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Potato/tomato psyllid in New Zealand: immediate options for control with insecticides

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Contents

1 Executive summary

The potato/tomato psyllid (*Bactericera cockerelli* (Hemiptera, Triozidae)) is a new invasive species in New Zealand. It is difficult to control with insecticides that are compatible with biological control of whitefly, thrips and two-spotted mite. Growers require information on insecticides and biocontrol agents that might be quickly developed for control of this insect in New Zealand. A literature and internet review was conducted on insecticides that might be used for potato/tomato psyllid control in covered crops in New Zealand.

1.1 Findings

A list of insecticides for potential use in the management of the potato/tomato psyllid in covered crops in New Zealand is provided. These chemicals have been selected with reference to their current registration in New Zealand, their reported efficacy on potato/tomato psyllid and other psyllids overseas, and their compatibility with current IPM programmes. These compounds include:

- Insecticides currently registered for covered crops in New Zealand: abamectin, buprofezin, neem seed derived products, canola oil, and pymetrozine. For growers not using bees or biological control, permethrin/pirimiphos-methyl (Attack®) is an option.
- Insecticides currently registered for other crops in New Zealand: diflubenzuron, imidacloprid, spinosad and sulphur. For pre-flowering crops not using bees or biological control, endosulfan is an option.
- Insecticides not registered for any crop in New Zealand: pyriproxyfen, spiromesifen (although registration is in progress), and active ingredients from chemical groups with the same mode of action (MoA) as diflubenzuron (MoA group 15) and imidacloprid (MoA group 4).
- Other compounds: kaolin-based particle film and sucrose octanoate.

By listing the insecticides above, we do not endorse their use in any way in covered crops outside of label claims. However, it should be noted that growers can use non-registered pesticides provided that they do not cause residues to exceed the maximum residue levels (MRLs) on produce at the time of harvest. Since, the default MRLs are very low, promising insecticides require residue data suitable for defining MRLs. Application of any insecticide through the irrigation system or to the roots of plants without an MRL is not advised as some insecticides persist in the plant for a long time.

2 Background

The potato/tomato psyllid (*Bactericera cockerelli* (Hemiptera, Triozidae)) is a new invasive species in New Zealand and is difficult to control with insecticides compatible with biological control of whitefly, thrips and two-spotted mite.

Growers require information on insecticides and biocontrol agents that might be quickly developed for control of this insect in New Zealand.

2.1 Project objectives

To identify insecticides and biocontrol agents that could be used in the near future for control of the potato/tomato psyllid in covered crops in New Zealand.

2.2 Project proposal

2.2.1 Insecticides

Undertake a literature and internet review on insecticides that might be used for potato/tomato psyllid control in covered crops in New Zealand and provide recommendations on efficacy, registration issues, and compatibility with current IPM programmes.

2.2.2 Biocontrol agents

Undertake a literature and internet review to determine the range of psyllid species and their natural enemies (predators, parasitoids, pathogens) found in New Zealand and indicate whether any natural enemies could be used for biocontrol of the potato/tomato psyllid in covered crops. This is reported separately.

3 Methods

Insecticides in New Zealand were checked in the NZ Agrichemical Manual 2007, an on-line database (www.spraybible.com), and a computer database, (Procheck). An internet search (www.google.com) and literature search (Web of Science) were done to establish current and potential use of insecticides for management of the potato/tomato psyllid. Overseas experts were also consulted directly.

Information on the safety of pesticides for biological control agents and bumble bees was taken from Biobest (http://www.biobest.be/) and Koppert (http://www.koppert.nl/e005.shtml).

4 Results

The information on pesticides is organised in three sections: insecticides registered for use in greenhouses in New Zealand; insecticides that are recommended by others elsewhere for control of potato/tomato psyllid or have shown promise in laboratory or field trials; insecticides that are used to control other psyllids. Information in each section is summarised in tables and briefly discussed.

4.1 Insecticides registered for greenhouse use in NZ

Table 1 lists insecticides currently registered for use in greenhouses in New Zealand and gives details of the pests and crops on which they are used. Growers also use insecticides that are not registered for use on greenhouses crops, (NA Martin, unpublished data 2004). In New Zealand no insecticide has a label claim for control of any psyllid species. Abamectin (Valle et al. 2005), buprofezin (Barrion et al. 1987; Pena et al. 1999; Dreistadt et al. 2001), dichlorvos (Yue 2001), neem (Al-Jabr 1999) and pymetrozine (Liu & Trumble 2005) have been used successfully overseas to control potato or other psyllids.

