heights. Reduction of drift for orifice size 12 nozzles was about 45-65%; for size 20 nozzles it was 10-30%.

Field evaluation of spray deposit and coverage. For oil deposition, there were no significant differences between oil deposits in the middle and upper parts of canopies ($F_{1, 252} = 0.463$, $p = 0.497$). Each sprayer applied sprays effectively. As there were no significant interactions between spray application methods (treatment) and sampling position in canopies ($F_{5, 252} = 1.885$, $p = 0.097$), comparisons between treatments were based on the average value of oil deposits from upper and middle canopy levels. There were significant differences between treatments for oil deposits ($F_{5, 252} = 6.233$, $p < 0.001$) and Ryan's Q test showed that the Hardi Auto-Track 75 L/ha treatment deposited more oil than by any other treatment (Table 33). There were no significant differences between other treatments.

For spray coverage, two parameters were measured on the water sensitive papers that were attached to leaves. These were:

- number of droplets/cm^2, and
- percentage of area covered.

For number of droplets/cm^2 there were no significant interactions between the spray application method (treatment) and sampling position within canopies (upper or middle canopy) ($F_{5, 914} = 1.211$, $p = 0.302$) but there were significant interactions between spray application method and deposits on water sensitive paper strips attached to adaxial and abaxial leaf surfaces ($F_{5, 914} = 4.770$, $p < 0.001$). The results were similar for percent coverage on water sensitive papers. There were no significant interactions between application method and sampling position within canopies ($F_{5, 914} = 2.170$, $p = 0.06$), and significant interactions between application method and leaf surface ($F_{5, 914} = 20.140$, $p < 0.001$).

Separate analyses for adaxial and abaxial leaf surfaces were performed to test differences between application methods for both of the measured parameters. There were significant differences between the treatments for both leaf surfaces for coverage ($F_{5, 458} = 33.11$, $p < 0.001$ for the adaxial surface, and $F_{5, 455} = 4.994$, $p < 0.001$ for the abaxial surface) and there were significant differences for droplets/cm^2 for both surfaces ($F_{5, 458} = 16.65$, $p < 0.001$ for the adaxial surface, and $F_{5, 455} = 9.01$, $p < 0.001$ for the abaxial surface).

For number of droplets/cm^2 of adaxial leaf surface, analysis based on the Dunnett T3 test showed that there were no significant differences between the conventional and air-assisted groundrigs, and that doubling spray volume had no significant influence on coverage (Table 34). Most groundrig applications achieved better coverage than helicopter did. The exception was the Hardi Twin, for which coverage in the 75 L/ha treatment did not differ significantly from the 60 L/ha helicopter treatment. However, there were no significant differences between the 30 L/ha and 60 L/ha helicopter treatments. Results for abaxial deposits were broadly similar to the results for adaxial deposits. The only difference was that for abaxial deposits there were no significant differences between 150 L/ha Hardi Auto-Track and the 60 L/ha helicopter treatments.

For percent coverage on adaxial leaf surfaces, analysis based on the Dunnett T3 test showed that coverage by sprays applied at 75 L/ha by the groundrig sprayers was significantly lower than that achieved with the 150 L/ha sprays applied by the same sprayers (Table 35). The 60 L/ha helicopter spray achieved similar levels of coverage as the 75 L/ha groundrig sprays, and was significantly better than that achieved by the 30 L/ha helicopter spray. Groundrig application at 150 L/ha, regardless of the air-assistance, achieved significantly better coverage than any other treatment. Coverage in the 30 L/ha helicopter treatment was significantly lower than in the other treatments. Results for abaxial coverage differed from those recorded for adaxial coverage. There were no differences between Hardi Auto-Track treatments, regardless of spray volume, and coverage in these treatments was as similar to coverage given by the Hardi Twin at 75 L/ha, but better than coverage achieved by the Hardi Twin at 150 L/ha and the helicopter at both 30 L and 60 L/ha. There were no significant differences between 30 and 60 L/ha helicopter treatments, and both of these treatments were as good as Hardi Twin at 150 L/ha.

Table 29. Impact of agricultural mineral oil on VMD, span and percentage of drift-prone droplets for flat fan nozzles (Hardi ISO F 110) at a range of pressures [1, 2 & 3].

