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Developing an insecticide resistance management strategy for aphids in potato crops

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Contents

1 Executive summary

- Intensive use of insecticides for control of aphids in potatoes to prevent virus transmission has contributed to a high level of insecticide resistance in the most important virus vector, the green peach aphid *Myzus persicae*. Resistance to a pyrethroid insecticide, as indicated by discriminatory dose assays (lambda-cyhalothrin at 5% of field rate), was detected in 38% of the 31 *M. persicae* collected from potatoes in Canterbury during late summer and early autumn 2004. At the same times in 2005, green peach aphids were collected from potatoes in the North and South Islands and tested for resistance to individual classes of insecticide chemistry. Of the 72 aphids tested, 62% contained mechanisms that conferred resistance to between one and four of the five classes of chemistry used on potatoes: organophosphates (Tamaron®), carbamates (Pirimor®), pyrethroids (Karate® Zeon) and neonicotinoids (Gaucho®).
- To combat a potential rise in resistance to insecticides in aphids, two insecticide management regimes are proposed:
  - **a calendar-based regime** using a range of five chemical classes applied to the same potato crop to prevent aphids developing resistance to any particular insecticide class. It caters for historic peak aphid flights and allows for beneficial insect predators to provide further control of aphids. An imidacloprid (Gaucho®) seed treatment is followed by a series of foliar insecticide applications commencing 50-55 days after planting. One application of pymetrozine (Chess®), or two applications 7-14 days apart during main periods of aphid flights are used. Pirimicarb (Pirimor®) is then used to control aphids remaining after the main summer aphid flights. Methamidophos (Tamaron®, Monitor®, Metafort®) is applied in late summer to control autumn incursions of aphids and potato tuber moth, and lambda-cyhalothrin (Karate® Zeon) is applied after desiccation of foliage to prevent virus transfer in leaf regrowth. This regime suits potato seed production by providing an insurance against the risk of virus transmission from aphids;

- **a strategic insecticide regime** uses imidacloprid seed treatment in high-value seed crops, with an option on its use in process or table potato crops for which historic spring aphid flights coincide with emergence of potato foliage and the risk of early colonisation by aphids is high. Aphid flights are monitored using yellow-bowl water traps. As soon as a period of high virus risk is evident, an insecticide can be applied to the foliage. The selection of the insecticide will depend on the timing of the virus risk: pymetrozine in spring; pirimicarb in mid summer; methamidophos in early autumn; lambda-cyhalothrin in late autumn after foliage desiccation. Methamidophos or lambda-cyhalothrin may need to be used to control out-breaks of potato tuber moth. This regime suits process and table potato production, for which the effect of virus transmission by aphids on market value is not as high as it is for seed production. It requires verification in field studies.

2 Introduction

Insecticides are applied to potatoes primarily to control aphids that vector viruses in potatoes, and potato tuber moth (*Phthorimaea operculella*) (Figure 1). In 2002 the New Zealand potato industry initiated a project to develop and implement a sustainable resistance management programme to control aphids that transmit viruses in potatoes. During 2002-05, insecticide use in potatoes, insecticide resistance in aphids, aphid flights, and the effects of current and strategic insecticide use on aphid control and virus incidence were recorded. These findings were used to formulate an insecticide management strategy for use in potatoes.

Green peach aphid (*Myzus persicae)*

Potato aphid (*Macrosiphum euphorbiae*)

Foxglove aphid (*Aulacorthum solani*)

Potato tuber moth (*Phthorimaea operculella*)

Figure 1: Wing and wingless forms of three aphid species that colonise potatoes and vector viruses, and potato tuber moth.

2.1 Current insecticide use

2.1.1 Questionnaire survey 2002

The insecticide practices used by seed producers in Canterbury to manage viruses in potatoes in 2001-02 were surveyed by questionnaire during October 2002 (van Toor & Teulon 2003). Seed treatments of phorate were used in 19% of the 31 paddocks surveyed, and most of the other paddocks contained seed treated with imidacloprid to control aphids. 45% of paddocks received at least one foliar application of an organophosphate (acephate, dimethoate or methamidophos) or dimethyl carbamate (pirimicarb) at label rates to control aphids in potato foliage. Only 13% of paddocks were treated for potato tuber moth as well as aphids. Of the 31 paddocks, 16% received three or more sequential applications of an organophosphate, a practice which can lead to the development of resistance amongst aphids to insecticides within this chemical group.

2.1.2 *Spray diaries 2003-04*

Seed growers

Insecticide use apparently increased in the following two years. Information on insecticide use based on potato grower spray diaries for 2003-04 was obtained for mid-Canterbury (Table 1). Seed potatoes in the 11 paddocks containing seed potatoes were treated with imidacloprid. The organophosphate methamidophos, and the pyrethroid lambda-cyhalothrin, were often applied in sequence on more than two occasions (Table 1). If representative of current insecticide practices in New Zealand, then these intensive insecticide regimes were applied to the 1200 ha grown for seed (Vegfed 2005, pers. comm.).

Table 1: Proportion of paddocks receiving numbers of foliar applications of insecticides within each chemical class in 2003-04 from seed producer insecticide spray diaries in Canterbury. Paddock sizes averaged 10 ha. All 11 paddocks contained imidacloprid-treated seed.

	No. of insecticides applied		
% of 11 paddocks studied	Pyridine-azomethine (pymetrozine)	Organophosphate (methamidophos)	Pyrethroid (lambda-cyhalothrin)
27		5-9	
27		5-9	1-3
37	1	5-6	
9	3	3	2

Many of the insecticides were applied to potato foliage during a period of low aphid flights. Superimposing the times of insecticide application by seed growers in Canterbury upon data for the timing of flights of aphids that colonise potatoes and vector viruses at Lincoln showed that many sprays were applied in summer, between the peak aphid flights in spring and autumn (Figure 2).

