PETROLEUM SPRAY OILS AND TOMATO INTEGRATED PEST AND DISEASE MANAGEMENT IN SOUTHERN AUSTRALIA

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Summary

Control of a range of pests of fresh and processing tomatoes by petroleum spray oils was compared with conventional synthetic pesticide-based programs used by commercial farmers. In an initial experiment on fresh tomatoes a significant negative exponential relationship was found between the level of tomato russet mite infestations and the concentration of petroleum spray oil applied to run-off (0.5–2% v/v). Leaf area declined as infestations increased. Some stunting of growth was apparent after 8–9 weekly 2% sprays but no other visible signs of phytotoxicity were observed after 11 sprays. In a subsequent larger fresh tomato experiment control of budworms, green peach aphid, greenhouse whitefly and two-spotted mite was significantly better in a 1% oil treatment than in a conventional pesticide treatment. However, Queensland fruit fly was not controlled by the oil and yields in oil treated plots were lower than in conventionally treated plots. Sprays in each treatment were applied at volumes ranging from 500 to 2,800 L/ha as plants grew. In the processing tomato experiments, yields, fruit quality (total soluble solids and acidity), and control of budworms (mostly *Helicoverpa armigera* Hübner), thrips, leafhoppers, greenhouse whitefly, green peach aphid and two-spotted mite generally either equalled or were significantly better in 1% oil treatments (250 to >1,800 L of spray/ha) than in conventional pesticide treatments (110 to 500 L of spray/ha). Significant relationships were derived for rotten fruit versus yield of ripe tomatoes and budworm damage. A purpose-built fan-assisted sprayer with an electric motor was used to apply the oil sprays in the processing tomato experiments. Spray coverage with this machine was significantly better than that given by broadacre air-assisted and boom sprayers typically used in the industry. A comparison of pesticide and application costs indicated that an oil-based pest and disease management program would be cheaper than a synthetic pesticide program in some instances but more expensive in others. The sustainability and other benefits of oil-based IPDM are discussed in relation to these costs.

INTRODUCTION

The most common pests and diseases of field-grown tomatoes in southern Australia include budworms (*Helicoverpa armigera* Hübner and *H. punctigera* Wallengren), tomato thrips (*Frankliniella schultzei* (Trybom)), plague thrips (*Thrips imaginis* Bagnall), common brown leafhopper (*Orosius argentatus* (Evans)), vegetable or green leafhopper (*Austroasca* viridigrisea (Paoli)), greenhouse whitefly (*Trialeurodes vaporariorum* (Westwood)), green peach aphid (*Myzus persicae* (Sulzer)), Queensland fruit fly (*Bactrocera tryoni* (Froggatt)), two-spotted mite (*Tetranychus urticae* Koch), tomato russet mite (*Aculops lycopersici* (Massee)), powdery mildews (e.g. *Oidium* sp. and *Leveillula taurica* (Lév.) Arnaud), bacterial speck (*Pseudomonas syringae* pv *tomato* (Okabe) Young, Dye and Wilkie) and tomato spotted wilt virus (TSWV) (Wicks 1981, Hely *et al.* 1982, Hamilton and Toffolon 1987).

Control of these pests relies on the use of synthetic pesticides (Hely *et al.* 1982, Smith *et al.* 1996) with most insecticides used by the processing industry targeted at budworms (Smith *et al.* 1996), the most destructive pests of tomatoes in Australia (Hamilton and Macdonald 1990). Spraying at 7–14 d intervals has been common practice for control of budworms since the 1940s (Hamilton and Macdonald 1990). According to Smith *et al.* (1996) the average number of insecticide sprays applied annually on surveyed farms in the early 1990s was 5.7 (range 3–9) in monitored crops and 7.6 (range 4–12) in conventional crops. Fungicides were applied 6–8 times annually in southern New South Wales (NSW) and Victoria but less frequently in northern NSW (Smith *et al.* 1996). The Australian processing tomato industry recognises the need for economic and environmentally sustainable integrated pest and disease management (IPDM) programs (Anonymous 1996). IPDM is also a key objective of a national strategy for the management of pesticides (Anonymous 1998a).

Petroleum spray oils (PSOs, also called mineral, white, summer, superior and horticultural oils) have been used for several decades to control a range of pests of horticultural crops, particularly citrus, but less commonly for pests of vegetables. They are organic products that offer several advantages over synthetic pesticides. Due to low mammalian toxicity they can be handled with minimal protective clothing such as overalls and goggles; they cause limited disruption of natural enemy activity; they rarely stimulate pest outbreaks; pests do not develop resistance; and spray deposits are not environmentally damaging (Beattie 1991). Traditionally they have been used to drown pests such as mites, armoured scales and young soft scales, a mode of action which limited their potential use until recent renewed interest in their fungicidal and fungistatic properties (Northover and Schneider 1996; Nicetic *et al.* in press) and their influence on arthropod behaviour (Liu and Stansly 1995a,c; Mensah *et al.* 1995; Mensah 1996; Beattie *et al.* 1995; Rae *et al.* 1996, 1997; Beattie and Smith 1997).

We report the results of five experiments that evaluated PSOs for inclusion in sustainable IPDM programs for field-grown fresh (two experiments) and processing tomatoes (three experiments) in southern Australia. Five different locations in NSW were used between 1993–1997. Because thorough spray application is required for PSOs to be effective, part of the work reported here deals with a novel electric fan-assisted horizontal boom-mounted sprayer used in the processing tomato experiments, and modifications to conventional spray equipment. The first of the fresh tomato experiments was an informal small-scale study undertaken primarily to observe the effects of multiple sprays on leaves, particularly acute phytotoxicity manifested as burns, and on pests and diseases. The second compared PSO-based spray programs with a conventional pesticide program and measured effects on yields, fruit quality and the incidence of pests. The processing tomato experiments were undertaken over consecutive years and measured effects on yields, fruit quality and the incidence of pests. PSO-based programs were compared with conventional spray programs and, in one experiment, an unsprayed control. Progressive improvements were made to the electric fan-assisted sprayer over the three years. A predatory insect attractant and budworm oviposition deterrent developed for use in cotton (Mensah 1996, 1997) was included in two of the processing tomato experiments.

MATERIALS AND METHODS

Field sites, climate and weather

The two fresh tomato sites were at NSW Agriculture's Biological and Chemical Research Institute (BCRI) at Rydalmere in autumn 1993, and a private farm at Peats Ridge in 1996/97. Both locations were in the Sydney and nearby Gosford coastal districts with average long-term minimum and maximum temperatures of 13 and 22°C respectively, and 1,200 mm of annual rainfall. The three processing tomato sites were on private farms at Darlington Point in 1994/95, Cowra in 1995/96 and Gooloogong in 1996/97. These three locations are west of the Great Dividing Range. Based on records from nearby Leeton, Darlington Point has an annual rainfall of 436 mm and mean minimum and maximum daily temperatures of 10.3 and 23°C. Cowra and Gooloogong have similar climates with average rainfall about 610 mm and mean minimum and maximum daily temperatures of 8.1 and 24.1°C. The latitude and longitude of each location and summarised Australian Bureau of Meteorology weather records for the respective growing seasons are presented in Table 1.

Plant cultivation

BCRI. Fresh tomato seedlings (cv. *Gross Lisse*) were planted 350–400 mm apart in four 15 m long beds in early March 1993. The beds were slightly raised and their centres were 1.5 m apart. Plants were individually staked and tied. Overhead sprinklers were used for watering. Weeds were removed regularly with a hoe.

Darlington Point. Processing tomato seedlings (cv. *Alta*) were planted in 500 mm wide raised beds on 14 November 1994. Row centres were 1.8 m apart and two rows of seedlings were planted in each bed. Furrow irrigation was used for watering. Weeds were controlled in interbed spaces on 7 February 1995 with Sertin (600 mL of 186 g/L product/100 L water) plus C23 Ampol D-C-Tron NR petroleum spray oil (500 mL of product/100 L water) applied at <250 L of spray/ha using a Hardi broadacre boom sprayer modified for the purpose.

Table 1. Summary of weather records for growing seasons (1 December to May 30) and long-term averages (in brackets) for the same intervals.

Location and season	Latitude and longitude	Average minimum °C	Average maximum °C	Highest °C	Average rainfall (mm)
Fresh tomatoes					
Peats Ridge 1996/97	33°31′ S 151°24′ E	13.5 (13.8)	24.0 (23.9)	35.0	97.1 (126.3)
Rydalmere 1992/93	33°49′ S 151°02′ E	—	—	—	—
Processing tomatoes					
Gooloogong 1996/97	33°36′ S 148°27′ E	13.2 (11.5)	27.5 (27.1)	39.7	37.1 (53.0)
Cowra 1995/96	33°90′ S 148°70′ E	12.0 (11.5)	25.7 (27.1)	40.0	44.8 (53.0)
Darlington Point 1994/95	34°34′ S 146°01′ E	13.6 (13.7)	27.1 (27.1)	43.2	39.2 (34.1)

Cowra. Processing tomato seedlings (cv. *UC 82B*) were planted in 500 mm wide raised beds on 1 November 1995. Row centres were 1.8 m apart and one row of seedlings was planted in each bed. Furrow irrigation was used for watering. Weed control was done manually with hoes, or with a cultivator. An imidacloprid (Gaucho: 2 mL of 600 g/L product/ 100 g seed) seed treatment was applied to all beds at planting for control of thrips and aphids during November.

Gooloogong. Processing tomato seedlings (cv. XPH 12047) were planted in 500 mm wide raised beds on 25 November 1996. Row centres were 1.8 m apart and one row of seedlings was planted in each bed. The plants were watered using overhead sprinklers. The grower's management procedures were used for fertiliser application and weed control. This involved application of sprays containing Sertin (600 mL/100 L water) and C24 Ampol D-C-Tron Plus (500 mL/100 L water) at rates of <250 L of spray/ha to interbed spaces on 15 January and 22 February 1997 using a modified Hardi broadacre boom (HBB) sprayer.

Peats Ridge. Fresh tomato seedlings (cv. Red Mountain) were planted on 17 December 1996 at 350 mm spacings within 60-m long trellised rows. The distance between the centre of each row was 2.6 m. The grower's management procedures for fertiliser application and weed control were used. The latter involved the application of sprays containing Sertin (750 mL/100 L of water) to interbed spaces on 10 January 1997 using a modified airblast sprayer.

Pesticides

The pesticides used at Darlington Point, Cowra, Gooloogong and Peats Ridge are listed in Tables 2–5. Three PSOs were used: C21 Caltex Lovis at BCRI, C23 Ampol D-C-Tron NR at Darlington Point, and C24 Ampol D-C-Tron Plus at Cowra, Gooloogong and Peats Ridge. (The C21–24 designations refer to mean *n*-paraffin carbon number equivalents (see Furness *et al.* 1987) which we use to characterise the distillation temperatures of the oils used in the experiments). Other details are given in Appendix Table 1. Envirofeast (Tables 2 and 3) is a mixture of complex carbohydrates and protein supplements (Mensah 1997).

Treatments and spray application

BCRI. Five treatments comprising a water-sprayed control and four Caltex Lovis treatments (0.5, 1, 1.5 and 2% v/v) were applied. Each treatment comprised four replicates of six plants in a randomised complete block design. Each treatment was sprayed weekly 11 times using a Chapin 2179, 9 L compressed-air sprayer equipped with Rega 031 fan-nozzles. The unit was shaken vigorously before each oil-based replicate was sprayed. All plants were sprayed methodically in an identical manner during downward and upward vertical passes with the nozzle directed to ensure run-off on upper and lower leaf surfaces. A portable plastic screen was used to prevent spray drift.

Darlington Point. There were three treatments (Table 2); conventional pesticides applied with a Hardi Mini Variant air-assisted sprayer (HMV), conventional pesticides applied with a prototype fan-assisted sprayer (FAS) designed at the South Australian Research and Development Institute's Loxton Research Centre, and a D-C-Tron NR and Envirofeast based program applied with the fan-assisted sprayer. Each treatment comprised three 25 m long and 5.4–m wide replicates in a completely randomised design. An esfenvalerate and mancozeb spray (Table 2) on 7 February 1995 was applied by the grower to all plots using the Hardi sprayer. The methamidaphos sprays on 13 and 30 December 1994 were inadvertently applied at lower than recommended rates.