Pressure (kPa)	Nozzle size	% oil	VMD (µm)	Span	% droplets < 141 µm
150	0075	Water	155.33 a	1.92 a	46.97 a
			(3.79)	(0.02)	(1.10)
		2%	156.67 a	1.76 b	46.43 a
			(0.58)	(0.02)	(0.31)
	015	Water	249.00 ab	1.30 a	14.73 a
			(8.72)	(0.06)	(1.42)
		0.25%	246.33 a	1.22 a	15.07 a
			(7.9)	(0.09)	(1.55)
		2%	255.00 b	1.12 a	14.30 a
			(5.73)	(0.12)	(0.74)
	03	Water	306.33 a	1.20 a	10.77 a
			(4.93)	(0.05)	(0.80)
		0.25%	323.67 b	1.16 a	7.83 b
			(4.27)	(0.01)	(0.57)
		2%	332.67 c	0.90 a	6.38 c
			(5.72)	(0.30)	(0.57)
	06	Water	339.67 a	1.26 a	5.37 a
			(8.14)	(0.02)	(0.12)
		0.25%	442.67 b	1.16 b	3.05 b
			(9.35)	(0.05)	(0.39)
		2%	446.00 b	1.12 b	2.42 c
			(9.21)	(0.07)	(0.12)
300	0075	Water	113.67 a	1.59 a	67.33 a
			(2.08)	(0.04)	(1.46)
		2 %	113.33 a	1.56 a	68.30 a
			(1.53)	(0.05)	(1.30)
	015	Water	178.67 a	1.23 a	35.17 a
			(8.14)	(0.06)	(4.61)
		0.25%	184.50 b	1.24 a	33.53 a
			(4.64)	(0.04)	(3.06)
		2%	193.33 b	1.21 a	28.53 b
			(5.09)	(0.06)	(2.81)
	03	Water	245.67 a	1.38a	19.13 a
			(3.51)	(0.07)	(1.16)
		0.25%	255.83 b	1.28 a	16.13 b
			(4.83)	(0.03)	(1.67)
		2%	262.50 c	1.29 a	14.48 c
			(2.35)	(0.12)	(1.15)
	06	Water	321.33 a	1.35 a	10.43 a
			(8.08)	(0.01)	(0.38)
		0.5 %	345.67 b	1.25 b	7.43 b
			(8.10)	(0.03)	(0.45)
		2 %	356.50 c	1.18 c	6.06 c
			(3.62)	(0.04)	(0.45)
500	0075	Water	93.33 a	1.6 a	79.63 a
			(3.21)	(0.05)	(2.40)
		2%	89.00 a	1.33 a	84.77 a
			(1.00)	(0.28)	(2.80)
	015	Water	142.67 a	1.52 a	52.10 a
			(5.51)	(0.04)	(2.63)
		0.25%	157.33 b	1.33 b	44.67 b
			(3.93)	(0.05)	(2.02)
		2%	162.17 b	1.31 b	42.45 b
			(4.58)	(0.08)	(2.50)
	03	Water	216.33 a	1.33 a	26.23 a
			(1.53)	(0.07)	(1.40)
		0.25%	224.17 b	1.26 b	21.88 b
			(2.93)	(0.06)	(1.62)
		2%	226.33 b	1.19 a	20.25 b
			(3.39)	(0.04)	(1.49)
	06	Water	285.33 a	1.46 a	15.63 a
			(6.43)	(0.05)	(0.31)
		0.25%	291.17 a	1.35 a	12.48 b
			(6.43)	(0.05)	(0.86)
		2%	303.33 b	1.11 a	11.13 c
			(6.25)	(0.43)	(0.40)

[1] Values in parenthesis represent standard deviations

[2] Means in the same column followed by the same letter are not significantly different (p = 0.05) using Ryan's Q test. The test was applied for each orifice size separately.

Table 30. Impact of mineral oil on VMD, span and percentage of drift-prone droplets for injet air inclusion nozzles (Hardi Injet) at a range of pressures [1, 2 & 3].

Pressure (kPa)	**Nozzle size**	**% oil**	**VMD (µm)**	**Span**	**% droplets < 141 µm**
300	015	Water	652.67 a	1.28 a	1.30 a
			(16.07)	(0.02)	(0.10)
		0.25%	599.83 b	1.06 b	1.41 a
			(11.02)	(0.06)	(0.21)
		2%	583.83 b	1.01 b	1.45 a
			(12.19)	(0.07)	(0.19)
	03	Water	725.67 a	1.29 a	1.10 a
			(22.12)	(0.05)	(0.10)
		0.25%	672.17 b	1.25 a	1.00 a
			(23.62)	(0.03)	(0.13)
		2%	651.50 c	1.25 a	1.40 b
			(11.72)	(0.01)	(0.13)
	04	Water	626.67 a	1.29 a	2.63 a
			(101.12)	(0.12)	(2.14)
		0.25%	639.50 a	1.24 a	1.57 a
			(12.68)	(0.06)	(0.29)
		2%	646.50 a	1.24 a	1.67 a
			(16.51)	(0.02)	(0.25)
600	015	Water	463.67 a	1.27 a	3.93 a
			(11.85)	(0.04)	(0.57)
		0.25%	439.50 b	1.06a	4.66 b
			(8.34)	(0.12)	(0.39)
		2%	433.83 b	1.09 a	4.93 b
			(7.30)	(0.16)	(0.50)
	03	Water	547.00 a	1.33 a	2.8 a
			(20.81)	(0.08)	(0.10)
		0.25%	526.00 b	1.11 b	2.97 a
			(12.18)	(0.04)	(0.22)
		2%	514.00 b	1.06 b	3.33 b
			(8.46)	(0.03)	(0.33)
	04	Water	561.33 a	1.33 a	3.37 a
			(4.73)	(0.02)	(0.21)
		0.25%	532.33 b	1.06 b	3.21 a
			(5.28)	(0.02)	(0.17)
		2%	528.17 b	1.09 b	3.85 b
			(10.30)	(0.12)	(0.39)