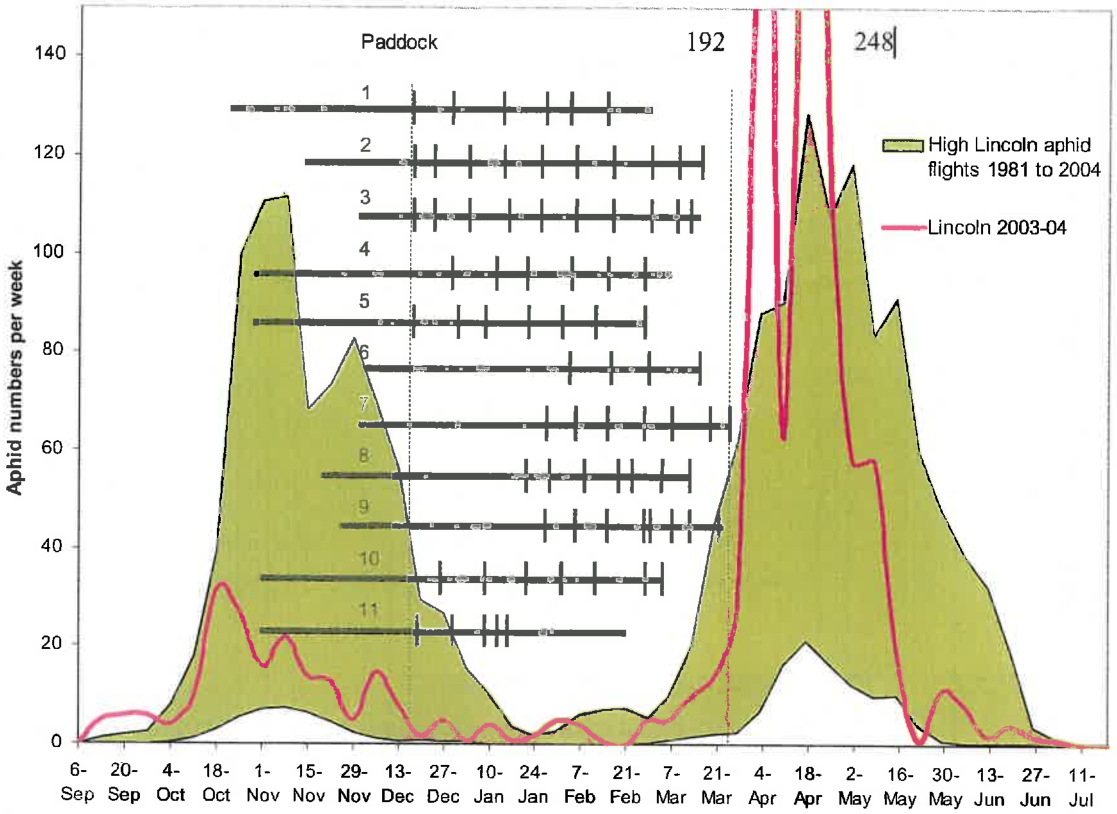


*Figure 2: Times of insecticide application to control aphids on potatoes during 2003-04 in relation to the average timing of flights of potato-colonising aphids (*M. persicae, M. euphorbiae, A. gossypii and A. solani*) over 23 years at the Lincoln suction trap. The suction trap was within 30 km of the furthest paddock. Horizontal lines represent the period between sowing and final desiccation; vertical lines the application times of insecticides. Vertical dotted lines show the range of spray dates.*

The process growers relied on much less insecticide than the seed growers to control aphids (Table 2). Almost all of the 84 paddocks surveyed had potatoes treated with imidacloprid, with 2% of paddocks containing seed treated with phorate. The majority of the paddocks received no foliar application, with only 2% receiving more than two sequential applications of one chemical class, the pyrethroid lambda-cyhalothrin (Table 2). Assuming that the results from this survey was representative of the practices for the whole of New Zealand, then 6000 ha received a modest amount of insecticide, with only a small area receiving insecticide regimes considered likely to induce insecticide resistance in aphid populations.

Table 2: Proportion of 84 paddocks receiving numbers of foliar insecticide applications by potato process producers in 2003-04.

	No. of insecticides applied		
% of 11 paddocks studied	OP (methamidophos, dimethoate)	Carbamate (pirimicarb)	Pyrethroid (lambda-cyhalothrin)
41			
43	1		
6			2
4	2		
4		1	2
2			3

2.1.3 *Insecticide application method*

Most of the foliar applications of insecticides in seed crops were applied by air to reduce the risk of mechanical virus transfer by vehicular traffic. The insecticides were applied at a low water rate in 80-100 litre water/ha. Higher water rates are recommended by manufacturers to ensure penetration of the insecticides into the under-storey of the crop. This is particularly important for methamidophos and pirimicarb, which translocate upwards in potatoes, and for lambda-cyhalothrin, which is a contact insecticide. The label minimum water rate for Pirimor is 200 litre/ha, for Chess® 350 litre/ha, and for Karate® Zeon and Tamaron® 500 litre/ha (NZ Agrichemical Manual, 2005, Agri Media Ltd, Christchurch). These rates achieve adequate kill of aphids and prevent premature resistance developing due to sub-lethal exposure by aphids to the active ingredient. While the 80-100 litre/ha rate may be adequate to achieve adequate penetration of the insecticides and to minimalise the risk of sub-lethal dose-induced resistance early after crop emergence, it is probably not adequate after inflorescence emergence when the crop cover is intensive. Since the cost of aerial application may preclude higher water rates, insecticides applied by air may be contributing to the prevalence of insecticide resistance in aphids on potatoes.

In process and table potato production, insecticides were applied mainly by truck or tractor in 200-400 litre water/ha. At these water rates, a higher penetration of active ingredient into the lower portions of the crop canopy would be expected than for insecticide applications by air.

2.1.4 *Virus incidence*

Irrespective of the amount of insecticide that is applied to crops, the incidence of virus remains high. In a survey of potato paddocks by John Fletcher of Crop & Food Research during 2003-04, 17% of paddocks were infected with potato leaf roll virus (PLRV), 43% with potato virus Y (PVY) and 83% with potato virus S (PVS) (Table 3). These viruses are mainly transmitted by aphids. Potato virus X (PVX) was present in 22% of paddocks, but is mechanically transmitted.

Table 3: Survey of virus incidence in 100 plants sampled from potato crops in Canterbury (John Fletcher, pers. comm.).

Year	Number of crops	% of paddocks that contained virus (range of % plants infected)			
		PVX	PVS	PLRV	PVY
2002-03	25	4 (1-1)	0 (-)	4 (2-2)	20 (5-20)
2003-04	35	17 (1-4)	78 (1-100)	3 (1-1)	44 (1-11)
2004-05	23	22 (1-5)	83 (1-100)	17 (4-100)	43 (1-100)

PLRV persists in the aphid's gut and can be controlled reasonably effectively by killing virus-carrying aphids with insecticides before the viruses are transmitted to potato foliage. PVY is non-persistent, and borne on the aphid's stylet. Insecticides are less effective in controlling virus infection because the viruses are often transmitted before the aphid is killed.

2.2 *Insecticide resistance*

The incidence of aphids showing resistance to different insecticide classes was ascertained in wingless aphid populations on potatoes in late summer and early autumn, by two methods. In 2003 and 2004, aphids were sprayed with commercial formulations of insecticides using a computer-controlled spraying apparatus. The aphids were sprayed with a discriminatory dose, which was determined for each insecticide as the minimum dose to kill 100% of susceptible aphids. This dose equated to 5% of field rate for each insecticide. An alternative method of detecting insecticide resistance was used in 2005. Aphids were tested for mechanisms of resistance, to indicate their potential resistance to four insecticide classes.

2.2.1 *Discriminatory dose tests with commercial insecticides*

Aphids of *Myzus persicae* (15 clones) were collected from potatoes in Canterbury in 2003. *M. persicae* (31 clones) and *Aphis gossypii* (four clones) were collected throughout New Zealand in 2004. The aphids (25 per clone) were treated with methamidophos (Tamaron®), pirimicarb (Pirimor®) and lambda-cyhalothrin (Karate® Zeon). There was no evidence of resistance by these aphids to Tamaron® or Pirimor®. However, 38% of 31 *M. persicae* clones tested in 2004 were resistant to Karate® Zeon.