4.2 Insecticide control of potato/tomato psyllid in greenhouses overseas

Overseas information on insecticides for control of the potato/tomato psyllid includes laboratory and field trials for greenhouse and outdoor crops as well as recommendations for control (Table 2). Most of these insecticides are available in New Zealand, but only a few are registered for use on greenhouse crops and not all are compatible with use of biological control organisms and bumble bees. Some of the newer active ingredients not yet available in New Zealand may be more compatible with biological control. Most of the information on the newer insecticides is based on laboratory and field trials and there is little experience with control in the field. There are relatively few recommendations for the potato/tomato psyllid in covered crops overseas. For example, there are no pesticides that are specifically recommended for psyllids in greenhouse crops in Ontario (Ferguson 2003). Insecticides that are best suited for management of the potato/tomato psyllid in covered crops in New Zealand are discussed in more detail below.

4.3 Insecticides used for psyllid (all species) control overseas

Many insecticides have been used overseas for the management of psyllids other than potato/tomato psyllid (Table 3). Many of the insecticides reported for psyllids other than the potato/tomato psyllid belong to groups of insecticides with the mode of action (MoA) that have been used for the control of potato/tomato psyllid, e.g. carbamates (MoA group 1A), neonicotinoids (MoA group 4), organophosphates (MoA group 1B) and pyrethroids (MoA group 3). Note that not all products with the same active ingredient have registrations for all crops and all pests listed. Insecticide MoA classifications have been made by the Insecticide Resistance Action Committee (IRAC) (Baker 2005).

There are also some MoA groups not used on potato/tomato psyllid, e.g. chitin biosynthesis inhibitors (MoA group 15), and octopaminergic agonists (MoA group 19). In addition, a number of 'alternative' compounds have been reported, such as kaolin, sucrose octanoate, petroleum mineral oils, fresh pine & spruce sawdust mulch, and turpentine & separate monoterpene hydrocarbons.

5 *Insecticides for potential use for management of potato/tomato psyllid in covered crops in New Zealand*

The following insecticides show potential for potato/tomato psyllid management in covered crops in New Zealand. These chemicals have been selected with the following criteria in mind:

- Registration status in covered crops in New Zealand;
- Reported efficacy on potato/tomato psyllid and other psyllids overseas;
- Compatibility with current IPM programmes especially with respect to toxicity to non-target organisms such as parasitoids and predators of pests and pollinators;
- Potential for potato/tomato psyllid and other insect and mite pests to develop resistance to the insecticides.

5.1 *Insecticides registered for covered crops in New Zealand*

5.1.1 *Broad spectrum insecticides, Mode of Action Groups 1A, 1B, and 3*

Several broad spectrum insecticides such as carbamates, (MoA group 1A), organophosphates (MoA group 1B), and synthetic pyrethroids (MoA group 3), have been used to control potato/tomato psyllid (Table 2) and other psyllids (Table 3) overseas and several of these products are registered for use in covered crops in New Zealand, or are regularly used by growers prior to fruit set (NA Martin, unpublished data). In general, these insecticides kill the natural enemies of pests (Tables 4 and 5) and can disrupt biological control so they are not considered further here.

5.1.2 Abamectin (Apostle, Avid, Verdex 18 EC)

Abamectin (MoA group 6) has a label claim for mite control in greenhouse tomato crops (Table 1). The potato/tomato psyllid was very susceptible to the chemical in preliminary laboratory tests (Table 2) and is regarded as very promising for field control (JT Trumble, pers. comm. 2006).

Abamectin is toxic for 1 or more weeks after application to most of the natural enemies used for control of greenhouse crop pests, but it is compatible with the use of bumble bees (Tables 4 and 5).

5.1.3 Buprofezin (Buprofezin, Ovation 50 WDG, Pilan)

Buprofezin (MoA group 16) is registered for control of whitefly in greenhouse vegetables and control of other Hemiptera (Table 1). It does not appear to have been tested for control of potato/tomato psyllid, but has been used overseas to control some citrus psyllids and other psyllids (Table 3).

Buprofezin is harmless to biological control agents used in New Zealand greenhouse vegetable crops and is compatible with bumble bees (Tables 4 and 5).

5.1.4 Neem seed derived products (Neem 600WP, Neemazal – T/S)

Neem seed derived insecticides are registered for use against insect pests in New Zealand greenhouses (Table 1) and showed some activity when applied to potato/tomato psyllid (Al-Jabr 1999). They have been used for control of other species of psyllids (Dreistadt et al. 2001; Rajendran et al. 2001; Lababidi 2002).

Azadirachtin (an active ingredient in neem oil, MoA group 26) is harmless or moderately toxic to natural enemies used to control greenhouse crop pests and is compatible with the use of bumble bees (Tables 4 and 5).

5.1.5 Pymetrozine (Chess)

Pymetrozine (MoA group 9B) has a label claim for control of aphids and whitefly on tomatoes in New Zealand greenhouses and was effective against the potato/tomato psyllid in greenhouse tomato studies in California (Liu & Trumble 2005). It is now recommended for potato/tomato psyllid control in tomato crops in California, USA (www.ipm.ucdavis.edu/PMG/r783303011.html). It is recommended for use against potato/tomato psyllids in greenhouses (Zalom et al. 2007). The addition of a non-ionic wetting agent (e.g. DC-Tron) is strongly recommended for use with this insecticide to improve its efficacy (G Follas, Syngenta, pers. comm.).