The HMV sprayer was operated at 6–8 km/h with the spray tank pressurised to 600 kPa. The boom was fitted with five number 16 jets for the first four sprays and five number 20 jets for the rest. The FAS was configured and operated as described in the Appendix.

Cowra. There were eight treatments (Table 3). These compared an unsprayed control with four 1% oil spray treatments applied at a range of volumes/ha, a 1% oil plus Envirofeast treatment (with spray volumes increasing during the season), and conventional pesticides applied with either a conventional HBB or a modified version of the prototype FAS previously used at Darlington Point. The experiment was a completely randomised block design with four 50 m long and 6 m wide replicates/ treatment. Sprays were applied on 5 (1% oil treatments only) and 12 December 1995, and 12 and 31 January, 15 February, and 12 and 22 March (oil treatment only on last occasion) 1996. Sprays coincided with the seedling stage, the vegetative stage, flower initiation, flowering, fruit set, fruit growth and fruit ripening.

The FAS was configured and operated as described in the Appendix. The grower's HBB sprayer was operated at 6–9 km/h. The 12 m boom was fitted with number 20 jets at 1.3 m intervals for the first four sprays, and number 20 jets and number 16 drop-nozzle jets at 1.3 m intervals for the other applications. Five beds were sprayed simultaneously.

Table 2. Darlington Point treatments.

Date and crop stage	Target pests and diseases	Treatment[a,b] (chemical rates/100 L of water and spray volumes/ha)		
		Pesticides with HMV	Pesticides with FAS	D-C-Tron NR and Envirofeast with FAS[c]
13 Dec 94 3–5 leaf and pre-flowering	thrips and leafhoppers	Azodrin (monocrotophos: 200 mL of 400 g/L product) at 110 L/ha	Nitofol (methamidophos: 50 mL of 580 g/L product) at 600 L/ha	Oil (1 L) at 600 L/ha
30 Dec 94 flowering	thrips, leafhoppers and budworms	Endosulfan (endosulfan: 1 L of 350 g/L product) at 110 L/ha	Nitofol (50 mL) at 800 L/ha	Oil (1 L) at 800–1000 L/ha
18 Jan 95 flowering and small green fruit	aphids, budworms and thrips	Hallmark (esfenvalerate: 150 mL of 500 g/L product) + Pennocozeb (mancozeb: 500 g of 800 g/kg product) at 200 L/ha	Endosulfan (190 mL) at 600 L of spray/ha	Oil (1 L) + food spray (190 g) at 1,600 L/ha
7 Feb 95 flowering and green fruit	budworms, thrips and fruit rots	Hallmark (200 mL) + Pennocozeb (500 g) at 200 L/ha	Hallmark (200 mL) + Pennocozeb (500 g) at 200 L/ha	Hallmark (200 mL) + Pennocozeb (500 g) at 200 L/ha
8 Feb 95 mature green fruit	aphids, budworms and thrips	Fastac (alpha cypermethrin: 100 mL of 100 g/L product) at 200 L/ha	Endosulfan (190 mL) at 300 L/ha	Oil (1 L) + food spray (190 g) at 1600 L/ha
22 Feb 95 pink fruit	mites, budworms and fruit rots	Endosulfan (1 L) + Thiovit (sulphur: 1.25 kg of 800 g/kg product) + Pennocozeb (1.25 kg) at 200 L/ha	Azodrin (150 mL) at 600 L/ha	Oil (1 L) + food spray (190 g) at 1600 L/ha
7 Mar 95 pink/ripe fruit	mites	Azodrin (250 mL) at 200 L/ha	Azodrin (250 mL) at 600 L/ha	Oil (1 L) + food spray (150 g) at 2,000 L/ha

[a] Full product details are mentioned once within the table.

[b] HMV = Hardi Mini Variant air-assisted sprayer; FAS = fan-assisted sprayer.

[c] On 7 February Hallmark and Pennocozeb were applied in all treatments with the HMV sprayer.

Gooloogong. Four treatments were compared (Table 4): D-C-Tron Plus applied with either a FAS or a conventional HBB, conventional pesticides applied with the HBB, and Ampol D-C-Tron Plus plus selected conventional pesticides applied with the HBB. The experiment was a randomised block design with four treatments each with four 70 m long and 6 m wide replicates.

The FAS was configured and operated as described in the Appendix. The HBB was operated at 7.0–10.2 km/h with the spray tank pressurised to 600 kPa. Other details are presented in Appendix Table 2.

Peats Ridge. There were four treatments, an unsprayed control and three sprayed treatments. Details of the sprayed treatments and the grower's spray program are presented in Table 5. The experiment was a completely randomised design with four 15 m long replicates of each of the four treatments allocated within four of the sites 60 m long rows. Each experimental row was separated by a row to which the grower applied his spray program. A Silvan Airblast 1500 sprayer was used for all sprays, and was operated at 2.75–3.75 km/h (compared to the grower's standard speed of 3.75–4.75 km/h) with the spray tank pressurised to 150–200 kPa. Other details are presented in Appendix Table 3. Each spray was applied to run-off. To achieve this, an additional nozzle that sprayed upwards towards plants at about 45° was mounted on the spray vat. A portable 2.2 m high and 3 m wide portable spray barrier was used to prevent spray drift.

Table 3. Cowra treatments.

Treatment[a]	Chemical(s)[b] (rate/100 L of water)	Spray volume (L/ha)	Application dates
1 - Oil with FAS	D-C-Tron Plus (1 L)	250–300	all dates[c]
2 - Oil with FAS	D-C-Tron Plus (1 L)	500–600	all dates
3 - Oil with FAS	D-C-Tron Plus (1 L)	800–1,000	all dates
4 - Oil with FAS	D-C-Tron Plus (1 L)	>1,200	all dates
5 - Conventional pesticides with HBB	Rogor (dimethoate: 375 mL of 400 g/L product) + Kocide (copper hydroxide: 1.25 kg of 500 g/kg product)	200	20 Dec
	Hallmark (esfenvalerate: 200 mL of 400 g/L product) + Lannate (methomyl: 500 mL of 225 g/L product) + Kocide (325 g) + Bravo (chlorothalonil: 390 mL of 500g/L product)	200	12 Jan
	Lannate (750 mL) + Kocide (1.1 kg) + Bravo (chlorothalonil: 1.5 kg of 750 g/kg product)	200	31 Jan
	Lannate (750 mL) + Manzate (mancozeb: 200 g of 750 g/kg product)	200	15 Feb
	Rogor (500 mL) + Kocide (1.1 kg/) + Bravo (1.5 kg)	200	12 Mar
6 - Conventional pesticides with FAS	as for treatment 5	250-300	as for treatment 5
7 - Oil and Envirofeast with FAS	D-C-Tron Plus (1 L) + Envirofeast (600 g L)	500	5 and 20 Dec
	D-C-Tron Plus (1 L) + Envirofeast (375 g)	800	12 and 31 Jan
	D-C-Tron Plus (1 L) + Envirofeast (300 g/100 L)	1,000	15 Feb
	D-C-Tron Plus (1 L) + Envirofeast (250 g)	1,200	12 Mar
8 - Untreated control			

[a] HBB = Hardi broadacre boom sprayer; FAS = fan-assisted sprayer.

[b] Full product details are mentioned once within the table.

[c] 5 and 20 December 1995, and 12 and 31 January, 15 February, and 12 and 22 March 1996.

Spray coverage

Spray coverage achieved by the FAS and the conventional sprayers was compared at Darlington Point (22 February 1995), Cowra (11 January 1996) and Gooloogong (4 February and 11 March 1997) by adding a yellow fluorescent pigment (South Australian Research and Development Institute) to sprays at 200 mL/100 L water. On each occasion single leaves were randomly picked within one hour of spraying from each of five locations (lower, middle, top, and two lateral sides) within the canopies of 20 randomly selected plants within each plot and examined in a dark room using a mercury vapour black light lamp. Deposits and coverage were assessed according to Furness *et al.* (1993).

Assessments

BCRI. The two central plants in each replicate were used for assessments. Oil induced necrosis on leaves (acute phytotoxicity) was assessed visually throughout the experiment. Five days after the seventh application of sprays the number of leaves/plant was determined *in situ* and the third terminal leaf of each plant was removed. These leaves were used to determine leaf area using a LAMBA

Table 4. Gooloogong treatments.

Date and crop stage	Target pests and diseases	Treatment[a,b] (chemical rates/100 L of water and spray volumes/ha)			
		D-C-Tron Plus with FAS	Conventional pesticides with HBB	D-C-Tron Plus with HBB	D-C-Tron Plus and selected conventional pesticides with HBB
23 Dec 96 3–5 leaf	thrips and leafhoppers	Oil (1 L) at 800 L/ha	Endosulfan (endosulfan: 1.4 L of 350 g/L product) at 150 L/ha	Oil (1 L) at 300 L/ha	Oil (1 L) at 300 L/ha
3 Jan 97 pre-flowering	thrips, leafhoppers and budworms	Oil (1 L) at 800 L/ha	Endosulfan (1.4 L) at 150 L/ha	Oil (1 L) at 300 L/ha	Oil (1 L) at 300 L/ha
14 Jan 97 flowering	aphids and budworms	Oil (1 L) at 800 L/ha	Rogor (dimethoate: 500 mL 400 g/L product) + Marlin (methomyl: 670 mL of 225 g/L product) at 150 L/ha	Oil (1 L) at 600 L/ha	Oil (1 L) at 600 L/ha Rogor (250 mL) at 300 L/ha
24 Jan 97 green fruit	budworms leafhoppers and thrips	Oil (1 L) at 800 L/ha	Endosulfan (1.4 L) at 150 L/ha	Oil (1 L) at 600 L/ha	Oil (1 L) at 600 L/ha
4 Feb 97 mature green fruit	aphids and budworms	Oil (1 L) at 1,200 L/ha	Endosulfan (420 mL) at 500 L/ha	Oil (1 L) at 1,200 L/ha	Oil (1 L) at 1,200 L/ha
18 Feb 97 pink fruit	budworms and bacterial speck	Oil (1 L) at 1,600 L/ha Blue Shield (copper hydroxide: 440 g of 500 g/kg product) at 500 L/ha	Endosulfan (420 mL) + Blue Shield (440 g) at 500 L/ha	Oil (1 L) at 1,400 L/ha Blue Shield (440 g) at 500 L/ha	Oil (1 L) at 1,200 L/ha Blue Shield (440 g) at 500 L/ha
28 Feb 97 pink fruit	budworms	Oil (1 L) at 1,600 L/ha	Chlorfos (chlorpyrifos: 200 mL of 500 g/L product) at 500 L/ha	Oil (1 L) at 1,400 L/ha	Oil (1 L) at 1,400 L/ha
11 Mar 97 pink fruit	budworms, target spot and fruit rots	Oil (1 L) at 1,800 L/ha Dithane (mancozeb: 440 g of 750 g/kg product) at 500 L/ha	Endosulfan (420 mL) + Marlin (200 mL) + Dithane (440 g) at 500 L/ha	Oil (1 L) at 1,400 L/ha Dithane (440 g) at 500 L/ha	Oil (1 L) at 1,400 L/ha Endosulfan (420 mL) + Marlin (200 mL) + Dithane (440 g) at 500 L/ha

[a] Full product details are mentioned once within the table.

[b] HBB = Hardi broadacre boom sprayer; FAS = fan-assisted sprayer.

Table 5. Peats Ridge treatments.