[1] Values in parenthesis represent standard deviations

[2] Means in the same column followed by the same letter are not significantly different (p = 0.05) using Ryan’s Q test. The test was applied for each orifice size separately.

Table 31. Impact of mineral oil on VMD, span and percentage of drift-prone droplets for ceramic hollow cone nozzles (Hardi 1299) at the range of pressures [1, 2 & 3].

Pressure (kPa)	Nozzle size	% oil	VMD (µm)	Span	% droplets < 141 µm
400	1299-12	Water	139.67 a	1.35 a	54.27 a
			(2.08)	(0.04)	(1.10)
		0.25%	178.83 b	1.01 b	28.83 b
			(3.54)	(2.79)	(1.72)
		2%	179.33 b	1.01 b	29.33 b
			(3.61)	(0.05)	(2.42)
	1299-16	Water	199.33 a	1.32 a	29.33 a
			(7.77)	(0.06)	(3.79)
		0.25%	215.33 b	1.13 b	20.00 b
			(4.037)	(0.06)	(1.41)
		2%	223.50 c	1.02 c	17.00 c
			(2.25)	(0.02)	(0.89)
	1299-20	Water	258.33 a	1.38 a	19.33 a
			(5.03)	(0.05)	(1.53)
		0.25%	276.83 b	1.24 b	13.33 b
			(2.79)	(2.72)	(0.82)
		2%	277.00 b	1.18 c	12.17 b
			(4.60)	(0.02)	(0.98)
800	1299-12	Water	125.00 a	1.37 a	62.83 a
			(3.61)	(0.01)	(2.02)
		0.25%	146.83 b	1.13 b	50.83 b
			(1.47)	(0.04)	(1.83)
		2 %	147.18 b	1.14 b	49.83 b
			(2.32)	(0.02)	(1.94)
	1299-16	Water	164.67 a	1.34a	42.00 a
			(2.31)	(0.01)	(1.00)
		0.25%	177.67 b	1.12 b	34.67 b
			(2.58)	(0.02)	(1.37)
		2%	181.33 c	1.09 b	31.83 c
			(1.37)	(0.03)	(0.75)
	1299-20	Water	203.00 a	1.46 a	32.00 a
			(1.73)	(0.02)	(1.00)
		0.25%	209.00 b	1.28 b	27.00 b
			(2.83)	(0.01)	(0.89)
		2%	210.50 b	1.26 b	25.50 c
			(2.81)	(0.06)	(0.84)
1200	1299-12	Water	118.33 a	1.35a	66.93 a
			(3.21)	(0.05)	(2.00)
		0.25%	126.67 b	1.27 a	63.67 b
			(1.75)	(0.06)	(1.21)
		2%	128.50 b	1.24 a	63.50 b
			(1.38)	(0.04)	(1.05)
	1299-16	Water	149.00 a	1.36 a	49.33 a
			(2.65)	(0.04)	(1.15)
		0.25%	155.67 b	1.25b	45.33 b
			(0.82)	(0.03)	(0.52)
		2%	156.83 b	1.23 b	44.33 c
			(0.75)	(0.02)	(0.52)
	1299-20	Water	172.67 a	1.57 a	40.67 a
			(3.21)	(0.07)	(2.08)
		0.25	173.50 a	1.43 b	39.00 ab
			(1.38)	(0.06)	(0.63)
		2%	174.17 a	1.38 b	38.33 b
			(2.14)	(0.05)	(0.81)

[1] Values in parenthesis represent standard deviations

[2] Means in the same column followed by the same letter are not significantly different (p = 0.05) using Ryan's Q test. The test was applied for each orifice size separately.