Pymetrozine is relatively harmless to natural enemies of greenhouse pests and safe for use with bumble bees (Tables 4 and 5).

5.2 Insecticides registered for other crops in New Zealand

By listing the insecticides below, we do not endorse their use in covered crops in any way outside of label claims.

5.2.1 Broad-spectrum insecticides, Mode of Action Groups 1A, 1B, 2A and 3

Some growers use broad-spectrum insecticides such as carbamates, (MoA group 1A), organophosphates (MoA group 1B), cyclodine organochlorines (MoA group 2A) and synthetic pyrethroids (MoA group 3), before flowering and fruit set (NA Martin, unpublished data). Some of these insecticides have been used to control potato/tomato psyllid (Table 2) and other psyllids overseas (Table 3). In general, these insecticides kill the natural enemies of pests (Tables 4 and 5) and can disrupt biological control so most are not considered further here. However, endosulfan, for example, was widely used by greenhouse tomato growers (NA Martin, unpublished data 2004) probably on small plants and may have a place in psyllid control prior to the first flower opening for tomato growers not using biological control.

5.2.2 Diflubenzuron (Dimilin 25 WP, Sniper) (MoA group 15)

Diflubenzuron is registered for control of a variety of insects in New Zealand, though not on vegetable crops. Overseas it has been used for control of pear psyllid (Table 3). It is harmless to natural enemies of greenhouse crop pests, but is not compatible with the use of bumble bees (Tables 4 and 5).

5.2.3 Imidacloprid (Confidor, Gaucho) and other neonicotinoids (MoA group 4)

Imidacloprid is registered for control of aphids and thrips on vegetable crops in New Zealand and beetles and Lygaeidae (Hemiptera) on other crops. Thiacloprid (Calypso) is registered for use on fruit crops (www.spraybible.com).

Imidacloprid gave good control of potato/tomato psyllid in greenhouse trials when watered onto the soil (Liu & Trumble 2004, 2005; Trumble 2006). It is now recommended for potato/tomato psyllid control in tomato crops in California, USA (www.ipm.ucdavis.edu/PMG/r783303011.html) and as a soil treatment for potatoes (Cranshaw & Hein 2004). Imidacloprid has been reported to be effective against a range of psyllids when used as drench and as a spray application (Table 3). Injection into the irrigation water has least impact on natural enemies in Californian tomato crops (JT Trumble pers. comm. 2006).

Imidacloprid sprayed onto plants is harmful to natural enemies of many greenhouse crop pests, though when applied as a drench or through the irrigation system, it is safe (Tables 4 and 5). However, both methods of application are not compatible with use of bumble bees.

Other neonicotinoid insecticides have been tested for control of potato/tomato psyllid, some with promising results, and some are recommended for field control of the psyllid on potatoes (Table 2). They have also been used in trials to control other species of psyllids (Table 3)

5.2.4 *Spinosad (Nursery Success Naturalyte, Success Naturalyte) (MoA group 5)*

Spinosad is registered for caterpillar control on fruit and vegetable crops in New Zealand (www.spraybible.com). In field trials overseas, it has shown promise for control of potato/tomato psyllid on capsicums and tomatoes (Table 2). Spinosad is compatible with the use of bumble bees, but there are mixed reports about its safety with biological control agents used in greenhouses (Tables 4 and 5).

5.2.5 *Sulphur*

Sulphur, which is normally used to control diseases in greenhouse and outdoor crops, used to be used for mite control. In the USA it is recommended for potato/tomato psyllid control on tomatoes in greenhouses (Table 2). Sulphur is compatible with use of bumble bees. It is harmful to *Encarsia formosa* (whitefly parasitoid), though safer with other natural enemies (Tables 4 and 5).

5.3 *Insecticides not registered in New Zealand*

By listing the insecticides below, we do not endorse their use in any way in covered crops outside of label claims.

5.3.1 *Amitraz*

Amitraz has been effective alone or in combination with diflubenzuron for control of pear psyllid in pear orchards in IPM programmes in Europe (Baudry 1994; Milenkovic et al. 1998; Champagne & Bylemans 1999). Amitraz may be phytotoxic if applied early in the season but had little effect on the anthocorid, *Anthocoris nemoralis*.

5.3.2 *Other chitin biosynthesis inhibitors (MoA group 15)*

Flufenoxuron and teflubenzuron, which belong to the same mode of action group as diflubenzuron, gave good control of 1^{st}-2^{nd} instars of pistachio psyllid (*A. targionii*) (Lababidi 2002; Saour 2005) (Table 3) and may have similar safety to natural enemies of pests as diflubenzuron.