Date and crop stage	Target pest and diseases	Sprayed treatments[a] (chemical rates/100 L of water and spray volumes/ha)			Grower's program (L/ha of pesticides as in conventional pesticide treatment)
		Conventional pesticides	D-C-Tron Plus	D-C-Tron Plus with pesticides	
27 Dec 96 3–5 leaf	thrips, aphids and budworms	Lorsban (chlorpyrifos: 150 mL of 500 g/L product) + Blue Shield (copper hydroxide: 150 g product) at 500 L/ha	Oil (1 L) at 500 L/ha	Oil (1 L) at 500 L/ha	325
6 Jan 97 pre-flowering	thrips, whitefly, budworms and target spot	Rovral (iprodione; 200 mL of 250 g/L product) at 500 L/ha	Oil (1 L) at 500 L/ha	Oil (1 L) at 500 L/ha	325
14 Jan 97 flowering	aphids, budworms and bacterial speck	Nitofol (methamidophos; 50 mL of 580 g/L product) + Blue Shield (150 g) at 500 L/ha	Oil (1 L) at 500 L/ha	Nitofol (190 mL) + Oil (1 L) at 500 L/ha	325
2 Feb 97 flowering	aphids, budworms, mites, target spot, bacterial speck, powdery mildew and botrytis	Lorsban (150 mL) + Blue Shield (150 g) + Kelthane (dicofol: 200 mL of 240 g/L product) + Bravo (chlorothalonil; 200 mL of 500 g/L product) at 2,000 L/ha	Oil (1 L) at 2,000 L/ha	Nitofol (190 mL) + Oil (1 L) at 2,000 L/ha	1,200
10 Feb 97 mature green fruit	aphids, whitefly, budworms, mites, target spot, bacterial speck and botrytis	Pennocozeb (mancozeb; 500 g of 800 g/kg product) + Thiovit (sulphur; 200g of 800 g/kg product) at 2,000 L/ha	Oil (1 L) at 2,000 L/ha	Kocide (250 g) + Oil (1 L) at 2,000 L/ha	1,200
19 Feb 97 mature green fruit	aphids, whiteflies, budworms and bacterial speck	Lorsban (150 mL) + Kocide (400 g of 500 g/kg product) at 2,800 L/ha	Oil (1 L) + Kocide (400 g) at 2,800 L/ha	Oil (1 L) + Kocide (400 g) at 2,800 L/ha	1,200
3 Mar 97 fruit ripening	mites, aphids, whiteflies, budworms, target spot, bacterial speck and botrytis	Thiovit (200g) + Rovral (200 mL) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	1,200
12 Mar 97 fruit ripening	mites, aphids, whiteflies, budworms and bacterial speck	Lorsban (150 mL) + Kocide (200 g) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	Lorsban (150 mL) + Oil (1 L) at 2,800 L/ha	1,200
19 Mar 97 fruit ripening	mites, aphids, whiteflies, budworm and bacterial speck	Kocide (400 g) at 2,800 L/ha	Oil (1 L) + Kocide (400 g) at 2,800 L/ha	Oil (1 L) + Kocide (400 g) at 2,800 L/ha	1,200
1 Apr 97 fruit ripening	mites, aphids, whiteflies and budworms	Kelthane (200 mL) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	1,200
16 Apr 97 fruit ripening	mites, aphids, whiteflies and budworms	Kelthane (200 mL) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	Oil (1 L) + Rogor (75 mL) at 2,800 L/ha	1,200
23 Apr 97 fruit ripening	mites, aphids, whiteflies, budworms, target spot, botrytis and fruit rots	Pennocozeb (500 g) + Rogor (75 mL of 400 g/L product) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	no spray
7 May 97 fruit ripening	mites, aphids, whiteflies and budworms	Lorsban (150 mL) + Kelthane (200 mL) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	Oil (1 L) at 2,800 L/ha	no spray

[a] Full product details are mentioned once within the table.

Instruments Corp LI-3000A leaf area meter before they were used to count all motile tomato russet mites on two 19 mm diameter leaf-discs punched from the proximal ends of the two proximal leaflets on each leaf. Leaves were stored in separate moistened paper bags for up to two days at 4°C during the assessment process.

Darlington Point. Yields (kg ripe fruit/m of row) and percent total soluble solids (TSS) were determined at harvest in March 1995. Assessments were based on fruit harvested within five randomly selected 1 m long sections of the beds in each plot. The TSS levels were measured using a refractometer as described by Kavanagh and McGlasson (1983).

Pheromone traps (Agrisense Funnel Trap Insect Monitoring Systems, Dunluce International Pty Ltd, St Ives, NSW) with laminate lures were used to determine the relative proportions of *H. armigera* and *H. punctigera* present during the season. Two traps, each with a species-specific lure, were placed more than 50 m apart in the extensive cropping area adjoining the experimental site. Traps were inspected and emptied every 7–10 days. Lures were changed every 3–4 weeks. An identification key (Goodyer 1995) was used to confirm the identity of captured moths and to identify larvae collected on 18 January (n=20) and 22 February 1995 (n=22). Budworm eggs were assessed by counting the number of eggs on a single randomly chosen third terminal leaf from each of 30 randomly selected plants per plot, one day before each spray application.

Two-spotted mite and tomato russet mite populations were assessed on leaflets picked on 13 March 1995. Random samples of 50 leaflets were picked from each plot, stored at 4°C and examined within 21 days with a stereomicroscope. All motile stages of each mite were counted. Leaflet areas were measured with a CID C1-202 leaf area meter after mite counts were completed. Thrips, leafhopper, whitefly and aphid infestations were assessed visually with 5× Zeiss prism loups one day before each spray application. For each assessment, 10 plants were chosen at random within each plot, and the upper and lower surfaces of three leaves examined per plant (one each from the lower, middle and upper canopy).

Cowra. Yields (kg of sound ripe fruit, green fruit and rotten fruit/m of row, and weight of 100 randomly selected sound ripe fruit/plot) were determined at harvest on 28 March 1996. These assessments were based on fruit harvested within three randomly selected 1 m long sections of the beds in each plot. Bacterial speck infection and budworm damage were assessed on 100 randomly harvested fruit/plot. Infection by bacterial speck was scored as present if there were 5 or more specks per fruit. Damage by budworms was scored as present/absent. Only three replicates in each treatment were used for these assessments because the grower inadvertently sprayed one replicate in mid February 1996.

The procedures used to trap budworm adults were similar to those used at Darlington Point but two traps of each type were used. Procedures used to check larval identity on 12 January (n=30), 15 February (n=45) and 12 March 1996 (n=45) and for assessing budworm egg numbers were identical to those used at Darlington Point. Two-spotted mite and tomato russet mite were assessed on leaflets picked on 10, 20 and 27 March 1996. Random samples of 25 leaflets were picked from each plot, stored at 4°C and then examined within 21 days using a stereomicroscope. All motile stages of each mite were counted. Thrips, leafhopper, whitefly and aphid infestations were assessed visually with 5× Zeiss prism loups one day before each spray application as at Darlington Point.

Gooloogong. Yields (kg of sound ripe fruit, green fruit and rotten fruit/m of row, and weight of 100 randomly selected sound ripe fruit/plot) and fruit quality (TSS and titratable acid) were determined at harvest on 2 April 1997. Yield assessments were based on fruit harvested from six randomly selected 1 m long sections of beds in each plot. For the TSS and titratable acid determinations, 20 fruit at colour stages 4 and 5 (McGlasson *et al.* 1985) were taken from each replicate and, within 4 hours of picking, stored at 4°C for 5 days before they were assessed using the methods of McGlasson *et al.* (1985). Bacterial speck and TSWV infections, and budworm damage were assessed on 100 randomly harvested fruit/plot. Infections by bacterial speck and TSWV, and damage by budworms were scored as at Cowra.

The procedures used to trap budworm adults and to identify larvae collected on 3 January (n=25), 4 February (n=37) and 28 February 1997 (n=28) were similar to those used at Cowra. Budworm eggs were assessed as at Darlington Point and Cowra but on this occasion sampling was based on 20 randomly selected plants per plot. Two-spotted mite and tomato russet mite populations were assessed on leaflets picked on 24 January, 18 February and 11 March 1997. The procedures used were the same as those used at Darlington Point but leaf areas were not measured. Thrips, leafhopper, whitefly and aphid infestations were assessed visually with 5× Zeiss prism loups one day before each spray application as they were at Darlington Point and Cowra but on this occasion leaves were examined on 20 randomly chosen plants per plot. Leafhoppers were sampled using an insect suction sampler (Holtkamp and Thompson 1985). Three suctions of 30 seconds each were made at each of two randomly chosen 1 m^2 samples per replicate. The contents of each sample were transferred to a 25 ml vial, stored at 4°C, and counted within 30 days.

Peats Ridge. Sound fruit were harvested at mature green to early colour stages once a week commencing from 19 March 1997. Peak harvest was on 1 April 1997. Final harvest was on 5 May 1997. Data from each harvest was pooled to give total kg of sound marketable tomatoes/15 m of row. For TSS and titratable acid determinations, 15 fruit at colour stage 2 (McGlasson *et al.* 1985) were taken from each replicate at peak harvest and, within 4 hours of picking, stored at 20°C for six days before they were assessed using the methods of McGlasson *et al.* (1985). Budworm and Queensland fruit fly damage (presence/absence) was assessed on fruit harvested from each plot on 1 April, 23 April and 7 May 1997.

Budworm eggs were assessed on 20 randomly selected plants per plot before each spray application. A single, randomly chosen leaf was examined per plant on each occasion. Two-spotted mite and tomato russet mite populations were assessed by randomly collecting 30 leaflets/replicate before each spray. Samples of leaves were stored at 4°C and the number of motile stages of each mite species counted within 21 days using a stereomicroscope.

Thrips, leafhoppers, whiteflies and aphids infestations were assessed visually with 5× Zeiss prism loups one day before each spray application. Twenty leaves were chosen at random from each plant and both the upper and lower surfaces were examined.

Analyses

The BCRI tomato russet mite data were analysed using the curve-fitting module of Fig P (Biosoft 1993). Analyses for Darlington Point, Cowra, Gooloogong and Peats Ridge were performed using SPSS Version 7 (SPSS 1997). Analyses comparing the abundance of each pest were only performed for dates when sufficient numbers were present. Prior to analysis, data were assessed for normality and variance homogeneity and suitable transformations applied whenever either assumption was violated. Experimental and sampling errors were pooled if they did not differ significantly at p=0.25 (Underwood 1981). When significant treatment differences were detected, pair-wise comparisons among all means were made using the Ryan's Q test (Day and Quinn 1986).

RESULTS

BCRI. No oil-induced necrosis was observed in any treatment after 11 sprays. After 8–9 sprays plants sprayed with 2% oil appeared stunted compared to plants in the other oil treatments, but they maintained a rich green appearance. A significant negative exponential relationship was derived for mean number of tomato russet mite/cm^2 versus oil concentration after seven sprays (Figure 1). Visual observations indicated that the growth of control plants was significantly retarded by tomato russet mite. Figures 2 and 3 indicate that this was due to the effect of tomato russet mite on leaf area rather than an effect on the number of leaves/plant.

Darlington Point. The higher volumes applied by the FAS deposited significantly more spray on leaf surfaces than the lower volumes applied by the HMV sprayer (Appendix Table 4). There was no significant difference between treatments for ripe fruit yields and TSS (Table 6).

Most (>90%) of the 807 adult budworms caught in the pheromone traps from December to March were found in the *H. armigera* trap. All moths caught in the *H. punctigera* trap were subsequently identified as *H. armigera*. All larvae were identified as *H. armigera*. Seasonal mean numbers of budworm eggs were lower in the oil, Envirofeast and FAS treatment than in the other treatments but the differences were not significant (Table 7). The mean number of thrips, common brown leafhopper and aphid adults did not differ significantly between treatments. Green leafhopper and greenhouse whitefly numbers were very low in all treatments and data were not analysed. Two-spotted mite numbers were significantly lower in the oil, Envirofeast and FAS treatment than in the other two treatments. Tomato russet mite was significantly less abundant in the conventional pesticide and FAS treatment than in the other two treatments. Numbers of tomato russet mite in the oil, Envirofeast and FAS treatment were lower than in the conventional pesticide with HMV treatment but the difference was not significant.

Table 6. Mean (± SD) ripe fruit yields and TSS at Darlington Point.

Treatment[a]	Yield (kg/m of bed)	TSS (%)
Pesticides with HMV at 200 L/ha	3.95 ± 1.07	6.70 ± 0.40
Pesticides with FAS at 200–600 L/ha	3.78 ± 1.68	6.75 ± 0.43
D-C-Tron NR with Envirofeast with FAS at 600–2,000 L/ha	4.03 ± 1.41	6.45 ± 0.58
Anova results	$F_{2,57} = 0.12$, $p = 0.88$	$F_{2,9} = 0.44$, $p = 0.65$

[a] HMV = Hardi Mini Variant air-assisted sprayer; FAS = fan-assisted sprayer.