Table 32. Comparison of drift for various sizes of flat fan, injet and hollow cone nozzles tested with water and 2% agricultural mineral oil. Flat fan and injet nozzles were tested at 300 kPa, and hollow cone nozzles at 500 kPa. Wind speed was 4.5 m/s. Nozzles were 35 cm above ground [1,2 &3].

Nozzle type	Nozzle size	% oil	5 cm above ground	15 cm above ground	25 cm above ground	30 cm above ground
Hardi flat fan ISO 110	0075	Water	194.89[1] a	209.92 a	72.26 a	12.55 a
			(13.84)	(12.20)	(24.08)	(3.25)
		2%	190.12 a	225.78 a	99.48 a	16.64 a
			(41.50)	(44.92)	(26.26)	(5.02)
	015	Water	169.49 a	179.31 a	19.61 a	4.84 a
			(17.52)	(23.70)	(5.27)	(1.01)
		2%	157.74 a	170.94 a	19.47 a	7.14 a
			(22.67)	(19.23)	(6.57)	(2.21)
	03	Water	207.05 a	147.67 a	25.06 a	7.33 a
			(23.02)	(23.21)	(14.20)	(5.01)
		2%	124.63 b	115.16 b	10.06 a	4.22 a
			(26.06)	(20.10)	(3.66)	(0.64)
Hardi injet	015	Water	25.59 a	24.21 a	15.60 a	13.98 a
			(1.2)	(3.27)	(3.26)	(4.18)
		2%	10.24 b	11.40 b	6.28 b	3.63 b
			(0.31)	(0.94)	(1.15)	(0.64)
	03	Water	18.90 a	16.53 a	6.86 a	5.68 a
			(0.28)	(1.04)	(0.97)	(1.37)
		2%	15.45 b	16.28 a	4.82 b	5.33 a
			(1.14)	(0.85)	(0.85)	(1.7)
Hardi ceramic hollow cone	1299-12	Water	343.47 a	292.35 a	180.10 a	125.98 a
			(18.74)	(75.44)	(34.31)	(151.35)
		2%	150.02 b	134.48 b	94.38 b	43.62 a
			(79.83)	(67.62)	(38.19)	(13.71)
	1299-20	Water	77.33 a	78.05 a	83.65 a	91.15 a
			(11.23)	(12.69)	(8.85)	(9.37)
		2%	68.09 b	57.99 b	55.40 b	64.54 b
			(16.67)	(10.46)	(3.22)	(5.41)

[1] Values in parenthesis represent standard deviations

[2] Means in the same column followed by the same letter are not significantly different ($p = 0.05$) using Ryan's Q test. The test was applied for each orifice size separately.

[3] Values are colour intensity as measured with a Perkin Elmer LS2 spectrofluorimeter.

Table 33. Comparison of oil deposits ($\mu g/cm^2$) on cotton leaves after application of 2 L oil/ha sprays applied at 75 L and 150 L/ha by conventional and air-assisted groundrigs, and at 30 L and 60 L/ha by helicopter.

Treatment	Upper canopy $\mu g/cm^2$	Middle canopy $\mu g/cm^2$	Average $\mu g/cm^2$
Hardi Twin 75 L/ha	4.70	4.36	4.52 [a]
	(0.58)	(0.48)	(0.37)
Hardi Twin 150 L/ha	4.47	3.60	4.04 [a]
	(1.93)	(0.44)	(0.30)
Hardi Auto-Track 75 L/ha	5.07	6.52	5.79 [b]
	(0.51)	(0.57)	(0.39)
Hardi Auto-Track 150 L/ha	4.56	3.53	4.04 [a]
	(0.41)	(0.47)	(0.32)
Helicopter 30 L/ha	3.93	3.45	3.65 [a]
	(0.34)	(0.24)	(0.42)
Helicopter 60 L/ha	3.62	3.44	3.53 [a]
	(0.38)	(0.71)	(0.42)

Table 34. Comparison of droplet numbers on water sensitive papers (attached to cotton leaves) after application of 2 L oil/ha sprays applied at 75 L and 150 L/ha by conventional and air-assisted groundrigs, and at 30 L and 60 L/ha by helicopter [1, 2].