5.3.3 *Pyriproxyfen*

Pyriproxyfen is a juvenile hormone mimic (MoA group 7C) that gave promising results in greenhouse tomato experiments and laboratory studies (Table 2). It is now recommended for potato/tomato psyllid control in tomato crops in California, USA (www.ipm.ucdavis.edu/PMG/r783303011.html). The insecticide is used overseas for whitefly control in greenhouse crops and is harmless to adult Encarsia formosa and other natural enemies used in greenhouses, and is compatible with the use of bumble bees (Tables 4 and 5).

5.3.4 Spiromesifen

In the USA, spiromesifen effectively controlled the potato/tomato psyllid in tomato, capsicum and potato crops (Table 2). It also gives good control of two-spotted mite, tomato russet mite and whitefly (Elbert et al. 2005). There is little information about safety for natural enemies used for control of greenhouse pests, though spiromesifen is compatible with bumble bees, safe for adult parasitoids, but moderately harmful to predatory mites (Tables 4 and 5). This spectrum of activity makes the insecticide more suitable for use with greenhouse tomatoes than with greenhouse capsicums.

5.4 Other compounds

5.4.1 Kaolin (aluminium silicate)

Kaolin-based particle film controlled potato psyllid on tomato plants in California (Liu & Trumble 2005) (Table 2) and partly controlled pistachio psyllid Agonoscena targionii in Syria (Saour 2005). The kaolin formulation, Surround, has been used for psyllid control (Table 3) and is used in New Zealand to protect apple trees and grape vines from sunburn and heat stress. Repeated spraying would be needed on actively growing greenhouse vegetable plants. It leaves a white deposit on leaves and fruit, which would have to be washed off.

5.4.2 Sucrose octanoate

In field trials in Florida, McKenzie & Puterka (2004) found that a formulation of a synthetic analogue of a natural sugar ester (sucrose octanoate) from leaf trichomes of wild tobacco, Nicotiana gossei, controlled the Asian citrus psyllid, Diaphorina citri, on citrus.

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Table 1: Insecticides registered for use in greenhouses in New Zealand (NZ Agrichemical Manual 2007 and www.spraybible.com).

Active ingredient	Product (New Zealand)	IRAC Mode of Action number, Group; chemical class**		Greenhouse crops with registrations*	Target pests in New Zealand greenhouses [& other crops]*
Abamectin	Apostle, Avid, Verdex 18 EC	6	Chloride channel activators; avermectins, Milbemycins	Tomatoes, ornamentals	Tomato russet mite, two-spotted mite
Bacillus thuringiensis	Agree WDG, Delfin WG, Dipel ES, Hortcare Bactur 48 LC, Hortcare Bactur WDG, XenTri WG, Dipel DF	Btk 11B2, Bta 11B1	Microbial disruptors of insect midgut membranes	Tomatoes – glasshouse	Looper caterpillar, tomato fruitworm
Buprofezin	Buprofezin, Ovation 50 WDG, Pilan	16	Inhibitors of chitin biosynthesis, type 1 Homopteran; Buprofezin	Cucumbers, eggplant, gerbera, melons, ornamentals, pepino, peppers, tomatoes, zucchini	Whitefly [leafhopper, mealybugs, scale]
Canola oil	Eco-oil		Contact	Protected crops	Greenhouse whitefly, green peach aphid, two-spotted mite, scales
Dichlorvos	Nuvos	1B	Acetylcholine esterase inhibitor; Organophosphate	Glasshouses	Aphids, caterpillars, mites, sciarid fly, thrips and whitefly
Methomyl	Lannate L	1A	Acetylcholine esterase inhibitor; Carbamate	capsicums, cucumber and tomatoes	Whitefly green peach aphid, looper caterpillar, tomato fruit worm [caterpillars, aphids]
Neem seed kernel extract	Neem 600WP Neemazal - T/S	18B	Ecdysone agonists / moulting disruptors;	Not specified	Aphids, thrips, whitefly, leafmining flies, mealy bug and scale
Permethrin + pirimiphos-methyl	Attack	3 1B	Sodium channel modulators; Pyrethroid Acetylcholine esterase inhibitor; Organophosphate	Cucurbits, tomatoes, ornamentals under glass	Whitefly
Pirimiphos-methyl	Actellic smoke generator	1B	Acetylcholine esterase inhibitor; Organophosphate		Greenhouse whitefly
Pymetrozine	Chess	9B	Selective feeding blocker	Tomatoes	Aphids, whitefly
Pyrethrum	Garlic & pyrethrum concentrate	3	Sodium channel modulators; Pyrethrins	No specific registration for greenhouse crops	[Aphids, cabbage moth, caterpillars, greenhouse whitefly, leaf hoppers, thrips]
Tau-fluvalinate	Mavrik Aquaflo, Nursery Mavrik	3	Sodium channel modulators; Pyrethroid	Ornamentals, cut flowers [and outdoor vegetables]	Aphids, caterpillars, European red mite, thrips, two-spotted mite, whitefly

* Note not all products with the same active ingredient have registrations for all crops and all pests listed.