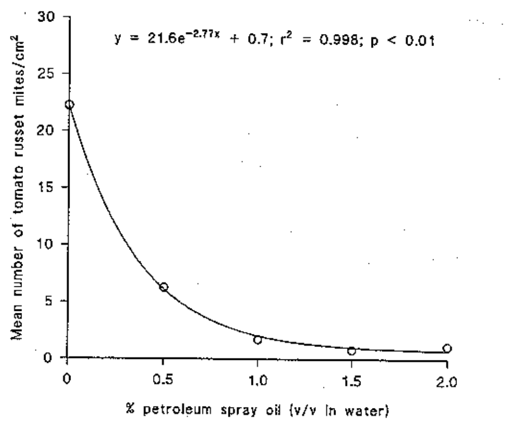

Figure 1. Influence of seven weekly applications of Caltex Lovis on tomato russet mite at the Biological and Chemical Research Institute.

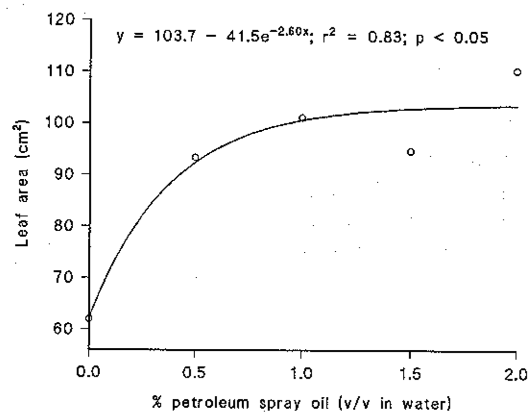

Figure 2. Influence of seven weekly applications of Caltex Lovis on leaf area of tomatoes at the Biological and Chemical Research Institute.

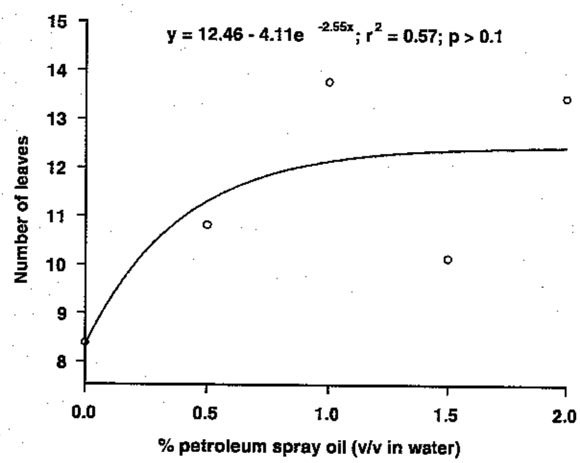

Figure 3. Influence of seven weekly applications of Caltex Lovis on the number of leaves on tomatoes at the Biological and Chemical Research Institute.

Table 7. Mean (± SD) numbers of insects/leaf and mites/leaflet at Darlington Point.

Treatment[a]	Number/leaf or leaflet[b]					
	budworm eggs	thrips adults	common brown leafhopper adults	green peach aphid adults	two-spotted mite[c]	tomato russet mite[c]
Pesticides with HMV at 200 L/ha	0.31 ± 0.98	0.30 ± 0.88	0.08 ± 0.46	0.82 ± 2.22	19.8 ± 17.0a	76.4 ± 67.3a
Pesticides with FAS at 200–600 L/ha	0.25 ± 0.78	0.45 ± 1.15	0.06 ± 0.37	1.58 ± 3.87	12.4 ± 8.0a	50.0 ± 56.3b
D-C-Tron NR and Envirofeast with FAS at 600–2,000 L/ha	0.15 ± 0.52	0.19 ± 0.70	0.11 ± 0.49	1.08 ± 2.09	6.4 ± 5.3b	60.1 ± 49.2a
Anova results	$F_{2,54} = 0.53$, $p = 0.60$	$F_{2,54} = 1.22$, $p = 0.30$	$F_{2,54} = 0.46$, $p = 0.60$	$F_{2,54} = 1.42$, $p = 0.25$	$F_{2,714} = 28.10$, $p < 0.001$	$F_{2,714} = 9.53$, $p < 0.001$

[a] HMV = Hardi Mini Variant air-assisted sprayer; FAS = fan-assisted sprayer.

[b] Means for budworms, thrips and leafhoppers based on samples taken on 12 and 21 December 1995, 16 and 30 January, and 21 February 1996. Means for aphids based on samples taken on 16 and 30 January, and 21 February 1996. Means for mites based on samples taken on 13 March 1996.

[c] Means followed by the same letter(s) within columns were not significantly different (Ryan's Q test).

Cowra. Spray coverage differed significantly between the four oil and fan-assisted treatments, with coverage increasing with spray volume (Appendix Table 4). Yields of ripe, green and rotten fruit and the mean weight of 100 sound (marketable) fruit are presented in Table 8. Significant differences occurred between treatments in the yield of sound ripe fruit, with the highest yields in the 1% D-C-Tron Plus at >1,200 L spray/ha treatment and the lowest in the unsprayed control. Discounting the 800–1,000 L/ha oil treatment, high-volume oil sprays generally gave yields equal to the conventional sprays. Extensive mechanical damage due to equipment failure on 18 February 1996 contributed to the low yield of ripe fruit in the 1% D-C-Tron Plus 800–1000 L spray/ha treatment. The number of rotten fruit differed significantly between treatments with the proportion of rotten fruit in plots an inverse function of the yield of ripe tomatoes (Figure 4). There were no significant differences between treatments for bacterial speck (Table 9). There were no significant differences in the weight of green fruit and for the weight of 100 sound ripe fruit. This implies that the differences in the yield of sound ripe fruit were due to differences in the number of fruit rather than size.

Budworm damage at harvest in all sprayed treatments was significantly lower than in the unsprayed control (Table 9), with the lowest damage recorded in the 1% D-C-Tron Plus 500–600 and >1,200 L spray/ha treatments and the conventional pesticide FAS treatment. The percentage of rotten fruit at harvest was positively correlated to budworm damage (Figure 5). Most (>75%) of the 87 adult budworms caught in the pheromone traps from December 1995 to March 1996 were found in the *H. armigera* traps. All of the moths caught in the *H. punctigera* traps were subsequently identified as *H. armigera*. All larvae were identified as *H. armigera*.

Table 8. Mean (± SD) yields at Cowra in 1995/96.

Treatment[a]	Yield (kg/m of row)[b]			kg of 100 sound ripe fruit
	sound ripe fruit	green fruit	rotten fruit	
1% D-C-Tron Plus with FAS at 250–300 L/ha	10.1 ± 0.3abc	2.8 ± 0.9	1.4 ± 0.1b	5.2 ± 0.3
1% D-C-Tron Plus with FAS at 500–600 L/ha	10.6 ± 0.6abc	1.7 ± 0.5	1.4 ± 0.4b	5.4 ± 0.5
1% D-C-Tron Plus with FAS at 800–1,000 L/ha	9.2 ± 0.4c	2.8 ± 0.5	1.5 ± 0.2b	5.5 ± 0.5
1% D-C-Tron Plus with FAS at >1,200 L/ha	11.8 ± 1.1a	1.9 ± 0.4	1.5 ± 0.1b	5.7 ± 0.2
Conventional pesticides with HBB at 200 L/ha	11.3 ± 1.0bc	3.3 ± 0.7	1.8 ± 0.2ab	5.8 ± 0.6
Conventional pesticides with FAS at 250–300 L/ha	10.1 ± 0.5ab	2.4 ± 0.6	1.4 ± 0.5b	5.4 ± 0.4
1% D-C-Tron Plus and Envirofeast with FAS at 500–1,200 L/ha	11.6 ± 0.5ab	2.5 ± 0.9	1.6 ± 0.2b	5.5 ± 0.4
Untreated control	9.1 ± 0.8c	2.8 ± 0.4	2.3 ± 0.3a	5.1 ± 0.2
Anova results	$F_{7,16} = 6.43$, $p = 0.001$	$F_{7,16} = 0.53$, $p = 0.79$	$F_{7,16} = 4.31$, $p = 0.007$	$F_{7,16} = 0.90$, $p = 0.53$

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.
[b] Means followed by the same letter(s) within columns were not significantly different (Ryan's Q test).

Table 9. Budworm and bacterial speck damage (± SD) on harvested fruit at Cowra on 28 March 1996.

Treatment[a]	Budworm damage (%)[b]	Bacterial speck damage (%)
1% D-C-Tron Plus with FAS at 250–300 L/ha	12.0 ± 1.0b	20.3 ± 1.5
1% D-C-Tron Plus with FAS at 500–600 L/ha	11.3 ± 2.1bc	16.3 ± 2.5
1% D-C-Tron Plus with FAS at 800–1,000 L/ha	13.0 ± 2.6b	18.0 ± 0.0
1% D-C-Tron Plus with FAS at >1,200 L/ha	9.3 ± 1.5bc	13.7 ± 3.1
Conventional pesticides with HBB at 200 L/ha	13.3 ± 0.6b	17.6 ± 3.2
Conventional pesticides with FAS at 250–300 L/ha	7.6 ± 0.6c	24.3 ± 2.5
1% D-C-Tron Plus and Envirofeast with FAS at 500–1,200 L/ha	12.6 ± 0.6b	20.6 ± 1.2
Untreated control	33.0 ± 6.1a	19.3 ± 9.0
Anova results	$F_{7,16} = 28.46$, $p<0.001$	$F_{7,16} = 2.07$, $p = 0.11$

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.
[b] Means followed by the same letter(s) within columns were not significantly different (Ryan's Q test).

Table 10. Mean (± SD) numbers of insects/leaf and mites/leaflet at Cowra[a].

Treatment[a]	Number/leaf or leaflet[b]			
	budworm eggs[c]	brown leafhopper adults[c]	greenhouse whitefly adults	two-spotted mite[c]
1% D-C-Tron Plus with FAS at 250–300 L/ha	0.2 ± 0.5ab	0.5 ± 1.2ab	0.9 ± 3.0	11.2 ± 9.8a
1% D-C-Tron Plus with FAS at 500–600 L/ha	0.2 ± 0.5abc	0.5 ± 1.2ab	1.0 ± 3.0	10.0 ± 10.2a
1% D-C-Tron Plus with FAS at 800–1,000 L/ha	0.2 ± 0.4bc	0.3 ± 0.7b	0.2 ± 0.9	10.1 ± 10.3a
1% D-C-Tron Plus with FAS at >1,200 L/ha	0.1 ± 0.3c	0.3 ± 0.6b	0.2 ± 0.6	6.5 ± 9.2b
Conventional pesticides with HBB sprayer at 200 L/ha	0.2 ± 0.5ab	0.4 ± 0.8ab	0.5 ± 1.6	14.2 ± 16.7a
Conventional pesticides with FAS at 250–300 L/ha	0.3 ± 0.6ab	0.3 ± 0.7ab	0.3 ± 1.2	8.8 ± 6.6b
1% D-C-Tron Plus and Envirofeast with FAS at 500–1,200 L/ha	0.2 ± 0.5ab	0.6 ± 1.3ab	0.4 ± 1.1	10.5 ± 11.8a
Untreated control	0.3 ± 0.6ab	0.8 ± 1.4a	0.8 ± 1.9	11.5 ± 11.4a
Anova results	$F_{7, 149} = 5.53$, $p < 0.001$	$F_{7, 149} = 2.83$, $p = 0.01$	$F_{7, 149} = 0.04$, $p = 0.99$	$F_{7, 149} = 3.77$, $p = 0.02$

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.
[b] Means for insects based on samples taken on 19 December 1995, and 12 and 30 January, 14 February and 11 March 1996; means for mites based on samples taken on 10, 20 and 27 March 1996.
[c] Means followed by the same letter(s) within columns were not significantly different (Ryan's Q test).