Treatment	**Leaf surface**	**Upper canopy (droplets/cm^2)**	**Middle canopy (droplets/cm^2)**	**Average (droplets/cm^2)**
Hardi Twin 75 L/ha	Adaxial	53.15	36.19	44.67^{AB}
		(11.87)	(6.01)	(6.68)
	Abaxial	44.92	33.27	39.09^{a}
		(12.39)	(7.87)	(7.32)
	Average	49.03	34.73	41.88
		(8.53)	(4.92)	(4.94)
Hardi Twin 150 L/ha	Adaxial	57.49	64.77	61.13^{A}
		(5.03)	(6.68)	(4.18)
	Abaxial	33.83	13.72	23.78^{a}
		(6.05)	(2.76)	(3.49)
	Average	45.66	39.25	42.46
		(4.13)	(4.60)	(3.09)
Hardi Auto-Track 75 L/ha	Adaxial	56.83	44.97	50.90^{A}
		(7.62)	(6.50)	(5.02)
	Abaxial	31.47	16.40	23.85^{a}
		(6.98)	(3.97)	(4.05)
	Average	44.48	30.88	37.64
		(5.35)	(4.15)	(3.41)
Hardi Auto-Track 150 L/ha	Adaxial	49.88	57.28	53.58^{A}
		(4.70)	(5.73)	(3.71)
	Abaxial	23.76	15.93	19.85^{a}
		(6.42)	(3.94)	(3.77)
	Average	36.82	36.61	36.71
		(4.22)	(4.18)	(2.96)
Helicopter 30 L/ha	Adaxial	20.23	10.27	15.45^{C}
		(3.15)	(2.20)	(2.02)
	Abaxial	5.09	4.26	4.69^{c}
		(0.90)	(1.54)	(0.87)
	Average	12.66	7.26	10.07
		(1.84)	(1.38)	(1.18)
Helicopter 60 L/ha	Adaxial	36.33	14.03	25.18^{BC}
		(4.70)	(2.35)	(2.90)
	Abaxial	14.98	2.62	8.80^{bc}
		(2.72)	(0.64)	(1.55)
	Average	25.65	8.33	16.99
		(2.95)	(1.37)	(1.76)

[1] Values in parenthesis represent standard deviations

[2] Means in the same column followed by the same letter are not significantly different ($p = 0.05$). Uppercase letters refer to comparisons for adaxial surfaces and lowercase letters refer to comparisons for abaxial surfaces. Comparisons were made using the Dunnett T3 test.

Table 35. Comparison of areas on water sensitive papers (attached to cotton leaves) covered by spray deposits after application of 2 L oil/ha sprays applied at 75 L and 150 L/ha by conventional and air-assisted groundrigs, and at 30 L and 60 L/ha by helicopter [1, 2].

Treatment	Leaf surface	Upper canopy (% area covered)	Middle canopy (% area covered)	Average (% area covered)
Hardi Twin 75 L/ha	Adaxial	7.58	2.92	5.25^{A}
		(1.06)	(0.48)	(0.63)
	Abaxial	3.23	1.30	2.26^{a}
		(1.04)	(0.23)	(0.54)
	Average	5.40	2.11	3.75
		(0.78)	(0.28)	(0.43)
Hardi Twin 150 L/ha	Adaxial	14.58	8.88	11.73^{B}
		(1.42)	(0.90)	(0.90)
	Abaxial	1.85	0.68	1.26^{b}
		(0.66)	(0.41)	(0.39)
	Average	8.21	4.78	6.50
		(1.06)	(0.68)	(0.64)
Hardi Auto-Track 75 L/ha	Adaxial	5.06	5.27	5.17^{A}
		(0.81)	(0.96)	(0.62)
	Abaxial	3.95	1.28	2.60^{a}
		(1.16)	(0.33)	(0.61)
	Average	4.52	3.30	3.91
		(0.70)	(0.56)	(0.45)
Hardi Auto-Track 150 L/ha	Adaxial	10.70	9.13	9.92^{B}
		(1.21)	(1.20)	(0.85)
	Abaxial	3.87	1.34	2.61^{a}
		(1.08)	(0.42)	(0.59)
	Average	7.29	5.24	6.26
		(0.89)	(0.77)	(0.60)
Helicopter 30 L/ha	Adaxial	2.27	1.06	1.69^{C}
		(0.31)	(0.19)	(0.20)
	Abaxial	0.21	0.10	0.15^{b}
		(0.05)	(0.02)	(0.03)
	Average	1.24	0.58	0.92
		(0.19)	(0.11)	(0.11)
Helicopter 60 L/ha	Adaxial	6.11	1.64	3.88^{A}
		(0.78)	(0.26)	(0.48)
	Abaxial	1.69	0.18	0.93^{b}
		(0.48)	(0.10)	(0.26)
	Average	3.90	0.91	2.49
		(0.52)	(0.16)	(0.30)

[1] Values in parenthesis represent standard deviations

[2] Means in the same column followed by the same letter are not significantly different ($p = 0.05$). Uppercase letters refer to comparisons for adaxial surfaces and lowercase letters refer to comparisons for abaxial surfaces. Comparisons were made using the Dunnett T3 test.