2.2.2 *Detecting mechanisms of resistance*

The prevalence of insecticide resistance mechanisms in populations of *M. persicae* in New Zealand was determined on parthenogenetic clones from aphids collected from potato paddocks in New Zealand during January to March 2005. Aphids were collected from Pukekohe, Christchurch, Seddonville (on the West Coast), Lincoln, Rakaia, Ashburton and Timaru. The aphids were tested at Rothamsted Research Station, UK, for mechanisms of resistance to four classes of insecticide chemistry. For each clone, the genotype was assessed using four microsatellite loci, and the presence of resistance mechanisms using biochemical tests, polymerase chain reaction (PCR) sequencing and diagnostic dose bioassays.

The 72 clones tested comprised 24 genotypes, with 62% containing mechanisms that conferred resistance to at least one of four of the five insecticide classes currently used in potatoes (Table 4). Of these clones 36% contained excessive carboxylesterases (E-carb) conferring resistance to organophosphates, and limited resistance to carbamates and pyrethroids; 24% contained modified acetylcholinesterase (MACE) that contributes to strong resistance to dimethyl carbamates; 56% contained a mutation in a voltage-gated sodium channel gene, called knockdown resistance (kdr), that confers resistance to pyrethroids; and 38% contained a second mutation on the gene (super-kdr) that gives enhanced resistance to pyrethroids. Resistance to pyrethroids was confirmed in triplicate dose response assays, where each young adult aphid (10 aphids per triplicate dish) was given 0.25 µL of 100 ppm deltamethrin. One in two clones contained multiple resistance mechanisms. Furthermore, 11% of the clones also showed mild resistance to imidacloprid (< 20-fold decrease in susceptibility) in diagnostic dose bioassays where each aphid was given 0.25 µL of 10 ppm imidacloprid.

Table 4: Percentage of the 72 clones showing any of the five mechanisms of resistance, and corresponding New Zealand genotypes and resistance to chemical classes. Some genotypes carried different mechanisms of resistance. X denotes mild resistance and XX denotes strong resistance.

			Chemical classes			
Resistance mechanisms	% of 72 clones	Genotypes (24)	Organo-phosphates	Carbamates	Pyrethroids	Neo-nicotinoids
E-carb, kdr, s-kdr	33	NZ3	XX	X	XX	
MACE, kdr, imidacloprid	8	NZ3, 2		XX	X	X
MACE, kdr	7	NZ2, 9		XX	X	
MACE	4	NZ11, 23		XX		
Kdr	3	NZ10, 18			X	
MACE, kdr, s-kdr	2	NZ3		XX	XX	
Imidacloprid	2	NZ22				X
E-carb	1	NZ5,	XX	X		
E-carb, MACE, kdr, s-kdr	1	NZ3	XX	XX	XX	
MACE, kdr, s-kdr, imidacloprid	1	NZ2		XX	XX	X
None	38	NZ1, 4-8, 12-17, 19-21, 24				

Although the microsatellite analysis identified 24 aphid genotypes from the 72 clones, the resistance mechanisms were carried mostly in just two of the genotypes, NZ2 and NZ3 (Table 4). NZ2 carried MACE but had lost E-carb. Aphids showing this trait are known as 'revertants'. Because of the fitness costs associated with E-carb resistance, these aphids have lost expression of E-carb in the absence of organophosphate selection pressure, but since DNA methylation has not been lost, they will regain resistance in the presence of further organophosphate sprays (Field & Foster 2002).

The aphids with almost of the resistance mechanisms were found in Ashburton and Timaru (Table 5). These are regions where many vegetable and arable crops are grown, and probably where insecticides are used intensively.

Table 5: Distribution of resistant genotypes of M. persicae*, showing the number of mechanisms carried by aphids, and the number of aphids from the genotypes carrying most of the resistance mechanisms at each location.*

Location	No. clones	No. of mechanisms /aphid	No. of genotypes		
			NZ3	NZ2	NZ4
Pukekohe	5	1.8	3	0	0
West Coast	1	0	0	0	0
Christchurch	19	0.2	1	0	4
Lincoln	3	2.0	2	0	0
Rakaia	21	1.6	10	1	0
Ashburton	19	2.8	10	7	0
Timaru	4	2.8	1	3	0

These mechanisms confer resistance insecticides commonly used to control aphids in potatoes. The insecticides include phorate (Crop Care Phorate, Ground Zero, Nufarm Phorate, and Thimet 20 G), methamidophos (Tamaron®, Monitor®, Methfort® 60 SL), pirimicarb (Pirimor® 50, Pirimisect, Prohive™), lambda-cyhalothrin (Karate® Zeon) and imidacloprid (Gaucho®). The only commonly-used insecticide registered for use on potatoes to which no resistance has been detected is the pyridine-azomethine, pymetrozine (Chess® WG) (Foster et al. 2002).

2.2.3 *Significance of insecticide resistance in aphids on potatoes*

The results of the diagnostic dose assays with commercial insecticide formulations in 2002-03 and the resistance mechanism studies in 2005 infer that unless current patterns for insecticide use are altered, many insecticides currently used to control aphids on potatoes could be ineffective in the future.

However, these findings need to be put in context. All aphids were collected in late summer and early autumn, after the potatoes had already received a number of insecticide applications. Thus, the proportion of aphids containing resistance mechanisms would be the highest of the expected potential in the population for the growing season. Since there are environmental fitness costs associated with the resistance mechanisms, the proportion of resistance aphids may have been lower if the aphids were sampled in spring. This is because the parent resistant aphids from the previous autumn would be least likely to survive the winter, leaving the insecticide-susceptible more likely to over-winter and colonise potatoes in the spring.

Fitness costs can reduce the survival of resistant aphids (Foster et al. 2003). The gene amplification for E-carb induces cold intolerance, so that aphids carrying this resistance mechanism are less likely to survive the winter. Aphids containing E-carb and kdr show reduced response to alarm pheromones and are less likely to avoid being attacked by predators. Thus, insecticide-resistant aphids are likely to die out once the insecticide to which they are resistant has been removed.

Another important consideration relates to methamidophos, which is an S-alkyl phosphorothiolate class of organophosphate. When in contact with potatoes, methamidophos is converted to methamidophos oxon, which is much more toxic to aphids than is the insecticide itself, but is a very poor inhibitor of AChE *in vitro* (Kasagami et al. 2002). Consequently, when applied to potato foliage, methamidophos can still be effective against aphids containing excessive carboxylesterases.

2.3 *Insecticide field trials*

Reducing the insecticide pressure on aphid populations will reduce the development of resistance, but may increase the risk of virus transmission in potatoes by virus-carrying aphids. The effect of reduced insecticide use in potatoes on aphid numbers and virus incidence was therefore tested in field trials.

2.3.1 *Trial description*

Trial sites were established in 2002 and 2003 at Lincoln and Pukekohe, and at Lincoln in 2004. They compared the effects of the common calendar-based methamidophos spray regime with targeted regimes in which insecticides were applied only when aphids were present. Russet Burbank seed potatoes certified as virus-free were sown between 22 October and 5 November in each year. The treatments were applied consistently over all trials and comprised:

1. untreated control;
2. imidacloprid (Gaucho®) seed treatment, followed by foliar applications of methamidophos (Tamaron®) applied every 10-14 days commencing 50 days after potato emergence;
3. imidacloprid seed treatment, followed by lambda-cyhalothrin (Karate® Zeon) or pymetrozine (Chess®) when numbers of wingless aphids exceeded 10 per 150 potato leaves;
4. foliar applications of insecticides (Karate® or Chess®) when numbers of wingless aphids exceeded 10 per 150 potato leaves.