** Insecticide mode-of-action classifications by Insecticide Resistance Action Committee (IRAC) (Baker 2005).

Table 2: Insecticides used for potato/tomato psyllid (Bactericera cockerelli) management overseas.

Active ingredient	NZ trade name(s)*	IRAC Mode of Action number **, Group, chemical class		Crop	Reference(s)
Abamectin	Apostle, Avid, Verdex 18 EC	6	Chloride channel activators, Avermectins, Milbemycins	Lab tests on eggs & nymphs	Valle et al. 2005
Acetamiprid		4	Nicotinic Acetylcholine receptor agonists / antagonists, Neonicotinoids	Greenhouse tomato	Al-Jabr 1999
Aluminium silicate coated + synthetic hydrocarbon			Kaolin-based particle film	Greenhouse tomato, experimental spray	Liu & Trumble 2005
Chlorpyrifos	Lorsban & others	1B	Acetylcholine esterase inhibitor Organophosphate	Capsicum spray trial	Aviles-Gonzalez et al. 2005
Clothianidin		4	Nicotinic Acetylcholine receptor agonists / antagonists, Neonicotinoids	Capsicum spray trial	Aviles-Gonzalez et al. 2005
Endosulfan	Flavylan 350 EC, Thiodan 35 EC, Thionex	2A	GABA-gated chloride channel antagonists; Cyclodiene organochlorines	Foliar application to potatoes	Cranshaw & Hein 2004
Imidacloprid	Confidor, Gaucho	4	Nicotinic Acetylcholine receptor agonists / antagonists; Neonicotinoids	Greenhouse tomato soil	Liu & Trumble 2005
				Laboratory studies	Zalom et al. 2007
				Soil treatment for potato, foliar spray for potatoes	Cranshaw & Hein 2004
Imidacloprid + cyfluthrin	Confidor Supra	4	Nicotinic Acetylcholine receptor agonists / antagonists; Neonicotinoids	Foliar spray for potatoes	Cranshaw & Hein 2004
		3	Sodium channel modulators; Pyrethroid		
Methamidophos	Metafort 60 SL, Monitor, Tamaron	1B	Acetylcholine esterase inhibitor; Organophosphate	Foliar application to potatoes	Cranshaw & Hein 2004
Neem	Neem 600WP Neem Azal-T/S	18B	Ecdysone agonists / moulting disruptors	Greenhouse tomato	Al-Jabr 1999

Active ingredient	NZ trade name(s)*	IRAC Mode of Action number **, Group, chemical class		Crop	Reference(s)
Permethrin esfenvalerate	various	3	Sodium channel modulators; Pyrethroid	Tomatoes, spray	Cranshaw 2006
Phorate	Phorate, Thimet	1B	Acetylcholine esterase inhibitor; Organophosphate	Soil treatment to potatoes at planting	Cranshaw & Hein 2004
Pymetrozine	Chess	9B	Selective feeding blocker	Greenhouse tomato trial	Liu & Trumble 2005
Pyriproxyfen		7C	Juvenile hormone mimics	Greenhouse tomato trial	Liu & Trumble 2005
Pyrethrins + piperonyl butoxide		3	Sodium channel modulators Pyrethrins + esterase antagonist	Greenhouse tomato spray recommendation	Selina & Bledsoe 2002
Spinosad	Nursery Success Naturalyte, Success Naturalyte	5	Nicotinic Acetylcholine receptor agonists (allosteric) (not group 4)	Greenhouse tomato trial	Liu & Trumble 2005
				Greenhouse tomato	Al-Jabr 1999
				Capsicum field trial	Aviles-Gonzalez et al. 2005
Spiromesifen		23	Inhibitors of lipid synthesis, tetronic acid derivatives	Field trials in capsicum, tomato, potato crops	Elbert et al. 2005
				Capsicum field trial	Aviles-Gonzalez et al. 2005
Sulphur	Various		None	Dusting tomatoes	Cranshaw 2006
Thiaethoxam		4	Nicotinic Acetylcholine receptor agonists / antagonists; Neonicotinoids	Soil treatment for potato, foliar spray for potatoes	Cranshaw & Hein 2004

* Note the formulations in New Zealand may be different from the products or experimental compounds used overseas.
** Insecticide mode-of-action classifications by Insecticide Resistance Action Committee (IRAC) (Baker 2005).

Table 3: Insecticides used for psyllid management (excluding potato/tomato psyllid) overseas.