5. Provide a conclusion as to research outcomes compared with objectives. What are the "take home messages"?

Part A. Impact of Selected Mineral Oils on Key Pests and their Natural Enemies, and Phytotoxicity.

Suppression of Helicoverpa *oviposition*. Our research demonstrated that mineral oil sprays can be used to significantly reduce oviposition by *Helicoverpa*. However, pest pressure in both 2001/2002 and 2002/2003 was low, and the extent of suppression that we believe would occur with higher population pressures cannot be predicted. Nevertheless, we believe, on the basis of other recent NSW Agriculture research on cotton, and UWS research on tomatoes (Singh *et al*. 2000), that the impact of sprays would be significant. Populations were too low in 2001/2002 to derive relationships between median *n*C*y* values of the three products (*n*C21, *n*C23 and *n*C24) tested, and too low in 2002/2003 to determine a relationship between oviposition suppression and oil rates/ha (deposits/cm^2). Research currently being undertaken by a PhD student at UWS strongly suggests that oviposition suppression increases with increasing median *n*C*y* values (i.e. *n*C21 oils are less effective than *n*C24 oils), and we would normally anticipate suppression to be inversely related to increasing deposits. Our ability to detect differences between treatments in 2002/2003 was clearly enhanced by increased sampling rigour; sampling 4 sets of 20 terminals per replicate was more effective than sampling single 1-m of row lengths.

In conclusion, it is clear that mineral oils can be used in cotton to suppress *Helicoverpa*. oviposition, either alone or in with other pesticides. Our results suggest that this can be achieved at spray volumes acceptable for use with groundrigs, and at 60 L/ha with helicopters (our use of a helicopter at Norwood in 2002/2003 went beyond our initial aims of applying oils only up to crop closure and we obtained strong evidence in these tthat it should be feasible to apply sprays by helicopter at 30 L/ha). We would anticipate the effectiveness to sprays would vary with plant growth rates and application frequency, and that at a given frequency sprays could be more effective in NSW cotton regions than in much warmer areas in Queensland (e.g., Emerald)

We have yet to determine how oil deposits affect adult *Helicoverpa* females. In 2002/2003 e applied 20, 40 and 60 μg oil/cm^2 of flat surface (ground surface). Deposits on plants would have been lower in each instance and more variable as plants grew. As such deposits are unlikely (in our opinion) to have any impact on plant physiology that would influence behaviour we assume, at this point, that tarsal sensilla are capable of detecting oil and that detection of deposits by only a few sensilla, perhaps on only one tarsus, is required to elicit a response that leads females to continue searching for suitable oviposition sites. We speculate that successive encounters then lead to reduced oviposition.

Impact on Helicoverpa *larvae*. We could not detect any impact of oil treatments on *Helicoverpa* larvae in either 2001/2002 or 2002/2003. Even with higher population densities a significant direct impact of oils on larval mortality would be unlikely given the volumes of spray applied. However, it is possible that indirect effects on larval mortality might have been detectable at higher population densities if deposits interfere with feeding behaviour. Nevertheless, the chance of this occurring at industry acceptable volumes of spray and oil per hectare would be low.

Impact on sucking pests, thrips and mites. The oil treatments had no impact on green mirid, jassids and thrips. Populations of aphids and mites were too low to assess accurately. These results were disappointing and in some instances limited, in addition to low aphid and mite densities, by our need to limit sprays volumes/ha to industry standards.

Beneficial arthropods. Counts in 2001/2002 were too low or variable to analyse. With D-vac sampling in 2002/2003 we detected no significant impact of sprayed treatments on predatory coccinellids, damsel bug, big-eyed bug or brown lacewing. We did detect detrimental effects on green lacewing and red and blue beetle in these samples but trends and their implications were not clear, and we could not determine if the effects were direct (i.e., mortality caused by the treatments) or indirect (i.e., related to prey densities). For green lacewing, the 4 L/ha oil treatment had a significant detrimental impact on numbers but oil at 6 L/ha did not, even though numbers in the latter and the conventional treatment appeared relatively low compared to the control and 2 L oil/ha treatment. For red and blue beetle, numbers in the 6 L oil/ha treatment and the conventional pesticide treatment were significantly lower than in the 4 L oil/ha treatment, but not lower than in the 2 L oil/ha and unsprayed control treatments. We did not determine the impact of treatments on parasitoids or on soil fauna for which recent studies in citrus orchards showed that the impact of mineral oils on beneficial arthropods was negligible compared to a carbamate (carbaryl) and an organophosphate (methidathion) (Liang 2002).