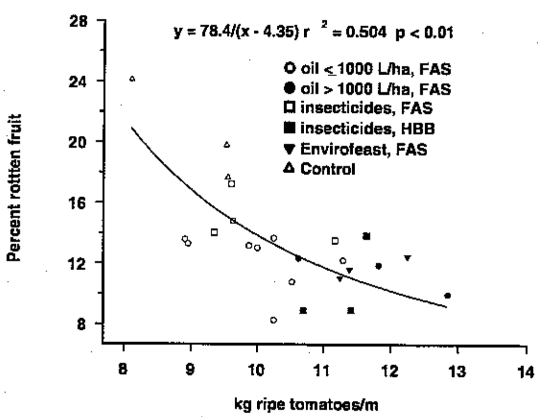

Figure 4. Relationship between rotten fruit and sound ripe fruit harvested from all treatments in March 1996 at Cowra. HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.

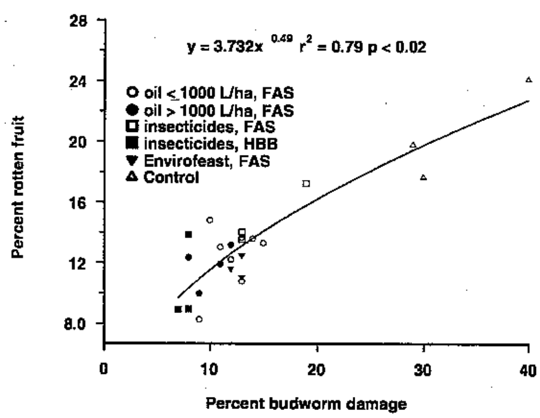

Figure 5. Relationship between rotten fruit and budworm damaged fruit harvested from all treatments in March 1996 at Cowra. HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.

Budworm eggs numbers differed significantly between treatments. The lowest numbers were recorded in the two higher volume D-C-Tron Plus and FAS treatments (Table 10). Similar trends were evident for common brown leafhopper and less clearly for two-spotted mite but the differences between treatments for greenhouse whitefly were not significant.

Gooloogong. Spray coverage results are presented in Appendix Table 5. There was a significant interaction effect between surface, canopy, and spray volume and sprayer type ($F_{20, 540} = 6.88$, $p < 0.001$) at the mature green fruit stage. In general, coverage on upper leaf surfaces was consistently better than on lower surfaces and coverage on both surface types increased as the spray volume increased regardless of sprayer type. The distribution of spray droplets around canopies was not even: the tops of canopies received better coverage than lower canopies and the lateral sides of plants. There was better coverage on lower leaf surfaces at lower canopy levels with the FAS than with the HBB. Overall, the FAS gave better coverage at comparable spray volumes than the HBB, but the latter tended to give better coverage to the upper surfaces of leaves on the lateral sides of plants than the FAS. The most effective coverage was achieved with the FAS at 1,800 L of spray/ha. Results were similar at the fruit ripening stage, with a significant interaction effect found between spray volume/sprayer type, canopy, and leaf surface ($F_{12, 360} = 6.05$, $p < 0.001$). Coverage patterns were essentially the same as on plants at the mature green fruit stage. The FAS was again more effective than the HBB sprayer at comparable spray volumes.

Yields of ripe, green, rotten and total fruit, and the mean weight of fruit are presented in Table 11. There were no significant differences in the yields of sound ripe fruit and total fruit but there were for green fruit although it was not significantly lower than yield of similar fruit in the D-C-Tron Plus/FAS treatment. The conventional pesticide treatment produced the lowest yield of green fruit. There were no significant differences in TSS and titratable acid among treatments (Table 12). Fruit damage by TSWV and bacterial speck did not vary significantly between treatments (Table 13).

Budworm damage was significantly higher in plants sprayed with D-C-Tron Plus using the HBB than in the other treatments (Table 13). Most (>93%) of the 431 adult budworms caught in the pheromone traps from January to March 1997 were found in the *H. armigera* traps. All of the moths caught in the *H. punctigera* traps were subsequently identified as *H. armigera*. All larvae were identified as *H. armigera*. Significantly fewer eggs were recorded in the D-C-Tron Plus/FAS treatment than in the other treatments but differences between treatments for larvae/leaf were not significant (Table 14). *F. schultzei* numbers did not differ significantly between treatments but *T. imaginis* was significantly less abundant in the D-C-Tron Plus/FAS treatment and in the D-C-Tron Plus, conventional pesticide and HBB treatment than in the other two treatments (Table 14). Both leafhopper species were significantly less abundant in the D-C-Tron Plus/FAS treatment than in the conventional pesticide treatment. Numbers in the other two treatments were intermediary (Table 14). Similar trends in leafhopper numbers were evident in the suction trap catches (Table 15). Although the abundance of green peach aphid adults did not differ significantly between treatments (Table 14) the aphid tended to be less abundant in the oil-based treatment than in the conventional pesticide treatment.

Table 11. Mean (± SD) yields at Gooloogong in 1996/97.

Treatment	Yield (kg/m of row)[b]				kg of 100 sound ripe fruit
	sound ripe fruit	green fruit	rotten fruit	total fruit	
D-C-Tron Plus with FAS at 800–1,800 L/ha	7.3 ± 1.4	1.6 ± 0.5ab	2.5 ± 0.7	11.4 ± 1.4	6.2 ± 0.7
Conventional pesticides with HBB at 150–500 L/ha	7.6 ± 2.0	1.4 ± 0.6a	3.0 ± 0.9	12.0 ± 2.5	6.4 ± 0.9
D-C-Tron Plus with HBB at 300–1,400 L/ha	6.5 ± 1.8	1.8 ± 0.6bc	3.0 ± 1.0	11.3 ± 2.2	6.2± 0.7
D-C-Tron Plus and selected conventional pesticides with HBB at 300–1,400 L/ha	7.5 ± 1.6	1.9 ± 0.6bc	2.7 ± 0.6	12.1 ± 1.7	6.4 ± 1.1
Anova results	$F_{3, 32} = 1.31$, $p = 0.26$	$F_{3, 32} = 2.76$, $p = 0.046$	$F_{3, 32} = 2.01$, $p = 0.11$	$F_{3, 32} = 3.69$, $p = 0.18$	$F_{3, 32} = 0.44$, $p = 0.72$

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.
[b] Means followed by the same letter(s) within columns were not significantly different (Ryan's Q test).

Table 12. Mean (± SD) sound ripe fruit total soluble solids and titratable acidity at Gooloogong in 1997.

Treatment[a]	Total soluble solids (%)	Titratable acidity (μmoles H^+/L)
D-C-Tron Plus with FAS at 800–1,800 L/ha	7.9 ± 0.3	56 ± 11
Conventional pesticides with HBB at 150–500 L/ha	8.0 ± 0.7	55 ± 16
D-C-Tron Plus with HBB at 300–1,400 L/ha	8.2 ± 0.4	63 ± 3
D-C-Tron Plus and selected conventional pesticides with HBB at 300–1,400 L/ha	8.3 ± 0.6	55 ± 4
Anova results	$F_{3, 11} = 0.52$, $p = 0.67$	$F_{3, 11} = 0.52$, $p = 0.65$

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.

Table 13. Budworm, TSWV and bacterial speck damage (± SD) on harvested fruit at Gooloogong on 2 April 1997.

Treatment[a]	Budworm damage (%)[b]	TSWV damage (%)	Bacterial speck damage (%)[b]
D-C-Tron Plus with FAS at 800–1,800 L/ha	4.8 ± 3.1a	4.1 ± 2.1	2.3 ± 1.7
Conventional pesticides with HBB at 150–500 L/ha	5.6 ± 1.8a	5.0 ± 2.8	2.4 ± 2.1
D-C-Tron Plus with HBB at 300–1,400 L/ha	7.9 ± 4.1b	3.9 ± 1.9	2.8 ± 2.4
D-C-Tron Plus and selected conventional pesticides with HBB at 300–1,400 L/ha	4.2 ± 2.3a	3.5 ± 1.9	1.9 ± 1.5
Anova results	$F_{3, 32} = 7.47$, $p < 0.001$	$F_{3, 32} = 2.10$, $p = 0.15$	$F_{3, 32} = 0.73$, $p = 0.53$

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.
[b] Means followed by the same letter(s) within columns were not significantly different (Ryan's Q test).

Table 14. Mean (± SD) numbers of insects/leaf at Gooloogong.

Treatment[a]				
D-C-Tron Plus with FAS at 800–1,800 L/ha	Conventional pesticides with HBB at 150–500 L/ha	D-C-Tron Plus with HBB at 300–1,400 L/ha	D-C-Tron Plus and selected conventional pesticides with HBB at 300–1,400 L/ha	Anova results
Budworm eggs over six dates[b*, c]				
0.3 ± 0.3b	1.2 ± 0.8a	1.2 ± 0.8a	1.1 ± 0.8a	$F_{3, 89} = 8.06$, $p<0.001$
Budworm larvae over four dates[b†]				
0.4 ± 0.3	0.3 ± 0.2	0.5 ± 0.3	0.4 ± 0.3	$F_{3, 48} = 0.92$, $p = 0.47$
***T. imaginis* adults over six dates[b§, c]**				
2.2 ± 1.7b	3.2 ± 0.8a	3.4 ± 1.1a	2.7 ± 1.0ab	$F_{3, 89} = 5.36$, $p=0.002$
***F. schultzei* adults over six dates[b§]**				
0.6 ± 0.3	0.8 ± 0.60	0.7 ± 0.5	0.7 ± 0.3	$F_{3, 89} = 1.68$, $p = 0.18$
Green leafhopper adults over six dates[b§, c]				
2.3 ± 0.7c	3.4 ± 0.7a	3.0 ± 0.9ab	2.8 ± 1.0bc	$F_{3, 89} = 7.53$, $p<0.001$
Common brown leafhopper adults over four dates[b‡, c]				
0.8 ± 0.5b	1.5 ± 0.9a	1.4 ± 0.7ab	1.0 ± 0.6ab	$F_{3, 57} = 3.23$, $p=0.029$
Green peach aphid adults over three dates[b¶]				
0.5 ± 0.3	1.3 ± 1.4	0.7 ± 0.5	0.5 ± 0.4	$F_{3, 41} = 1.17$, $p = 0.30$

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.
[b]* 2, 13 & 23 January, 17 & 27 February, 10 March; †23 January, 17 & 27 February, 10 March: ‡22 December, 2, 13 & 23 January, 17 & 27 February; ‡ 13 & 23 January, 17 & 27 February; ¶23 January, 17 & 27 February.
[c] Means followed by the same letter(s) within rows were not significantly different (Ryan's Q test).

Table 15. Mean (± SD) number of adult leafhoppers in suction samples at Gooloogong.

Date	Treatment[a]: D-C-Tron Plus with FAS at 800–1,800 L/ha	Conventional pesticides with HBB at 150–500 L/ha	D-C-Tron Plus with HBB at 300–1,400 L/ha	D-C-Tron Plus and selected conventional pesticides with HBB at 300–1,400 L/ha	Anova results
		Green leafhopper adults/sample[b]			
2 Jan 97	10.3 ± 2.3	11.3 ± 4.1	9.6 ± 2.1	8.5 ± 4.3	$F_{3,25} = 1.27, p = 0.30$
13 Jan 97	9.3 ± 4.7a	11.0 ± 1.5ab	14.5 ± 3.2b	11.5 ± 3.4ab	$F_{3,25} = 4.01, p = 0.018$
23 Jan 97	8.3 ± 3.1a	15.0 ± 3.7bc	16.3 ± 3.8c	11.9 ± 2.7ab	$F_{3,25} = 9.35, p < 0.001$
17 Feb 97	6.4 ± 2.8a	12.0 ± 3.3b	11.8 ± 2.1b	7.6 ± 2.7a	$F_{3,25} = 10.87, p < 0.001$
27 Feb 97	8.4 ± 1.4a	13.0 ± 3.4b	16.4 ± 3.2b	15.0 ± 3.6b	$F_{3,16} = 8.13, p = 0.006$
		Common brown leafhopper adults/sample[b]			
2 Jan 97	2.8 ± 2.0	2.5 ± 2.3	1.8 ± 1.8	1.0 ± 0.9	$F_{3,25} = 1.47, p = 0.25$
13 Jan 97	0.9 ± 1.0	1.0 ± 0.9	1.1 ± 1.1	1.1 ± 0.8	$F_{3,16} = 0.72, p = 0.97$
23 Jan 97	0.9 ± 1.0a	3.1 ± 2.0ab	4.1 ± 2.8b	1.6 ± 1.7ab	$F_{3,25} = 4.39, p = 0.013$
17 Feb 97	1.8 ± 0.9	2.5 ± 2	3.3 ± 1.6	2.4 ± 1.5	$F_{3,25} = 1.72, p = 0.19$
27 Feb 97	2.6 ± 1.2a	3.9 ± 1.2ab	5.1 ± 1.6b	3.5 ± 1.8ab	$F_{3,25} = 4.37, p = 0.013$

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.
[b] Means followed by the same letter(s) within rows were not significantly different (Ryan's Q test).