The treatments were replicated six times and arranged in a randomised block design. Plots, which were 6 m long, contained six rows each. Two of the middle rows were sampled weekly for aphids and their invertebrate predators. The other two rows were sampled for potato yields and virus incidence.

Potato plants were visually scored for virus symptoms during the course of the trial. The aphid species that colonise potatoes and vector viruses – *M. persicae* (green peach aphid), *Macrosiphum euphorbiae* (potato aphid), *Aulocauthum* solani (foxglove aphid) (see Figure 1) and *Aphis gossypii* (melon aphid) – were also recorded on potato foliage in on-site suction traps. Aphid predators – the large (*Megangynaa novaezelandiae*) and small

(*Melanostoma fasciatum*), hoverflies, lacewing (*Micromus tasmaniae*; Figure 3), and ladybirds – were recorded on potato foliage at the sites. Aphid mummies parasitized by parasitoids, such as *Aphidius* species, were also recorded.

Figure 3: Effective predators of aphids commonly found on potato foliage - lacewing (Micromus tasmaniae) *adult and larvae, and small hoverfly* (Melanostoma fasciatum) *larvae and adult (clockwise from top left).*

The potato haulms in both trials were desiccated as per grower practice, with no re-growth of foliage occurring at both sites. This reduced the risk of virus transmission by aphids during this time. Potatoes were harvested as per commercial practice. Potato tubers from selected treatments were sprouted prior to ELISA testing of the foliage for levels of infection by potato virus Y (PVY) and potato leaf roll virus (PLRV). In 2003, 2004 and 2005, 360, 250 and 600 tubers per treatment were sampled for virus assessment, respectively. This allowed for theoretical precision in detecting 0.16-0.25% differences in virus incidence between treatments.

2.4 Aphids, predators and virus symptoms

2.4.1 Pukekohe

The major flights of aphids that could have colonised potato foliage occurred in spring and autumn (Figure 4).

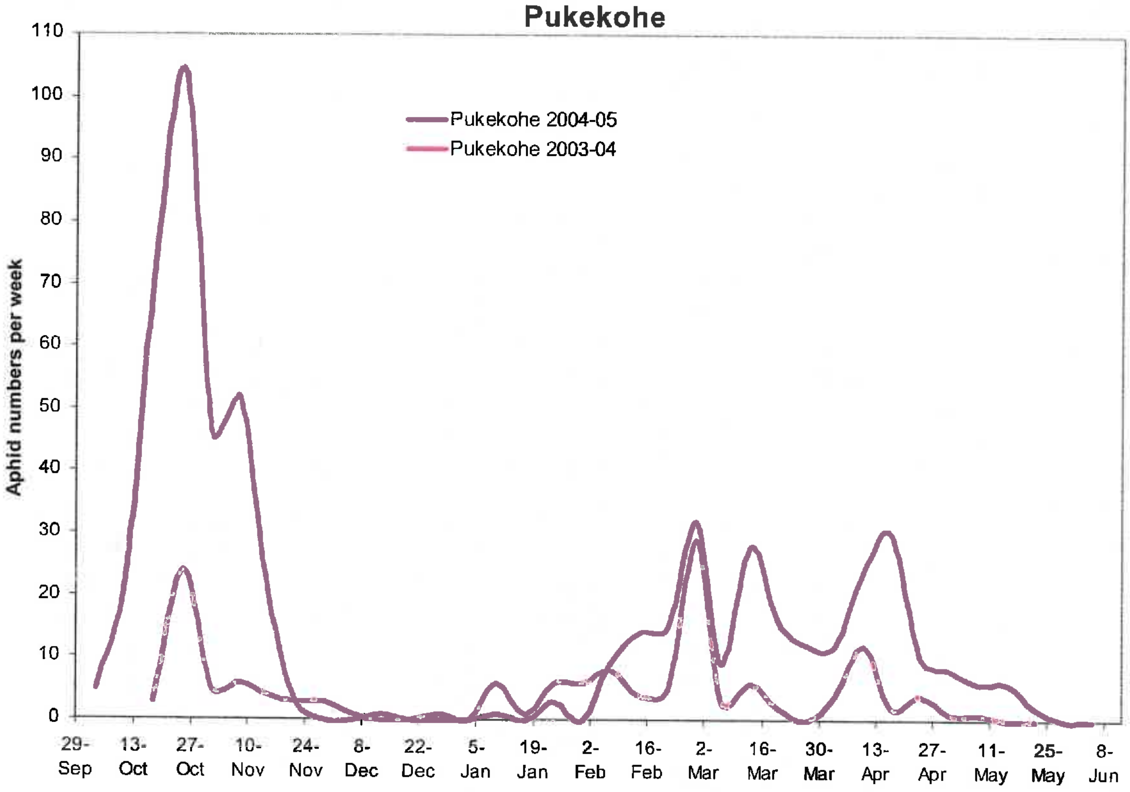


Figure 4: Numbers of winged Macrosiphum euphorbiae, Myzus persicae, Aulocauthum solani *and* Aphis gossypii *caught in suction traps at the Pukekohe trial site.*

In 2002-03, wingless aphids were not found in the potato foliage in untreated plots until late January, and remained below the proposed action threshold of 10 aphids per 150 leaves until 11 February (Table 6). The first four applications of Tamaron® were unnecessary for aphid control on foliage. Two further applications of methamidophos kept aphid populations below the aphid control threshold until mid-February. Then, populations of wingless aphids in Tamaron® treated plots were 98 per 150 leaves, significantly higher than the 11 aphids per 150 leaves found in the untreated plots.

Table 6: Pukekohe 2002-03 - numbers of wingless aphids/150 leaves.

Treatments[1]	21 Jan	28 Jan	4 Feb	11 Feb
Untreated	8	2	4	11
Gaucho® + 7 Tamaron® @ 14 days	0	0	3	13
7 Tamaron® @ 14 days	6	0	8	98
Gaucho® + 1 Karate® @ threshold	3	3	8	3
1 Karate® @ threshold	5	3	10	1
1 Chess® @ threshold	1	1	10	2
$LSD^2_{(0.05);\ df=25}$	7	4	13	38

[1] Tamaron® was applied on 27 November 2002, 34 days after planting, and on 11 and 23 December 2002, 8 and 21 January, and 5 and 19 February 2003; Karate® and Chess® were applied on 5 February 2003; foliage desiccated on 28 February 2003.

[2] Least significant difference: if the difference between two treatment means within the column is greater than the LSD, the means are significantly different from one another at the 5% level.

The large numbers of aphids in the methamidophos-treated plots were possibly due to the elimination of aphid predators by the insecticide. On 21 January 2003, numbers of lacewing larvae and eggs were reduced from 13 per 150 leaves in plots not treated with Tamaron® to four per 150 leaves ($LSD_{(0.05)} = 6$) in plots treated with the organophosphate. The following week, they were reduced from 15 in untreated plots to four per 150 leaves ($LSD_{(0.05)} = 7$) in all plots treated with insecticides. Alternatively, the aphids may also have developed resistance to the organophosphate insecticide.