Active ingredient	Trade name(s) in New Zealand*	Insecticide group, chemical class; IRAC Mode of Action number***		Psyllid/crop and application**	Reference(s)
Abamectin	Apostle, Avid, Verdex 18 EC	6	Chloride channel activators; Avermectins, Milbemycins	Psyllids in general	Dreistadt et al. 2001
				Pear psyllid (*Cacopsylla pyri*) in apple, pear & peach crops	Chireceanu & Drosu 2002
				Pear psyllid (*Cacopsylla pyri*)	Pasqualini & Civolani 2006
				+ white oil on pear psyllid (*Cacopsylla pyri*) in pear orchards	Pollini et al. 1992
Acephate	Lancer 750 DF, Orthene WSG	1B	Acetylcholine esterase inhibitor; Organophosphate	Psyllids in general	Dreistadt et al. 2001
				Acizzia indica on *Albizia lebbeck* trees	Rajendran et al. 2001
Acetamiprid	Saurus (overseas name)	4	Nicotinic Acetylcholine receptor agonists / antagonists, Neonicotinoids	Citrus psyllid *(Diaphorina citri*) in greenhouse	Nakano et al. 1999
Amitraz	Mitaban, Preventic (overseas names)	19	Octopaminergic agonists	Pear psyllid (*Cacopsylla pyri*) in pear orchards	Milenkovic et al. 1998; Champagne & Bylemans 1999; Yue 2001
Amitraz and diflubenzuron		19 15	Octopaminergic agonists plus Inhibitors of chitin biosynthesis, type 0, Lepidopteran; Benzoylureas	Foliar mixture to pear psyllid (*Cacopsylla pyri*) in pear orchard	Milenkovic et al. 1998
Azadirachtin	Neem Azal-T/S	18B	Ecdysone agonists / moulting disruptors	Psyllids in general	Dreistadt et al. 2001
				Asian citrus psyllid (*Diaphorina citri*)	Weathersbee & McKenzie 2005
Buprofezin	Buprofezin, Ovation 50 WDG, Pilan	16	Inhibitors of chitin biosynthesis, type 1, Homopteran	Citrus psyllid (*Diaphorina citri*) on lime trees	Pena et al. 1999
				Leucaena psyllid (*Heteropsylla cubana*) on Leucaena	Barrion et al. 1987
Carbaryl	Various	1A	Acetylcholine esterase inhibitor; Carbamate	Psyllids in general	Dreistadt et al. 2001
Λ-cyhalothrin	Karate	3	Sodium channel modulators; Pyrethroid	Oriental psyllid (*Diaphorina citri*)	Pellizzari et al. 2005
				Pistachio psyllid (*Agonoscena targionii*)	Saour 2005
Deltamethrin	Ballistic, Decis Forte Deltaphar 25 EC, Cislin, Insectigone	3	Sodium channel modulators; Pyrethroid	Foliar to pear psyllid (*Cacopsylla pyri*) on pear trees	Bylemans 2002; Bues et al. 2003
				Soil drench olive psyllid (*Euphyllura olivina*) on olive trees	Chermiti & Onillon 1993
				At leaf fall on pear psyllid (*Cacopsylla pyri*) in pear orchards	Pollini et al. 1992

Active ingredient	Trade name(s) in New Zealand*	Insecticide group, chemical class; IRAC Mode of Action number***		Psyllid/crop and application**	Reference(s)
				Pear psyllid (*Cacopsylla pyri*) in pear orchards	Bylemans 2002
Dichlorvos	Nuvos	1B	Acetylcholine esterase inhibitor; Organophosphate	Pear psyllid (*Cacopsylla pyri*) in pear orchard	Yue 2001
Diflubenzuron	Dimilin 25 WP, Sniper	15	Inhibitors of chitin biosynthesis, type 0, Lepidopteran; Benzoylureas	Foliar to pear psyllid (*Cacopsylla pyri*) on pear trees	Szeoke 1995
Dimethoate	Dimezyl 40 EC Perfekthion S	1B	Acetylcholine esterase inhibitor; Organophosphate	Soil drench for olive psyllid (*Euphyllura olivina*) on olive trees	Chermiti & Onillon 1993
DNOC		13	Uncouplers of oxidative phosphorylation via disruption of proton gradient	At oviposition of pear psyllid (*Cacopsylla pyri*) in pear orchards	Pollini et al. 1992
Flufenoxuron		15	Inhibitors of chitin biosynthesis, type 0, Lepidopteran; Benzoylureas	1^{st}-2^{nd} instars of pistachio psyllid (*Agonoscena targionii*) on pistachio trees	Lababidi 2002
Fluvalinate	Mavrik (taufluvalinate)	3	Sodium channel modulators; Pyrethroid	Psyllids in general	Dreistadt et al. 2001
Fresh pine &spruce sawdust mulch			Turpenoids	Carrot psyllid (*Trioza apicalis*) in carrot fields	Nehlin et al. 1994
Imidacloprid	Confidor, Gaucho	4	Nicotinic Acetylcholine receptor agonists / antagonists; Neonicotinoids	Soil drench and foliar application to psyllids in general	Dreistadt et al. 2001
				Endotherapy to oriental psyllid (*Acizzia jamatonica*) on ornamental shade tree	Pellizzari et al. 2005
				Foliar to apple psyllid (*Cacopsylla mali*) in apple orchards	Yanovskii & Larcheva 2000
				Foliar to pear psyllid (*Cacopsylla piricola*) in pear orchard	Yue 2001
				Foliar to citrus psyllid (*Diaphorina citri* on trees in orchard & greenhouse	Nakano et al. 1999
Kaolin	Surround		Kaolin-based particle film	Pistachio psyllid (*Agonoscena targionii*) on pistachio trees	Saour 2005
				Pear psyllid (*Cacopsylla pyri*) on pear trees	Daniel et al. 2005
Malathion (= maldison)	Various	1B	Acetylcholine esterase inhibitor; Organophosphate	Psyllids in general	Dreistadt et al. 2001
Methomyl	Lannate L	1A	Acetylcholine esterase inhibitor; Carbamate	Longan psyllid (*Neophacopteron auporine*)	Wen et al. 2002
Mineral oil	Various		Mineral oil	Pear psyllid (*Cacopsylla pyri*) on pear trees	Liang et al. 2004
					Capella et al. 1998