Peats Ridge. Yield was significantly higher in the experiment's conventional pesticide treatment than in the oil-based treatments and the unsprayed control (Table 16). There was no significant difference in total yield between the oil-based treatments but their yields were significantly higher than in the control. (Yields from pseudo-replicated plots within the grower's standard program were more similar to the D-C-Tron Plus spray treatment yield than the yield in the conventional pesticide treatment.) The high yield in the experiment's conventional pesticide treatment was attributed to improved spray application.

Fruit in the untreated control had significantly lower % TSS and titratable acidity levels than the sprayed treatments (Table 16). The oil sprayed fruit had significant higher % TSS levels than the conventional pesticide treatment and titratable acidity was significantly higher in the D-C-Tron Plus than in the conventional pesticide treatment but the difference between the two oil-based treatments was not significant.

Budworm damage was significantly lower on fruit in the oil-based treatments than in the conventional pesticide treatment and the unsprayed control treatment. Damage in the two oil-based treatments did not differ significantly and damage in the unsprayed control treatment was significantly greater than in the other three treatments (Table 17). Queensland fruit fly damage was significantly higher in the oil-based treatments and the unsprayed control than in the conventional pesticide treatment. On two of the three harvest dates, damage recorded in the unsprayed control was significantly greater than in the two oil-based treatments. The mean number of budworm eggs recorded in the D-C-Tron Plus treatment was significantly lower than in the other treatments. The mean number recorded in the oil with pesticides treatment was significantly lower than in the conventional pesticide treatment and in the unsprayed control, which did not differ significantly.

Similar trends were recorded for greenhouse whitefly (Table 18), but in this case the mean number recorded in the conventional pesticide treatment was significantly lower than the number recorded in the unsprayed control. Green peach aphid adults were significantly less abundant in the D-C-Tron Plus treatment than in the other treatments. Infestations in the conventional pesticide treatment and in the unsprayed control were not significantly different but they were significantly greater than the mean number recorded in the oil and pesticide treatment. Two-spotted mite was significantly more abundant (>4-fold) in the unsprayed control than in the sprayed treatments, and significantly more abundant in the conventional pesticide treatment than in the two oil-based treatments (Table 18). Its abundance in the two oil-based treatments did not differ significantly.

Table 16. Mean (± SD) yields and quality of fruit at Peats Ridge.

Treatment	Marketable tomatoes (kg)[a]	Total soluble solids (%)[a]	Titratable acidity (μmoles H^+/L)[a]
Conventional pesticides at 500–2,800 L/ha	85 ± 10a	4.6 ± 0.1b	74 ± 2b
D-C-Tron Plus at 500–2,800 L/ha	61 ± 2b	4.8 ± 0.1a	77 ± 1a
D-C-Tron Plus with pesticides at 500–2,800 L/ha	64 ± 4b	4.8 ± 0.1a	75 ± 1ab
Untreated control	44 ± 4c	4.0 ± 0.1c	59 ± 2c
Anova results	$F_{3, 12} = 32.9$, $p < 0.001$	$F_{3, 12} = 68.8$, $p < 0.001$	$F_{3, 12} = 99.3$, $p < 0.001$
Grower's program at 325–1,200 L/ha	71 ± 3b		

[a] Means followed by the same letter(s) within columns were not significantly different (Ryan's Q test).

Table 17. Budworm and Queensland fruit fly damage (± SD) on fruit harvested at Peats Ridge.

Date	Treatment[a]				Anova results
	Conventional pesticides at 500–2,800 L/ha	D-C-Tron Plus at 500–2,800 L/ha	D-C-Tron Plus with pesticides at 500–2,800 L/ha	Untreated control	
			Budworm damage (%)		
1 Apr 97	10.3 ± 1.0b	3.8 ± 0.5c	4.3 ± 01.0c	18.8 ± 2.2a	$F_{3, 12} = 111.6$, $p < 0.001$
23 Apr 97	12.0 ± 2.7b	4.8 ± 0.5c	5.50 ± 0.6c	18.8 ± 1.5a	$F_{3, 12} = 67.2$, $p < 0.001$
7 May 97	10.5 ± 1.9b	3.5 ± 1.0c	3.8 ± 1.0c	16.0 ± 2.7a	$F_{3, 12} = 44.5$, $p < 0.001$
			Queensland fruit fly damage (%)		
1 Apr 97	2.5 ± 1.9c	15.8 ± 2.2b	16.0 ± 1.8b	21.0 ± 1.4a	$F_{3, 12} = 72.1$, $p < 0.001$
23 Apr 97	4.3 ± 1.0b	12.3 ± 0.5a	13.5 ± 1.0a	14.3 ± 2.2a	$F_{3, 12} = 48.1$, $p < 0.001$
7 May 97	3.8 ± 0.5c	13.5 ± 1.0b	12.0 ± 1.6b	19.3 ± 2.2a	$F_{3, 12} = 74.2$, $p < 0.001$

[a] Means followed by the same letter(s) within rows were not significantly different (Ryan's Q test).

Table 18. Mean (± SD) numbers of insects/leaf and mites/leaflet at Peats Ridge.

Treatment[a]				Anova results
Conventional pesticides at 500–2,800 L/ha	D-C-Tron Plus at 500–2,800 L/ha	D-C-Tron Plus with pesticides at 500–2,800 L/ha	Untreated control	
		Budworm eggs/leaf		
2.0 ± 1.0a	0.7 ± 0.7c	1.2 ± 0.9 b	2.4 ± 1.1a	$F_{3, 313} = 48.4$, $p < 0.001$
		Greenhouse whitefly adults/leaf		
3.7 ± 3.2c	0.6 ± 0.7a	1.0 ± 0.9b	8.8 ± 4.2d	$F_{3, 313} = 97.2$, $p < 0.001$
		Green peach aphid adults/leaf		
3.3 ± 2.3c	0.7 ± 0.7a	1.4 ± 1.4b	5.9 ± 3.7c	$F_{3, 313} = 42.0$, $p < 0.001$
		Two-spotted mite/leaflet		
14.2 ± 3.2b	6.3 ± 1.3c	7.5 ± 2.0c	59.5 ± 10.0a	$F_{3, 473} = 820.5$, $p < 0.001$

[a] Means followed by the same letter(s) within rows were not significantly different (Ryan's Q test).

DISCUSSION

Most research on the use of PSOs in tomato propagation has focused on enhancing the effectiveness of synthetic pesticides for control of sweet-potato whitefly (*Bemisia tabaci* (Gennadius) B biotype = silverleaf whitefly, *B. argentifolia* Bellows and Perring), South American tomato pinworm (*Scrobipalpuloides absoluta* (Meyrick)) and some other pests (Veierov *et al.* 1988; Hilje 1993; Marcano and Gonzalez 1993; Peralta and Hilje 1993; Guedes *et al.* 1995; Branco *et al.* 1996; Silvia *et al.* 1996; Csizinszky *et al.* 1997). Some of the studies reported by these and other authors also focused on control of viruses by direct control of their insect vectors or the use of PSOs to reduce transmission of disease (Allen *et al.* 1993). These effects can be as important as direct control of vectors such as aphids, thrips and whiteflies, particularly in instances where PSOs do not appear to give direct effective control of the vector, as is the case with western flower thrips, *Frankliniella occidentalis* Pergande (Allen *et al.* 1993). The effects of PSOs on transmission of non-persistent viruses by aphids are almost certainly entirely related to reduced retention of viruses in stylets (Wang and Pirone 1996). Matthieu and Verhoyen (1983) found that transmission rates fell as the distillation properties of the oils tested increased.

When used alone in tomato pest and disease control programs PSOs have generally been applied to suppress the incidence of tomato viruses through control of *B. tabaci* at various stages of crop growth (Castellani *et al.* 1979; Yassin 1983; Rosset 1988; Sastry 1989; Csizinszky *et al.* 1997). In laboratory and greenhouse studies dried oil deposits repelled and killed adult silverleaf whitefly (Liu and Stansly 1995a,b) and through repellency reduced oviposition by adult females (Liu and Stansly 1995c). Eggs and nymphs on leaves dipped in oil were also very susceptible (Liu and Stansly 1995b). Products have also been recommended for control of mites and leafminers (e.g. Monkman 1992, JMS Flower Farms Inc 1994) but efficacy data do not appear to have been reported.

Our research clearly shows that, with the exception of Queensland fruit fly, multiple high-volume 1% petroleum oil sprays can be used to control a broad-range of Australian tomato pests simultaneously without additional use of synthetic pesticides. These pests include budworms, tomato thrips, plague thrips, brown leafhopper, green leafhopper, greenhouse whitefly, green peach aphid, two-spotted mite, and tomato russet mite. In major field experiments at Darlington Point, Cowra, Gooloogong and Peats Ridge the level of control we achieved either exceeded or equalled that obtained with conventional pesticides.

The experiment at Rydalmere on Gross Lisse plants demonstrated clear relationships between tomato russet mite numbers and oil concentration in sprays (Figure 1), and infestation levels and leaf area (Figure 2). Subsequent laboratory-based Potter spray tower bioassays showed that the susceptibility of the pest to oil is temperature and humidity dependent (Grant Herron, NSWA, and Anjali Kallianpur, UWSH, unpublished data). This may explain the ineffectiveness of the oil spray treatment at Darlington Point (Table 7) although the cumbersome use of the FAS could have been the sole reason for the poor result. Unfortunately, the mite was not recorded at Cowra and Gooloogong as use of the sprayer became more effective, or at Peats Ridge where sprays were applied with modified conventional equipment.

The control of budworms we achieved contradicts some results obtained on cotton (Mensah *et al.* 1995) and on tomatoes (Zhongmin Liu, UWSH, unpublished data). In choice and no-choice tests in a mesh-house Mensah *et al.* (1995) found that single 0.5% spray deposits of Lovis significantly suppressed oviposition by *H. punctigera* but not *H. armigera*. Fortnightly 0.5% sprays at a maximum of 150 L of spray/ha from late October reduced the number of eggs laid in field experiments and numbers recorded in the oil treatment were significantly lower than in an unsprayed control and a conventional pesticide treatment from late January. However, larvae were significantly more numerous in the oil treatment than in the conventional pesticide treatment and yield was significantly lower. Similar responses by both species to oil deposits were found in other experiments (Mensah 1996). The tomato studies were conducted under laboratory conditions using D-C-Tron Plus and *H. armigera*, and spray deposits were found to not influence oviposition (Liu, unpublished data). These results and those of Mensah *et al.* (1995) and Mensah (1996) could naturally indicate that our results were due to suppression of oviposition by *H. punctigera*, but as all budworm adults and larvae identified in our processing tomato experiments were *H. armigera* this was clearly not the case in our study.