A similar, but not so pronounced, trend occurred in the following year, with untreated populations of aphids not reaching the threshold until February (Table 7). On 3 February 2004, aphid numbers in plots that had received three fortnightly applications of Tamaron® were significantly lower than in the untreated control plots. But 1 month later, on 3 March, aphid numbers in Tamaron®-treated plots were similar to those in the untreated control.

Tamaron® again appeared to reduce the number of aphid predators on foliage. On 13 January, there were 36 Syrphid eggs/150leaves compared with 20 eggs/150 leaves ($LSD_{0.05} = 15$) on plots treated with Tamaron®. On 3 February, there were 15 Syrphid larvae/150 leaves compared with two larvae/150 leaves ($LSD_{0.05} = 7$) on plots treated with Tamaron®; on 17 February there were four larvae compared with no larvae ($LSD_{0.05} = 3$).

Only one application of Chess® on 11 February (Table 7), after aphids had exceeded the threshold in the previous week, was required to keep the aphids numbers on foliage near or below the threshold. In a year of low aphid numbers, Gaucho® seed treatment alone, or one foliar application of Chess® was all that was required to keep aphid numbers at or below the aphid threshold.

Table 7: Pukekohe 2003-04 - numbers of wingless aphids per 150 leaves.

Treatments[1]	18 Dec	6 Jan	13 Jan	19 Jan	27 Jan	3 Feb	10 Feb	17 Feb	24 Feb	3 Mar	9 Mar
Untreated	0	2	0	0	1	10	13	0	3	12	5
Gaucho® + 5 Tamaron® @ 14 day	0	0	0	0	3	2	2	0	7	1	2
5 Tamaron® @ 14 day	1	0	2	1	1	0	9	0	4	8	6
Gaucho®	0	0	0	1	9	3	3	0	8	0	1
Chess®	0	2	1	0	2	8	18	1	1	0	5
LSD[2] $_{(0.05);\ df=25}$	1	2	2	1	11	8	15	1	10	7	7

[1] Tamaron® was applied on 30 December 2003, 56 days after planting, and thereafter fortnightly on 14 and 28 January, and 11 and 25 February 2004; Chess® was applied on 11 February 2004; foliage desiccated on 16 March 2004.

[2] Least significant difference: if the difference between two treatment means within the column is greater than the LSD, the means are significantly different from one another at the 5% level.

2.4.2 *Lincoln*

As at Pukekohe, historic aphid flights at Lincoln followed a bimodal pattern. An exception occurred in 2004-05 when the wet and cold conditions in December postponed the spring flight by about 4 weeks from average (Figure 5). In that year, only one peak of aphid flights was recorded.

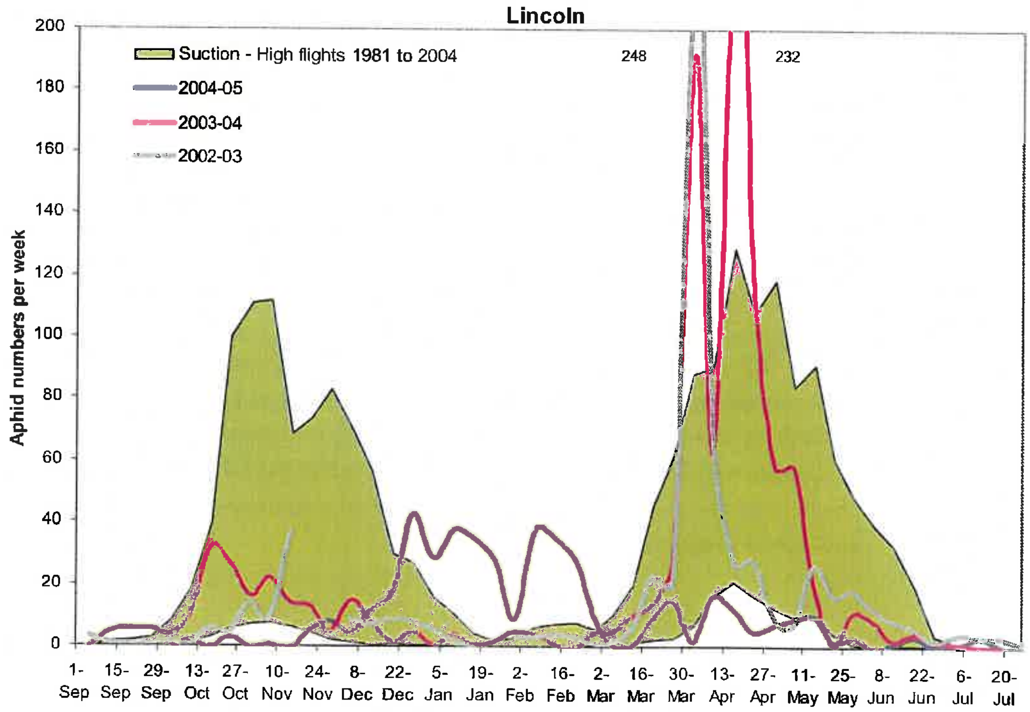


Figure 5 : Number of winged Macrosiphum euphorbiae, Myzus persicae, Aulocauthum solani *and* Aphis gossypii *caught in suction traps at the Lincoln trial site.*

In 2002-03, aphid numbers initially exceeded the threshold on untreated foliage, but only one insecticide application was required to keep aphid numbers low thereafter (Table 8). On 11 December 2002, symptoms of PVY and PVX appeared in 2.8% of plants; there was no significant effect of the seed treatment, the only treatment that had been applied at that time. On 19 February 2003, the numbers of larvae from the aphid predator, Syrphid species, were reduced from 2.9 larvae/150 leaves in Gaucho® treated plots to 0 larvae/150 leaves in Tamaron® treated plots ($\text{LSD}_{(0.05)} = 2.6$).

Table 8: Lincoln 2002-03 - numbers of wingless aphids/150 leaves.

Treatments	11 Dec	24 Dec	29 Jan	12 Feb	19 Feb	26 Feb
Untreated	44	4	1	3	6	13
Gaucho® + 6 Tamaron® @ 14 day	1	0	0	0	0	0
6 Tamaron® @ 14 day	0	1	0	0	0	0
Gaucho® + Karate® @ threshold	3	4	3	0	1	5
Karate® @ threshold	32	2	3	4	6	6
Chess® @ threshold	40	3	2	3	5	4
LSD[2]$_{(0.05);\ df=25}$	16	5	4	4	7	9

[1] Tamaron® was applied on 9 December 2002, 46 days after planting, and thereafter fortnightly on 24 December 2002, and on 4, 18 and 30 January and 14 February 2003; Karate® and Chess® were applied on 15 December 2002; foliage desiccated on 5 March 2003.

[2] Least significant difference: if the difference between two treatment means within the column is greater than the LSD, the means are significantly different from one another at the 5% level.

In 2003-04, numbers of aphid flights were low during spring and summer, with high numbers of aphids flying in mid-autumn at a time when the potato foliage had begun to senesce (Figure 5). Populations of wingless aphids never exceeded the threshold in untreated or treated plots. They were not significantly affected by the Tamaron®-Gaucho® insecticide treatments (Table 9). Karate® and Chess® were not applied. Symptoms of PVY were evident in 4% of plants, with no significant difference between treatments in the percentage of plants infected.