Active ingredient	Trade name(s) in New Zealand*	Insecticide group, chemical class; IRAC Mode of Action number***		Psyllid/crop and application**	Reference(s)
Monocrotophos	Nuvacron 36 EC	1B	Acetylcholine esterase inhibitor; Organophosphate	*Indigofera tinctoria* against psyllid *Arytaina punctipennis*	Skaria et al. 1996
Neem oil		18B	Ecdysone agonists / moulting disruptors	*Acizzia indica* on *Albizia lebbeck* trees	Dreistadt et al. 2001
				Pistachio psyllid (*Agonoscena targionii*) on pistachio trees	Lababidi 2002
				Acizzia indica on *Albizia lebbeck* in forest nurseries	Rajendran et al. 2001
Permethrin	Various	3	Sodium channel modulators; Pyrethroid	Psyllids in general	Dreistadt et al. 2001
Potassium salts of fatty acids			Insecticidal soap	Psyllids in general	Dreistadt et al. 2001
				Pear psyllid (*Cacopsylla pyri*) on pear trees	Pasqualini et al. 1997
Spiromesifen		23	Inhibitors of lipid synthesis; tetronic acid derivatives	Psyllids on vegetables and field crops	Elbert et al. 2005
Sucrose octanoate			Sugar	Sprayed on citrus trees against Asian citrus psylla (*Diaphorina citri*)	McKenzie & Puterka 2004
Teflubenzuron		15	Inhibitors of chitin biosynthesis, type 0, Lepidopteran; Benzoylureas	1^{st}-2^{nd} instars of pistachio psyllid (*Agonoscena targionii*) on pistachio trees	Lababidi 2002; Saour 2005
Thiacloprid	Calypso	4	Nicotinic Acetylcholine receptor agonists / antagonists; Neonicotinoids	Foliar on pistachio psyllid (*Agonoscena targionii*) on pistachio	Saour 2005
				Foliar on apple psyllid (*Cacopsylla mali*) in apple orchards	Yanovskii & Larcheva 2000
Thiamethoxam	Cruiser (overseas name)	4	Nicotinic Acetylcholine receptor agonists / antagonists; Neonicotinoids	Foliar on oriental psyllid (*Diaphorina citri*)	Pellizzari et al. 2005
				Citrus psyllid *(Diaphorina citri)* in greenhouse trees	Nakano et al. 1999
Turpentine & separate monoterpene hydrocarbons			Turpenoids	Carrot psyllid *(Trioza apicalis*) in carrot fields	Nehlin et al. 1994

* Note the formulations in New Zealand may be different from the products or experimental compounds used overseas.
** Generic psyllid names are standardised as per Percy (2005).
*** Insecticide mode-of-action classifications by Insecticide Resistance Action Committee (IRAC) (Baker 2005).

Table 4: Information from Biobest (<u>www.biobest.be/</u>) on the safety of selected insecticides to natural enemies to control pests of greenhouse crops and safety to bumble bees. Safety score for natural enemies: 1 = safe, 2 = slightly harmful, 3 = moderately harmful, 4 = harmful; weeks = number of weeks harmful to natural enemies and days = days bumble bee hives must be removed from the greenhouse after spray application.