The major differences between our Darlington Point, Cowra, Gooloogong and Peats Ridge studies and those of Mensah *et al.* (1995) and Mensah (1996) were crop, oil type and concentration, and spray volume. We applied 1% sprays that would have deposited more oil/cm^2. We also used D-C-Tron NR and D-C-Tron Plus which, because they penetrate leaf tissue less readily than Lovis (with the extent of penetration dependent on ambient temperature), would have given longer-lasting surface residues than Lovis. Reasons for the contrast between the tomato results are less easily explained. Robert Mensah (pers. comm., August 1998) believes that leaf leachates, such as sugars, and other chemicals which govern the attractiveness of host plant tissue for oviposition could be involved. PSOs might dilute or mask these chemicals, affect their production or enhance their breakdown to an extent dependent on environmental conditions. Oviposition responses of European corn borer (*Ostrina nubilalis* Hübner), cotton boll weevil (*Anthonomous grandis* Boheman) and tobacco budworm (*Heliothis virescens* (Fabricius)) are related to plant sugars and other factors such as host-plant volatiles (Fiala *et al.* 1985, 1990; Hedin and McCarty 1990; Mitchell *et al.* 1991; Shaver and Lopez 1996). In studies on cotton Navasero and Ramaswamy (1993) found that *H. virescens* females laid more eggs on younger rather than older leaves, and on undamaged rather than damaged leaves. The occurrence of these interactions needs to be determined for tomatoes. Additionally, if budworms are influenced by light reflected from host substrates then the possibility of PSO (particularly oils, such as D-C-Tron Plus, with UV sunscreens) deposits influencing behavioural responses to varying degrees under laboratory and field conditions cannot be ignored. It is possible that tomato leaves grown under ideal conditions in greenhouses might be more attractive for budworm oviposition for a number of reasons than leaves in field-grown crops, with PSOs having a greater effect on the latter.

Budworm pressure varied between our experiments. Hamilton and Macdonald's (1990) threshold of five eggs/30 compound leaves was exceeded in one or more treatments at each location. The highest pressure in the processing tomato experiments was recorded at Gooloogong where the seasonal mean number of eggs/30 leaves recorded in the conventional pesticide and HBB treatment was 36.9. In the fresh tomato experiment at Peats Ridge the highest numbers were recorded in the unsprayed control which averaged 70.8 eggs/30 leaves over the season. The levels of pressure recorded were broadly comparable to levels reported by Smith *et al.* (1996).

The fact that Envirofeast did not enhance the effect of oil on budworm oviposition at Darlington Point and Cowra was unexpected given the experiments reported by Mensah (1996). In mesh-house choice and no-choice experiments on cotton he found that several oils (Lovis, D-C-Tron NR, and vegetable, peppermint and fish oils) applied separately with Envirofeast significantly reduced oviposition by both budworm species, whereas Lovis mixed with a polysaccharide had no such effect on *H. armigera*. Further evaluations may be relevant on tomatoes.

The FAS used in the processing tomato experiments clearly applied sprays more effectively than the conventional sprayers used at each location. We improved the performance of the FAS as the studies progressed. Inefficient application was probably the main reason for the ineffectiveness of the oil with the conventional sprayer at Gooloogong, the only location where an almost direct comparison was made between the FAS and a conventional sprayer at similar spray volumes/ha. The FAS was noteworthy in giving particularly good coverage to lower leaf surfaces. Our results indicate that application is critical for effective use of PSOs in processing tomatoes and that the performance of conventional sprayers will need to be improved to achieve this outcome. This might be possible with existing sprayers (e.g. by using better nozzles) although we took care to optimise the operation of the sprayers at Cowra and Gooloogong. We did not compare aerial application of sprays with tractor-drawn ground-rigs. However, given the very low volumes applied by air (40–50 L/ha; Fred Fay, Cowra Airport, pers. comm., 24 September 1998) and the general inefficiency of aerial application (Richards and Pascoe 1994) it is unlikely that even undiluted or concentrated (e.g. 10% v/v) sprays would be effective. The issue of ineffective application of pesticides by air is particularly important in Victoria where most sprays are applied by aircraft (Smith *et al.* 1996). However, a recent trend towards the use of trickle irrigation in Victoria may lead to increased use of ground rigs (Peter Ridland, Agriculture Victoria, pers. comm., 2 September 1998).

With the exception of stunting of plants observed at BCRI after 8–9 weekly 2% sprays of Lovis no phytotoxicity was recorded in our experiments. Processing tomato yields and quality were not adversely affected by oil treatments that effectively controlled budworms. Yields in fresh tomatoes at Peats Ridge were significantly lower than in our high-volume conventional pesticide treatment but the difference was due to poor control of Queensland fruit fly. TSS did not differ significantly between treatments in the processing tomato experiments at Darlington Point and Gooloogong. In the fresh tomato experiment at Peats Ridge levels were significantly higher in the two oil treatments than in our conventional pesticide treatment and the untreated control. Similar trends were recorded for titratable acidity. The TSS levels at Gooloogong (7.9–8.3%) were well above standard values of 4.0–5.6% given by Kavanagh *et al.* (1986) and Ashcroft *et al.* (1997). However, acidity at this location (55–63 μmoles H^+/L) was within levels found in most commercial varieties (Kavanagh *et al.* 1986; Ashcroft *et al.* 1997). May and Gonzales (1994) and Branthome *et al.* (1994) reported that water stress during late fruit development and ripening causes a reduction in yield but an increase in TSS. The overhead irrigation system at Gooloogong may have stressed plants during critical phases of crop development, leading to higher than normal TSS levels.

Other workers have recorded phytotoxicity with the use of PSOs but comparisons are difficult due to different growing practices, spray application procedures and the properties of the oils used. In laboratory studies Liu and Stansly (1995 b) recorded irregular chlorotic spots and varying levels of desiccation on excised trifoliate tomato leaves (cv. *Lanai*) held at 25°C under fluorescent lights for several days after they were dipped once in 3% C21 Sunspray Ultrafine. Csizinszky *et al.* (1997) concluded that 12 weekly 935 L/ha sprays of 2% C23 Brandt Saf-T-Side oil could not be recommended for trellised fresh tomatoes because they reduced yields. However, their experimental design and data do not justify this conclusion; their treatments included various mulches, and only one of these treatments included oil as a spray. We applied 11, 2% Caltex Lovis sprays at Rydalmere but did not record the volume of spray/ha. At Peats Ridge we applied 13, 1% sprays to trellised plants at an average of 2,150 L of spray/ha.

Further work is required to improve control of Queensland fruit fly in PSO-based tomato IPDM programs. These studies could focus on baits and particular oil fractions. Recent studies have shown that the impact of petroleum oil molecules on Queensland fruit fly oviposition is related to the size and type of molecule (Zhongmin Liu, unpublished data). The results suggest that a product with particular distillation properties could be used as a cover spray to suppress oviposition more effectively than D-C-Tron Plus did at Peats Ridge. This work is the focus of current research.

Two-spotted mite is a relatively difficult pest to drown with PSOs (Herron *et al.* 1995) and the level of control we achieved might seem surprising. However, concurrent work on roses has shown that the mite can be controlled with fortnightly high-volume applications of 0.5% D-C-Tron Plus (Nicetic *et al.* 1997), the success of which can be partially explained by the effect of oil deposits on feeding and oviposition behaviour (Zhongmin Liu, unpublished data).

Most fungicides applied by the growers involved in our work appeared to be unnecessary. Tomato powdery mildews, for which most of the fungicides were applied, were not present at discernible levels in any experiment. However, Anjali Kallianpur (UWSH, unpublished data) has shown in laboratory bioassays related to this study that several powdery mildews, including *Oidium* sp., are very susceptible to PSOs. In other related work, Oleg Nicetic (UWSH, unpublished data) recently controlled heavy powdery mildew outbreaks in greenhouse tomatoes with two applications of 0.5 and 1% sprays of D-C-Tron Plus applied one week apart. Had the disease been present in our experiments we are confident that it would have been controlled by oil. Fungicide residues in processing tomatoes have recently been of concern in the United States of America (Precheur *et al.* 1992). Use of PSOs to control susceptible diseases could help to address this issue. However, in instances where PSOs cannot control diseases (e.g. bacterial speck and anthracnose), copper or other fungicides will still be required.

Efficacy is one of several factors that need to be assessed when determining the suitability of products for control of pests and diseases. Others include the cost of control, and health and environmental impacts. Table 19 summarises the relative costs of using common pesticides at rates registered for use on tomatoes, their application costs and the cost of using PSO. Costings are based on information contained in Infopest (Queensland Department of Primary Industries), industry sources, an average of 300 L of spray/ha for conventional chemicals (Michelle Storrier, pers. comm., 28 October 1998) and an average of 850 L for PSOs. PSOs would usually be more expensive to use than other products. For example, 1% D-C-Tron Plus would cost \$45/ha (\$17 for the oil plus \$28 for application) compared to endosulfan at \$23.95/ha (\$5.10 for product, \$1.50 for surfactant and \$17.35 for application), α-cypermethrin at \$25.15/ha (\$6.30 for product plus surfactant and application costs) and methamidaphos at 38.05/ha (\$19.20 for product plus other costs). Although rates used by industry generally exceed registered rates, the cost of most of the chemicals, when used alone, would still be \$10–20 cheaper/ha than the 850 L of spray/ha required for PSOs, using costs estimated by Riverina Contract Spraying to apply oil at 1%. In some cases costs would be similar (e.g. esfenvalerate at registered rates). Furthermore when two or more products are used simultaneously to control insects, mites and diseases (e.g. budworms, thrips, aphids, two-spotted mite and powdery mildew), as often occurs, some conventional programs would be more expensive to use than PSO alone at 1% for the same purposes. These comparisons only apply to ground rigs. Even though use and application costs for most pesticides are similar to ground rigs it is unlikely that aerially applied sprays of current PSO formulations would be effective against a wide range of pests and diseases. This means that opportunities for using PSO use in processing tomatoes in Victoria could be limited. However, the advantages of using PSOs, changes in irrigation practices and the general ineffectiveness of aerial application might encourage Victorian growers to use ground rigs.

Table 19. Relative costs of PSO and other selected products (at their registered rates) applied by ground rigs in processing tomatoes.

Product	Pests and diseases	mL or g of product/100 L	Product cost/100 L ($)	Product cost/ha/spray
PSO				
D-C-Tron Plus	aphids, looper caterpillars and budworms, leafhoppers, thrips, tomato russet mite, two-spotted mite, whiteflies, botrytis, powdery mildew	1000	2.00	17.00
Surfactant		75	0.50	1.50
Insecticides and acaricides				
Alpha cypermethrin (100 g/L)	cluster caterpillar and budworms	20–50	0.85–2.10	2.55–6.30
Betacyfluthrin (250 g/L)	budworms	40–80	1.05–2.10	3.15–6.30
Chlorpyrifos (500 g/L)	budworms, green peach aphid, green vegetable bug	150–200	2.50–3.30	7.50–9.90
Deltamethrin (25 g/L)	budworms	50	2.00	6.00
Dicofol (240 g/L)	tomato russet mite, two-spotted mite	200	3.10	9.30
Dimethoate (400 g/L)	aphids, green vegetable bug, Queensland fruit fly, thrips, tomato russet mite	60–75	0.50–0.60	1.50–1.80
Endosulfan (350 g/L)	budworms and caterpillars, aphids, green vegetable bug, greenhouse whitefly, leafhoppers, thrips, Rutherglen bug, tomato russet mite	190	1.70	5.10
Esfenvalerate (400 g/L)	cluster caterpillar, budworms	200	8.35	25.05
Methamidophos (580 g/L)	aphids, budworms	50–190	1.70–6.40	5.10–19.20
Methidathion (400 g/L)	aphids, leafhoppers, Rutherglen bug	125	3.15	9.45
Methomyl (225 g/L)	caterpillars, budworms, green vegetable bug	50–200	0.60–2.55	1.80–7.65
Monocrotophos (400 g/L)	budworms, tomato russet mite, two-spotted mite	180–250	2.75–3.80	8.25–11.40
Fungicides				
Chlorothalonil (500 g/L)	botrytis, target spot, anthracnose, fruit rots	230–300	4.00–5.30	12.00–15.90
Copper hydroxide (500 g/kg)	bacterial speck, target spot	200	1.50	4.50
Iprodione (500 g/L)	botrytis, target spot	100	6.90	20.70
Mancozeb (800 g/kg)	target spot, fruit rots	150–200	1.00–1.25	3.00–3.75
Sulphur (800 g/kg)	powdery mildew, mites	200–350	0.60–1.05	1.80–3.15

[a] Costs based on lowest prices quoted by industry sources, averages of 300 L of spray/ha for conventional pesticides and 850 L/ha for petroleum oil for seven sprays per season, with application costs of $17.35/ha and $28/ha respectively per spray. To calculate the total cost/ha/spray add product cost/ha and application cost/ha but see discussion. An average of 7.6 sprays are applied annually within the Australian processing tomato industry; see Smith *et al.* (1996) for further details including the frequency of use of pesticides in each region.