Table 9: Lincoln 2003-04 - numbers of wingless aphids per 150 leaves.

Treatments	1 Dec	9 Dec	15 Dec	22 Dec	30 Dec	5 Jan	12 Jan	26 Jan	10 Feb	22 Mar
Untreated	3	2	3	3	3	0	1	1	1	0
Gaucho® + 11 Tamaron® @ 14 days	2	3	3	0	1	3	0	0	0	0
11 Tamaron® @ 14 day	3	2	3	0	0	1	0	0	0	2
Gaucho®	0	7	3	1	0	1	0	0	0	0
LSD$^{2}_{(0.05);\ df=26}$	3	4	4	3	2	2	1	1	1	1

[1] Tamaron® was applied on 16 December 2003, 55 days after planting, and thereafter fortnightly on 31 December 2003, on 13 and 28 January, and 11 and 25 February, 10 and 24 March, 7 and 21 April 2004; foliage desiccated on 17 May 2004.

[2] Least significant difference: if the difference between two treatment means within the column is greater than the LSD, the means are significantly different from one another at the 5% level.

In 2004-05, delayed aphid flights resulted in potato foliage being colonised by wingless aphids at a number exceeding the threshold in untreated plots during 14 December to 14 January (Table 10). Gaucho® and nine foliar applications of Tamaron® gave complete control of wingless aphids. One foliar application, at the aphid threshold, of Chess® on 4 January 2005 to Gaucho®-treated seed and on 25 December 2005 to untreated seed kept aphid numbers near or below the threshold thereafter. Tamaron® appeared to influence where lacewing adults laid their eggs. On 31 January, 50 eggs per 150 leaves were found in untreated plots, and 20 per 150 leaves (LSD$_{(0.05)}$ = 20) in the Gaucho®-Tamaron® treated plots.

Table 10: Lincoln 2004-05 - numbers of wingless aphids/150 leaves.

Treatments[1]	6 Dec	14 Dec	22 Dec	28 Dec	4 Jan	10 Jan	18 Jan	31 Jan
1. Untreated	2	18	13	35	28	8	3	0
2. Gaucho® + 9 Tamaron® @10 day	0	0	0	0	0	0	0	0
3. Gaucho® + Chess® @ threshold	0	0	2	2	6	3	1	2
4. Chess® @ threshold	1	15	8	19	3	0	0	2
LSD$^{2}_{(0.05);\ df=15}$	2	15	8	17	11	4	2	4

[1] Tamaron® was applied on 15 December 2003, 50 days after planting, and thereafter every 10 days on 25 December 2003, 4, 11, 20 and 31 January, 16 and 24 February, and 9 March 2005; Chess® applied to treatment 4 on 25 December 2004 and to treatment 3 on 4 January 2005; foliage desiccated on 18 March 2005.

[2] Least significant difference: if the difference between two treatment means within the column is greater than the LSD, the means are significantly different from one another at the 5% level.

Despite the fluctuating aphid flights between years, repeated applications of methamidophos kept aphids on potato foliage at zero or negligible numbers every year over 3 years of trials (Table 8, Table 9, Table 10). Therefore, there was no evidence of aphids being resistant to Tamaron®.

Virus incidence in tubers

There was no evidence of repeated applications of methamidophos (Tamaron®) or any other insecticide treatment in reducing the incidence of secondary (aphid-borne) virus infection in potatoes (Table 11).

Table 11: Percentage virus infection (95% confidence limits) in potatoes from plants untreated or treated with insecticides at Lincoln over 3 years. The sampling sizes allowed for a detection of 0.16-0.25% difference between treatments in incidence of virus in tubers.

	2002-03		2003-04		2004-05	
Treatments	PLRV	PVY	PLRV	PVY	PLRV	PVY
Untreated control	0	3 (1-11)	2 (1-8)	20 (13-30)	4 (1-12)	0.4 (0.0-4.5)
6 Tamaron® 14 day	0	7 (3-15)	-	-	-	-
Gaucho® + 9 Tamaron® 10-14 day	-	-	4 (2-11)	23 (16-33)	3 (1-11)	3.6 (1.6-8.0)
Gaucho® + 1 Chess® @ threshold	-	-	-	-	2 (0-10)	1.2 (0.3-4.9)
1 Chess® @ threshold	-	-	-	-	4 (1-13)	3.1 (1.3-7.4)

2.5 Trial conclusions

Repeated applications of methamidophos (Tamaron®) were often wasted, as they were applied to potato foliage when there were negligible numbers or no aphids present. They also induced aphid populations larger or similar to those in the untreated plots at the Pukekohe site, either as a result of resistance to organophosphates developing in aphid populations or the removal of aphid predators. Furthermore, there was no evidence that this insecticide contributed to a reduction in virus incidence in tubers, even in periods when aphid numbers were high, such as in 2004-05 at Lincoln. Numbers of aphids could be kept at or below a threshold of 10 aphids per 150 leaves with one foliar insecticide application per year, applied when the numbers of wingless aphids exceeded the threshold. At Lincoln, aphid thresholds were exceeded in spring, so an imidacloprid seed treatment was needed as a precaution against early aphid flights.

At Pukekohe, aphids tended to colonise potato foliage after January, when the insecticidal effects of imidacloprid had attenuated. Thus in that region, aphids may be able to be kept below the threshold with just one strategic application per year. At Lincoln, one spring insecticide application also sufficed to keep the wingless aphid numbers below the threshold in these trials. But because a strong aphid flight normally occurs in autumn in this district, an insecticide application in autumn will probably be required under normal circumstances.

3 Managing insecticide resistance

3.1 Introduction

3.1.1 Aphids

Insecticide aphid management strategies have been developed for New Zealand conditions (Cameron 1996; Martin & Cameron 1997). The general strategy is to reduce the need for control of aphids by reducing virus sources and aphid reservoirs. Selection pressure on aphids in crops can then be reduced by applying insecticides only when necessary to reduce feeding damage. They include:

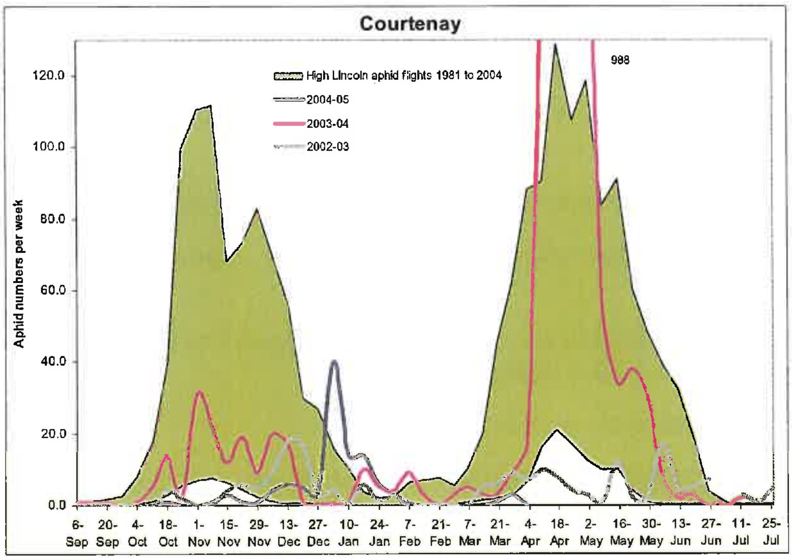
- maximise virus control by using virus-free seed or transplants from pathogen testing schemes, removing virus infected plants within a crop, eliminate weed sources and volunteer crop plants that may harbour viruses, and in greenhouses, using screens over intake vents to prevent aphids contamination;
- remove alternative host plants for aphids such as Solanums, Brassicas and ornamentals;
- monitor plants to ensure insecticides are applied only when necessary;
- choose insecticides based on knowledge of insecticide resistance patterns;
- use correct label rates and application procedures to ensure an insect lethal dose is applied to the plant;
- alternate between insecticide groups;
- treat crops with an insecticide from a different chemical group if resistance is suspected;
- desiccate the potato foliage completely, or harvest the potatoes, before the historic autumn aphid flights (Figures 5 and 6), to prevent virus transmission by aphids from green or senescing foliage to the tubers.