Yields and pesticide costs. For 2002-2003, when we incorporated an unsprayed control in the experiment and increased sampling rigour, there was no significant difference between treatment yields even at 6 L oil/ha; the lowest yield was recorded in the control. This suggests that application of the oils and pesticides was not warranted, but use of larger areas may have led us to detect differences between treatments (our control replicates may have been influenced by surrounding areas). In this year, oil treatments were applied on 8 occasions and other pesticides (Gemstar twice, and Affirm once) were incorporated in the oil treatments on 3 of these dates. Based on current prices, the total cost of the 2 L, 4 L and 6 L/ha treatments was $154, $210 and $266/ha respectively. The cost of pesticides in the conventional pesticide program, in which sprays were applied on 7 occasions, was $484/ha. Clearly, use of mineral oils is a cost-effective means of improving management of *Helicoverpa*.

Sampling protocols. Our results at Norwood in 2002/2003 clearly indicated that single 1-m row lengths are not suitable for determining differences between treatments in these types of experiments. Furthermore, sampling based on terminals (or whole plants at the beginning of the season) was faster and, particularly given increased sampling rigour, more cost effective. We only detected differences in arthropod populations when we sampled two 1-m row lengths or 80 terminals (20 terminals in each of 4 subplots) per replicate (plot).

Part B. Spray Application Technology

Laboratory evaluation of conventional groundrig nozzle spectra and drift.

1. The impact of *n*C24 AMO on droplet spectra and the spray drift is highly dependent on the nozzle type, orifice size and the pressure at which the liquid is applied.
2. Increasing AMO concentration in sprays can, in some instances, increase the impact of the oil on droplet spectra but emulsifier concentration in the AMO had no impact.
3. For flat fan and hollow cone nozzles, oil tended to increase droplet size and reduce the percentage of drift-prone droplets. However, for injet nozzles, reduced droplet size and increased proportions of drift-prone droplets were recorded.
4. Drift reduction was more pronounced for hollow cone nozzles than for flat fan nozzles: for the latter it was significant only for the larger orifice size (03). The impact of oil on drift from injet nozzles is unlikely to have practical implications.
5. Recommendations for use of HMOs and AMOs for reducing spray drift should be based on nozzle type, orifice size and operating pressure.

Field evaluation of spray deposit and coverage.

1. Satisfactory canopy penetration was achieved with groundrigs at 75 L and 150 L/ha, and by helicopter at 30 L and 60 L/ha.
2. Increases in spray volume achieved by increasing droplet size did not lead to a clear improvement in leaf coverage and did not improve oil deposition; relatively lower oil deposition by the conventional groundrig sprayer at 150 L/ha may have been due to relatively greater run-off of sprays applied in this treatment.

3. Air-assistance (Hardi Twin) did not improve canopy penetration or oil deposition on the abaxial surfaces of leaves.
4. Helicopter application, even at industry standard 30 L/ha, achieved satisfactory canopy penetration and oil deposition, but the surface area of leaf covered by sprays (aqueous oil emulsion) was lower.
5. Higher volume in this experiment was achieved using different nozzle sizes. Further work should evaluate the effect of different volumes by increasing pressure and /or reducing tractor speed while keeping the nozzle size constant. Different settings for the air assisted sprayer, which vary the angle and quantity of air, should also be tested

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6. Detail how your research has addressed the Corporation's three Outputs - Economic, Environmental and Social?

The research addressed these outputs by focusing on the use of relatively low cost 'pesticides' that pose no risk to the environment and human health, and to which resistance has not been recorded in more than 100 years.

7. Provide a summary of the project ensuring the following areas are addressed:

a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.)

The project did not lead to patents or licences, or to improvements in the formulation of mineral oil products.

b) other information developed from research (eg discoveries in methodology, equipment design, etc.)

Project results will improve spray application efficacy from groundrigs and helicopters.

c) are changes to the Intellectual Property register required?

No.

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

(a) to further develop or to exploit the project technology.

Although current laboratory PhD studies indicate a relationship between increasing median *n*C*y* values and suppression of *Helicoverpa* oviposition we need to confirm this under field conditions with medium to high pest pressure as we were not able to do so with low pest pressure in 2001/2002.

We also need to undertake further research on the use helicopters and fixed-wing aircraft to apply sprays and to focus this research on the impact of relationships between spray volumes, oil volumes and their impact on *Helicoverpa* oviposition. These experiments will require at least medium pest pressure.

(b) for the future presentation and dissemination of the project outcomes.

We plan to present the results of this project at field days during 2004.

(c) for future research.

We would welcome an opportunity to repeat our studies on the impact of sprays on *Helicoverpa* populations in seasons with higher pest pressures than we encountered in 2001/2002 and 2002/2003. We plan to apply to CRDC for further funding when the industry recovers from the impact of drought (but we cannot predict seasonal pressures).