	Amblyseius cucumeris		*Aphidius colemani*			*Crysoperla carnea*			*Encarsia formosa*			*Phytoseiulus persimilis*		Bumble bees	
	Thrips predator		Aphid parasitoid			Lacewing			Whitefly parasitoid			Mite predator		Bombus species	
Active ingredient	Nymph/ adult	Weeks	Larvae	Adult	Weeks	Larvae	Adult	Weeks	Larvae	Adult	Weeks	Nymph/ adult	Weeks	Colony	Days
Abamectin	2	1	*	4	1	1	4	1	1	3	1	4	1	Remove	1
Acetamiprid		?			?			?	3		2	3	1	Remove	2
Azadirachtin	1	0	1	1	0	*	1	0	1	2	? 0	3	0.5	Remove	1.5
Buprofezin	1	0	1	1	0	1	?	?	2	1	? 0	2	? 0	Compatible	0
Chlorpyrifos		?	4	4	?			?	3	4	>8	1	0	Not compatible	
Diflubenzuron	1	0	1	1	0	4	3	?	1	1	0	1	0	Not compatible	
Endosulfan	4	4	3	?	?	1	4	?	1	4	6	4	2	Not compatible	
Imidacloprid	4	?	4	4	?	4	4	?	3	4	?	3	?	Not compatible	
Imidacloprid-Ir	1	0	1	1	0	1	1	0	1	1	0	2	?	Not compatible	
Methamidophos	4	?	4	4	>4	4	4	>8	2	4	>4	4	>6	Not compatible	
Permethrin	4	>8	4	4	>8	3	4	>8	4	4	>8	4	>8	Not compatible	
Pymetrozine	1	0	1	2		1	1	0	1		0	2	?	Compatible	0
Pyriproxyfen	1	0	1	1	0	1	1	0	3	1	?	2	?	Compatible	0
Spinosad	1	0	3	?	1	1	?	0	2	?	1	1	0	Remove	1
Spiromesifen							?								
Sulphur		?		2 or 3?	?					4	>4	2	1	Compatible	0
Thiamethoxam		?			?			?			?	3	?	Not compatible	

Table 5: Information from Koppert (www.koppert.nl/e005.shtml) on the safety of selected insecticides to natural enemies to control pests of greenhouse crops and safety to bumble bees. Safety score for natural enemies: 1 = safe, 2 = slightly harmful, 3 = moderately harmful, 4 = harmful; weeks = number of weeks harmful to natural enemies and days = days bumble bee hives must be removed from the greenhouse after spray application.

	Amblyseius cucumeris		*Aphidius colemani*			*Crysoperla carnea*			*Encarsia formosa*			*Phytoseiulus persimilis*		Bumble bees	
	Thrips predator		Aphid parasitoid			Lacewing			Whitefly parasitoid			Spider mite predator		Bombus species	
Active ingredient	Nymph &/or adult	Weeks	Mummy	Adult	Weeks	Larvae	Adult	Weeks	Pupa	Adults	Weeks	Nymph &/or adult	Weeks	Colony	Days
Abamectin		?		4	1	1	4	3	1	4	3	4	2	Remove	1.5
Acetamiprid		?		4	>2	4	3	?	3	4	>2	1	0	Incompatible	
azadirachtin		?		1	0	1		0	1	3	?	1	0	Remove	1.5
Buprofezin	1	0	1	1	0			?	2	1	0.5	1	0	Cover	0
Chlorpyrifos	4	6 to 8	4	4	?	4	4	8 to 12	3	4	8 to 12	3	0.5	Incompatible	
Diflubenzuron	1	0	1	1	0	1	1	0	1	1	0	1	0	Incompatible	30
Endosulfan	4	6 to 8		3	1 to 2	1	4	?	1	4	8 to 12	4	2	Incompatible	14
Imidacloprid	4	2	4	4	*	4	?	4	4	4	>2	4	0	Incompatible	30
Imidacloprid-drench	1	0	1	1	0	1	1	0			?	1	0	Incompatible	30
Methamidophos	4	?	4	4	>4	4	4	8	3	4	8	4	6 to 8	Incompatible	21
Permethrin	4	8 to 12	4	4	8 to 12	4	4	8 to 12	4	4	8 to 12	4	8 to 12	Incompatible	10
Pymetrozine	1	0	1	3	0.5	2	1	0	1	2	0	2	?	Cover	0
Pyrethrins + pip. but. oxide	4	1	1	4	?	2	1	1	2	4	2	4	1	Remove	1.5
Pyriproxyfen	0			1	0	1	1	0	4	1	?	1	0	Cover	0
Spinosad	4	1		4	2	1	4	?		4	2	4	1	Remove	0.5
Spiromesifen		?		1	0			?		1	0	3	2 to 3	No action	0
Sulphur	2	?	1	2	?	1	1	0	1	4	>4	1	0	Remove	1.5
Thiamethoxam	1	0		2	0	2		?		4	3	1	0	Incompatible	
Thiamethoxam-drench														Remove	3