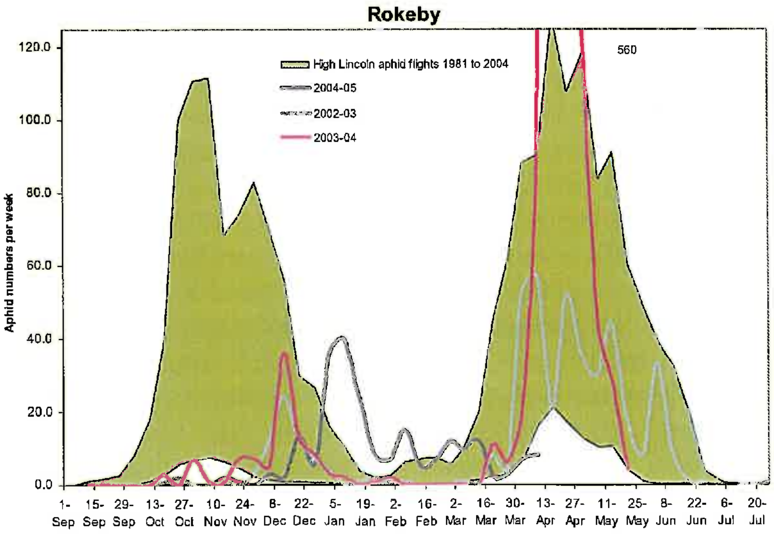
Recent research demonstrated that the various insecticide classes used on potatoes in New Zealand for control of virus-aphid vectors were not equally effective in reducing the level of virus transfer between plants. While imidacloprid (Gaucho®) and pymetrozine (Chess®) reduced transmission of PLRV by *M. persicae* through acquisition by 100% and 87%, respectively, and by 56% and 94% through inoculation, methamidophos (Tamaron®, Monitor®) was not as effective, reducing transmission by 31% through acquisition and by 16% through inoculation (Mowry 2005). The pyrethroid tested in the research was esfenvalerate (Sumi-Alpha®) and, as a contact/repellent, reduced the incidence of PLRV by 28% through acquisition and 71% through inoculation. The same results could be expected for lambda-cyhalothrin. Therefore, reliance on methamidophos to control aphids may not have been the best strategy in preventing the spread of viruses in potatoes.

Use of the new aphicide, pymetrozine, which has shown no cross-resistance to these insecticide classes (Foster et al. 2002), was recommended for inclusion in any insecticide resistance-management strategy.

The New Zealand practice of applying a pyrethroid such as cypermethrin plus oil to potato crops to decrease the spread of viruses was not recommended. In the UK, the pyrethroid-oil combination led to an increase in the numbers of resistant aphids (Harrington et al. 1989). This could be because aphids stuck in the oil were not able to move over the surface of the sprayed foliage to acquire a lethal dose of the contact pyrethroid insecticide.

The periods of predominant aphid flights in Canterbury (Figures 5 and 6), where most of the seed potatoes are grown, were also considered in constructing the insecticide regimes.





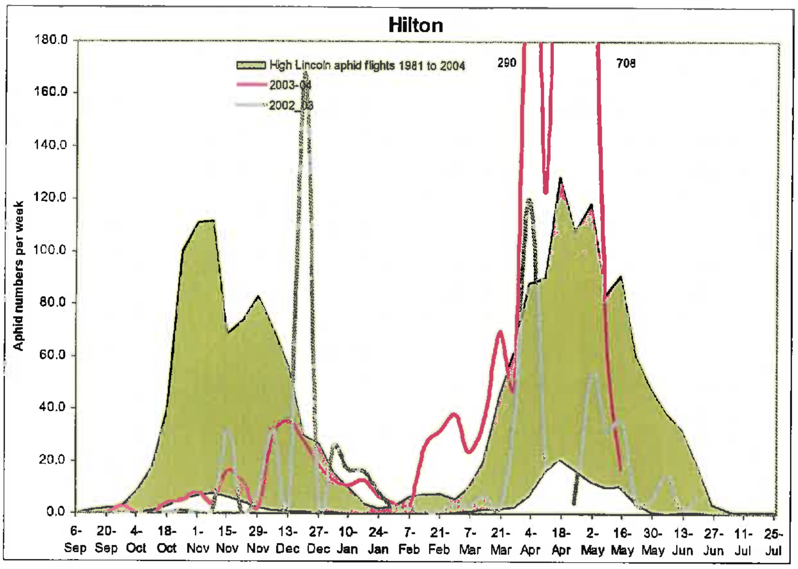


Figure 6: Numbers of winged Macrosiphum euphorbiae, Myzus persicae, Aulocauthum solani *and* Aphis gossypii *caught in suction traps at three sites in Canterbury during the 2002-05 programme, compared with historic aphid flights.*

3.1.2 *Potato tuber moth*

Since insecticides applied to control potato tuber moth also affect any aphids resident in the crop. The insecticide management strategies below will control aphids and potato tuber moth larva and adults. It is important to minimise the number of insecticides applied to a potatoes, to limit insecticide resistance developing in tuber moth. Use of insecticides can be restricted to crops and periods of highest risk of damage to potatoes:

- February and March, when tuber moth populations peak;
- crops in which tubers are late to bulk or plants have no foliage;
- crops with dry soil and cracked moulds in which the tubers are exposed to tuber moth larvae;
- crops in which tuber moth pheromone traps have caught more than 10 moths per day, or tuber moth mines visible (usually on the lower leaves) (Figure 7) on 40 randomly sampled plants per paddock.

The insecticides registered for potato tuber moth are listed in the Appendix. Their use for control of potato tuber moth has been built in to the regime for insecticide control of aphids.

Figure 7: Leaf mining of potato foliage by larvae of potato tuber moth (Phthorimaea operculella).

3.2 Insecticide resistance-management strategies

With these considerations discussed above, two insecticide resistance-management strategies are proposed. One is a calendar-based spray regime which can be readily adopted by potato seed growers who currently follow the methamidophos spray regime. The other regime minimises the use of insecticides for application only when virus risk becomes apparent, therefore reducing the pressure for insecticide resistance to develop in aphids. In this regime, only one foliar insecticide application may be required in a growing season. Results from the field trials suggest that one strategic application of insecticide will not increase the incidence of virus in potatoes.