PSOs offer considerable health and environmental advantages over conventional pesticides. Although we did not assess their impact on natural enemies, work on cotton (Mensah 1997) and citrus (Weiguang Liang, UWSH, pers. comm., September 1998) suggests that their effects on predators and parasites in tomato crops should be significantly less than the effects of most synthetic pesticides. In most cases the impact of PSOs on natural enemies in tomatoes would probably be benign but detailed studies are required. Higher levels of natural enemy activity in the absence of disruptive synthetic pesticides could lead to a reduction in the number of sprays required per season and the cost of pest and disease management. Mineral oils are approved under the National Standards for Organic and Bio-dynamic Produce as materials suitable for controlling plant pests and diseases (Anonymous 1992). As such, their use should enhance the development of domestic and export markets for organic produce and help the Rural Industries Research & Development Corporation achieve its objectives (Anonymous 1998b) for organic produce. Their safety, the fact that no empirically demonstrated incident of resistance has been recorded, and our work indicates that they are ideally suited to sustainable organic and conventional IPDM programs within the fresh and processing tomato industry. Recent studies with PSOs and biopesticides (Kallianpur and Beattie, UWSH, unpublished data) indicate significant scope for improving the effectiveness and cost of organically-based IPDM programs in the tomato industries.

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APPENDIX

Ideally complete, even coverage of both sides of leaves within the canopy is required for maximum efficacy of PSOs (Beattie 1991). To achieve this when spraying processing tomato plants in a broadacre system, a different spaying system to that currently in use is required. As part of the project, a novel electric fan-assisted horizontal boom-mounted sprayer was designed at the South Australian Research and Development Institute's Loxton Research Centre. The initial configuration produced in 1994 was a prototype, which was subsequently modified over the next three years as the project progressed.

Darlington Point. It had six spray heads mounted at 1.3 m intervals on a horizontal bar. Each head comprised a plastic shroud, a six-bladed 500 mm diameter axial flow fan, and eight hydraulic nozzles mounted behind the fan. Each nozzle was fitted with SS TX 6 outjets (100 μm diameter droplets) when the conventional pesticides were used or SS TX 25 outjets (150 μm diameter droplets) when oil was used. Three heads were mounted on each side of the bar. Only one side was used during the experiment. Each fan was driven by a 415 V (AC), 3-phase 2.2 kW electric motor. Spray liquid was fed to each head at 680 kPa. Each head was directed down at about 45^{o} towards a single bed of tomatoes. The fan-assisted sprayer was operated at 8–9 km/h.

Cowra. The FAS was a three-point linkage mounted version of the sprayer used at Darlington Point, with six heads mounted at 1.3 m intervals on an 8 m bluff plate boom. This configuration was used to spray five parallel beds (each with two rows of tomatoes) simultaneously. Variation in spray volume was achieved by varying the number and type of outjet used. At a tractor speed of 5.2 km/h, 250–300 L/ha of spray was achieved using eight SS TX 6 outjets per head, 500–600 L/ha using four SS TX 25 outjets, and 800–1,000 L/ha using eight SS TX 25 outjets. At a tractor speed of 4.2 k/h, >1,200 L/ha was achieved using eight SS TX 25 outjets per head.

Gooloogong. The FAS was the same unit used at Cowra but the frame was strengthened and fitted with hydraulic rams to facilitate lowering and raising of the boom, and only five heads mounted at 1.3 m intervals on the bluff plate boom were used. The sprayer was operated at 2.9–6.0 km/h with five parallel beds being sprayed simultaneously (Appendix Table 2).

Table 1. Specifications of petroleum spray oils[a].

Characteristic	Test method[bc]	C21 Caltex Lovis	C23 Ampol D-C-Tron NR	C24 Ampol D-C-Tron Plus
Distillation temperature: °C at 101.33 kPa	ASTM D 447			
10% point		320	345	355
50% point (median)		361	380	392
90% point		393	410	421
Equivalent *n*-paraffin carbon number [c]	ASTM D 2887			
10% point		18.3	20.1	20.9
50% point (median)		21.4	23.0	24.1
90% point		24.2	25.8	27.0
Mean molecular weight density 15°C	ASTM D 4052		350	367
Viscosity: Saybolt Universal Seconds at 37.8°C	ASTM D 2161	63	64.7	75
Viscosity: Kinematic	ADTM D 445			
at 40°C		9.178	11.65	15.17
at 100°C		2.533	3.02	3.48
Pour point maximum (°C)	ASTM D 97	−15	−15	−12
Unsulphonated residue: % min volume	ASTM D 483	92.1	94	92
Density at 15°C	ASTM D 1298	0.839	0.846	0.852
Molecular types	ASTM D 3238			
C_P (paraffins)			70	69
C_N (naphthenes)			28	28
C_A (aromatics)			2	3

[a] Supplied by Ampol Research and Development and Caltex Oil (Australia) Pty Ltd.
[b] American Society for Testing Materials (1961).
[c] American Society for Testing Materials (1983).

Table 2. Details of sprayer operation at Gooloogong.

Date	Operation	Treatment[a]			
		D-C-Tron Plus with FAS	Conventional pesticides with HBB	D-C-Tron Plus with HBB	D-C-Tron Plus and selected conventional pesticides with HBB
23 Dec 96	Tractor speed	6 km/h	9 km/h	km/h	km/h
	Nozzle type	High volume outjets	TX 18	TX 18	TX 18
	Number of heads	5	3	3	3
3 Jan 97	Tractor speed	6 km/h	km/h	6 km/h	6 km/h
	Nozzle type	High volume outjets	1553–20	1553–30	1553–30
	Number of heads	5	10	10	10
14 Jan 97	Tractor speed	6 km/h	km/h	2.6 km/h	2.6 and 6 km/h
	Nozzle type	High volume outjets	1553–20	1553–30	1553–30
	Number of heads	5	10	10	10
24 Jan 97	Tractor speed	6 km/h	km/h	2.6 km/h	2.6 km/h
	Nozzle type	High volume outjets	1553–20	1553–30	1553–30
	Number of heads	5	10	10	10
4 Feb 97	Tractor speed	3.8 km/h	7–8 km/h	2.6 km/h	2.6 km/h
	Nozzle type	High volume outjets	1553–20 + two droplegs	1553–30+two droplegs	1553–30 + two droplegs
	Number of heads	5	10	10	10
18 Feb 97	Tractor speed	3.2 km/h	7–8 km/h	2.6 km/h	2.6 km/h
	Nozzle type	High volume outjets	1553–20 + two droplegs	1553–40 +1553–30 (two droplegs)	1553–40 +1553–30 (two droplegs)
	Number of heads	5	10	10	10
28 Feb 97	Tractor speed	3.2 km/h	7–8 km/h	2.6 km/h	2.6 km/h
	Nozzles type	High volume outjets	1553–20+two droplegs	1553–40+1553–30 (two droplegs)	1553–40+1553–30 (two droplegs)
	Number of heads	5	10	10	10
11 Mar 97	Tractor speed	2.9 km/h	7–8 km/h	2.6 km/h	2.6 km/h
	Nozzle type	High volume outjets	1553–20+1553–30 (two droplegs)	1553–40+1553–30 (two droplegs)	1553–40+1553–30 (two droplegs)
	Number of heads	5	10	10	10

[a] HBB = Hardi broadacre boom sprayer; FAS = fan-assisted sprayer.

Table 3. Details of sprayer operation at Peats Ridge.

Date of spray	Tractor speed	Tank pressure	Nozzle(s)	Discharge rate/nozzle
27 Dec, 6 Jan, 14 Jan	2.75 km/h	150 kPa	one, spray gun	5.7 L/min
2 Feb, 10 Feb	3.00 km/h	200 kPa	two nozzles (1.8 mm)	6.2 L/min
19 Feb onwards	3.75 km/h	200 kPa	three nozzles (1.8mm) and one nozzle (2.0 mm) from additional spray line	6.5 L/min 2.8 L/min (spray line nozzle)

Table 4. Mean (± SD) spray coverage on leaves sprayed on 22 February 1995 at Darlington Point and 11 January 1996 at Cowra using different sprayers.

Location	Treatment[a]	Spray coverage (%)[a]
Darlington Point	Pesticides with HMV at 200 L/ha	45 ± 26a
	Pesticides with FAS at 200–600 L/ha	55 ± 19a
	D-C-Tron NR with Envirofeast with FAS at 600–2000 L/ha	80 ± 19b
	Anova results	$F_{2, 57} = 10.5$, $p < 0.001$
Cowra	1% D-C-Tron Plus with FAS at 250–300 L/ha	39 ± 26c
	1% D-C-Tron Plus with FAS at 500–600 L/ha	57 ± 31b
	1% D-C-Tron Plus with FAS at 800–1,000 L/ha	74 ± 19ab
	1% D-C-Tron Plus with FAS at >1,200 L/ha	81 ± 17a
	Anova results	$F_{3, 20} = 3.69$, $p = 0.029$

[a] HMV = Hardi Mini Variant air-assisted sprayer; FAS = fan-assisted sprayer.

[b] Means followed by the same letter(s) within a Location were not significantly different (Ryan's Q test).

Table 5. Effect of sprayer type, spray volume, and canopy position on spray coverage on processing tomato leaves at Gooloogong in 1997 (means ± SD).

Leaf surface, sprayer and spray volume[a]	Spray coverage (%) on leaves				
	Top	Middle	Lower	Lateral left	Lateral right
Mature green fruit on 3 February 1997					
Lower					
HBB at 150 L/ha	6 ± 4	1 ± 3	0 ± 0	5 ± 5	2 ± 2
HBB at 600 L/ha	27 ± 7	19 ± 10	10 ± 7	27 ± 17	39 ± 17
HBB at 1,200 L/ha	41 ± 12	30 ± 7	21 ± 6	27 ± 5	27 ± 5
FAS at 800 L/ha	35 ± 14	28 ± 6	18 ± 9	27 ± 5	30 ± 2
FAS at 1,200 L/ha	54 ± 21	52 ± 20	43 ± 10	47 ± 12	38 ± 13
FAS at 1,800 L/ha	100 ± 0	78 ± 10	53 ± 14	73 ± 13	48 ± 22
Upper					
HBB at 150 L/ha	18 ± 10	7 ± 6	6 ± 5	19 ± 6	11 ± 8
HBB at 600 L/ha	69 ± 7	73 ± 5	66 ± 5	64 ± 17	53 ± 20
HBB at 1,200 L/ha	90 ± 6	71 ± 6	66 ± 5	64 ± 10	64 ± 10
FAS at 800 L/ha	76 ± 12	49 ± 28	22 ± 11	60 ± 11	42 ± 10
FAS at 1,200 L/ha	100 ± 0	90 ± 18	90 ± 9	61 ± 11	56 ± 10
FAS at 1,800 L/ha	100 ± 0	93 ± 7	80 ± 7	93 ± 11	85 ± 21
Fruit ripening on 11 March 1997					
Lower					
HBB at 800 L/ha	25 ± 6	12 ± 11	6 ± 7	28 ± 22	34 ± 21
HBB at 1,200 L/ha	31 ± 12	26 ± 4	14 ± 9	22 ± 9	20 ± 12
FAS at 1,200 L/ha	63 ± 12	53 ± 12	44 ± 10	40 ± 16	38 ± 13
FAS at 1,600 L/ha	100 ± 0	71 ± 17	53 ± 14	74 ± 14	50 ± 20
Upper					
HBB at 800 L/ha	67 ± 9	62 ± 10	56 ± 10	60 ± 13	41 ± 25
HBB at 1,200 L/ha	91 ± 7	65 ± 11	58 ± 10	75 ± 19	61 ± 12
FAS at 1,200 L/ha	100 ± 0	83 ± 13	85 ± 8	58 ± 10	55 ± 11
FAS at 1,600 L/ha	100 ± 0	94 ± 7	78 ± 13	87 ± 21	83 ± 17

[a] HBB = Hardi broadacre boom; FAS = fan-assisted sprayer.

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