We plan to determine benefits of using mineral oils to enhance the efficacy of biological and other pesticides. Such research will include studies on the impact of oils on spray deposition (oils will enhance deposition) and the effectiveness of deposits (oils enhance the effectiveness on many synthetic pesticides, allowing the latter to be used in many instances at reduced rates: see Rae 2002).

We also plan to evaluate the use of oils formulated with environmentally acceptable ‘sunscreens’ to enhance the effectiveness of UV-sensitive pesticides, particularly NPV and *Bt* formulations. We plan to commence laboratory studies on formulations in 2004/2005.

Our work on mineral oils and spray application technology will continue beyond this project as part of a PhD thesis.

We do not plan, at this point, to continue research directly on sucking pests, thrips and mites as the results we obtained with the spray volumes used in 2001-2002 and 2002-2003 were not promising. Nevertheless, in any future work we will continue to assess the impact of sprays on these pests and their natural enemies.

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

We plan to summarise the results related to the effects of mineral oil deposits on *Helicoverpa* oviposition for publication in the Australian Cotton Grower. We plan to summarise and publish the results of our studies on spray application in the Australian Cotton Grower and in a refereed journal.

10. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry or the Australian community.

The results should lead to widespread use mineral oils, either alone or in combination with other chemicals, to reduce oviposition by *Helicoverpa*.

The financial implications of the technology are difficult determine at this point as impact of the technology needs to be tested under higher pest pressures to establish yield differences between sprayed treatments and unsprayed controls. However, the relatively low cost of mineral oils compared to most other pesticides and the impact of oil deposits on *Helicoverpa* oviposition suggests that their inclusion in spray programs would have significant economic benefits for conventional and *Bt* cotton.

Part 4 – Final Report Executive Summary

Provide a one page Summary of your research that is not commercial in confidence, and that can be published on the World Wide Web. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

Research at Narrabri and Moree in two low pest pressure seasons (2001/2002 and 2002/2003) demonstrated that mineral oils can be used to significantly suppress oviposition by *Helicoverpa*. However, we could not demonstrate relationships between volumes of oil applied per hectare and levels of oviposition suppression. We also could not demonstrate relationships between a key distillation property (median equivalent *n*-paraffin carbon number values) of mineral oils and oviposition suppression although non-project laboratory studies suggest that suppression increases with increasing median equivalent *n*-paraffin carbon number values (*n*C21 to *n*C24). Application of an *nC24* product (SACOA BioPest™) at 2, 4 and 6 L/ha did not reduce yields (an indicator of chronic phytotoxicity) and no symptoms of acute phytotoxicity (e.g., burns) were observed. We did not demonstrate any significant impact of mineral oil sprays on *Helicoverpa* larvae or on key sucking pests (e.g., green mirid) in field studies. Populations of mites and aphids were too low to assess the impact of sprays adequately. The results suggested possible impacts of mineral oil sprays on some predators but the significant effects when recorded (for green lacewing and red and blue beetle) were not related to rates of oil per hectare.

The implications of these finding for cotton industry are that we are confident, based on this and other research, that horticultural and agricultural mineral oils (products that meet internationally recommended standards) can be used alone or in combination with other pesticides to help manage *Helicoverpa* in cotton, and that these products can be used a rates of 2-6 L/ha without causing phytotoxicity that can under some circumstances lead to reduced yields.

Our work on droplet spectra and drift that recommendations for use of oil to reduce drift from groundrig sprayers should be based on nozzle type, orifice size and operating pressure. Drift reduction was more pronounced for hollow cone nozzles than for flat fan nozzles: for the latter it was significant only for the larger orifice size nozzles (03).

In our comparison of groundrig sprayers and application of sprays by helicopter canopy penetration was achieved with groundrigs at 75 L and 150 L/ha, and by helicopter at 30 L and

60 L/ha. Increases in spray volume achieved by increasing droplet size did not lead to a clear improvement in leaf coverage and did not improve oil deposition; lower oil deposition by the conventional groundrig sprayer at 150 L/ha may have been due to relatively greater run-off of sprays applied in this treatment. Air-assistance (Hardi Twin) did not improve canopy penetration or oil deposition on the abaxial surfaces of leaves. Helicopter application, even at the industry standard 30 L/ha, achieved satisfactory canopy penetration and oil deposition, but the area of leaf surface covered by spray (an aqueous emulsion) was lower. Higher volume in this experiment was achieved using different nozzle sizes. Further work should evaluate the effect of different volumes by increasing pressure and /or reducing tractor speed while keeping the nozzle size constant. Different settings for the air assisted sprayer, which vary the angle and quantity of air, should also be tested