3.2.1 Calendar-based regime

This regime uses several insecticide-control factors that cause independent stresses on aphids. It includes a mix of chemical classes to prevent aphids developing resistance to any particular insecticide class. It also takes into account the beneficial effects of insect predators in controlling the aphid population, by postponing the use of broad-spectrum insecticides that kill the predators of aphids until the end of the growing season, when the predators have naturally declined. Insecticides that are selective against aphids used early in the season will allow aphid predators to kill remaining aphids.

The regime is summarised in Table 12. A seed treatment of the systemic imidacloprid (chloronicotinyl) is used to provide protection against early spring flights that are common in Canterbury (Figure 5). Chloronicotinyl acts as an agonist at nicotinic acetylcholine receptors in the nerve synapse of insects. Protection by imidacloprid from virus transmission persists for at least 50 days (confirmed at the Lincoln trial). Alternatively, one foliar application of systemic pymetrozine can be used 50-55 days after planting, or two applications 7-14 days apart during periods of high numbers of aphids. Pymetrozine, a pyridine azomethine, has a different mode of action to the chloronicotinyls, acting on the serotonin pathway (Kaufmann et al. 2004). These two insecticides are selective against aphids and will provide protection against late spring and early summer aphid incursions.

The carbamate pirimicarb is used in early summer to control any aphids remaining on the potato foliage after the main summer aphid flights in Canterbury. Pirimicarb acts primarily by contact, but is also partially systemic, killing any aphids on the underside of the leaves. It is also benign to aphid predators.

The broad-spectrum translocating methamidophos (organophosphate) is applied in late summer to control autumn incursions of aphids, and potato tuber moth. To control aphids in the autumn to prevent virus transfer in regrowth of senescent foliage, the contact lambda-cyhalothrin (synthetic pyrethroid) can be applied with a foliar desiccant in autumn, as the herbicide prevents translocation of systemic or translocating insecticides.

Table 12: Recommended calendar-based insecticide spray programme for potatoes. The programme is designed to avoid development of insecticide resistance and enhance survival of aphid and potato tuber moth predators. To achieve this, label insecticide and water rates need to be applied.

Potato crop stage	Active ingredient	Chemical class	Target pest
1. Planting late Oct	Imidacloprid (Gaucho®)	Chloronicotinyl	Aphids
2. Moulding late Dec	Pymetrozine (Chess®)	Pyridine azomethine	Aphids
3. Foliage mid-Jan	Pymetrozine (Chess®)	Pyridine azomethine	Aphids
4. Flowering late Jan	Pirimicarb (Pirimor®, Primisect®, Prohive®)	Carbamate	Aphids
5. 70% tuber size mid-Feb	Methamidophos (Metafort®, Monitor®, Tamaron®)	Organophosphate	Aphids & tuber moth
6. 80% tuber size late Feb	Methamidophos (Metafort®, Monitor®, Tamaron®)	Organophosphate	Aphids & tuber moth
7. Desiccation early Mar	Lambda-cyhalothrin (Karate® Zeon)	Pyrethroid	Aphids & tuber moth
8. Desiccation late Mar	Lambda-cyhalothrin (Karate® Zeon)	Pyrethroid	Aphids & tuber moth

Label rates of insecticides in 300-600 litres/ha of water should be used to ensure a lethal dose of insecticide is deposited evenly over and at the base of the potato foliage. Sub-lethal doses of insecticides select for aphids that are partially resistant to the insecticide, and are more likely to lead to resistance than lethal doses.

Reducing the number of insecticides applied to a potato seed crop from the total of up to nine applications often used by growers in the past in their calendar-based programmes (Table 1) will lessen the risk of insecticide resistance developing. The insecticides that can be eliminated from the spray programme in Table 12, if no aphids are present in the crop, are the second application of Chess®, the application of Pirimor® and the second application of Karate® Zeon. Thus a minimum of four foliar insecticides can be used in this calendar-based programme (Table 13).

Table 13: Recommended calendar-based partial insecticide spray programme for seed potatoes under low aphid pressure, for control of aphids and potato tuber moth while minimising resistance to insecticides and enhancing survival of beneficial insects.

Potato crop stage	Active ingredient	Chemical class	Target pest
Planting late Oct	Imidacloprid (Gaucho®)	Chloronicotinyl	Aphids
Moulding late Dec	Pymetrozine (Chess®)	Pyridine-azomethine	Aphids
Flowering late Jan	Pirimicarb (Pirimor®, Primisect®, Prohive®)	Carbamate	Aphids
80% tuber size late Feb	Methamidophos (Metafort®, Monitor®, Tamaron®)	Organophosphate	Aphids & tuber moth
Desiccation early Mar	Lambda-cyhalothrin (Karate® Zeon)	Pyrethroid	Aphids & tuber moth

3.3 *Strategic foliar insecticide applications*

3.3.1 *Seed treatment*

An imidacloprid seed treatment is recommended for potato seed crops grown in regions where spring aphid flights historically occur at crop emergence. Process and table potato growers can consider not applying an imidacloprid seed treatment. No reduction in the incidence of viruses in potato tubers was seen at the Lincoln trial during 2004-05, when only one foliar insecticide was applied to seed not treated with insecticide when aphids had reached the threshold for spraying (Table 10).

3.3.2 Foliar treatments

Applying insecticides to potato foliage whenever aphid numbers exceed a threshold can reduce the number of insecticide applications from calendar-based programmes. However, a simple method is required to monitor aphids flying on to the potato crops, or those colonising potatoes. The suction traps provide good historic information on aphid flights for regions, but are expensive and do not provide data on local flights. Routinely counting wingless aphids on 150 leaves randomly selected throughout the potato crop (as done in the field trials) is time-consuming, and risks spreading viruses within the crop. It is also back-breaking, and requires a keen eye to distinguish aphids from other small insects common on the foliage. Yellow-bowl water traps provide a cheap and convenient method of monitoring aphid flights for strategic applications of insecticides.

3.3.3 Yellow-bowl water traps

Flora, 30 cm diameter, yellow-bowl traps (Figure 8) have been used to predict when virus-carrying aphids colonise sugar beet (Stevens et al. 1994). In Scotland, the traps have been used to assess virus-carrying aphids flying on to potato crops, and time of haulm destruction and insecticide applications for aphid control, saving potato growers up to $NZ105/ha (Northing et al. 2004). Yellow-bowl traps have been evaluated by potato growers in Canterbury for predicting periods of aphid-vectored virus risk.

Figure 8: Flora yellow-bowl (30 cm diameter) positioned in field (left), aphids in bottom of trap (centre), and aphids collected for species identification by Courtenay potato grower John Colee (right).

At Lincoln, the numbers of aphids in the suction trap for 2004-05 were closely related to the numbers caught in the yellow-bowl trap in a potato paddock situated 1 km away (Figure 8). The numbers of wingless aphids colonising potato foliage that not had been sprayed with insecticides increased shortly after the first aphids of concern in potatoes were recorded in the suction and yellow-bowl traps, then decreased before the main aphid flights. The aphid population crash was due probably to a combination of aphid predators found at the site and dry weather.

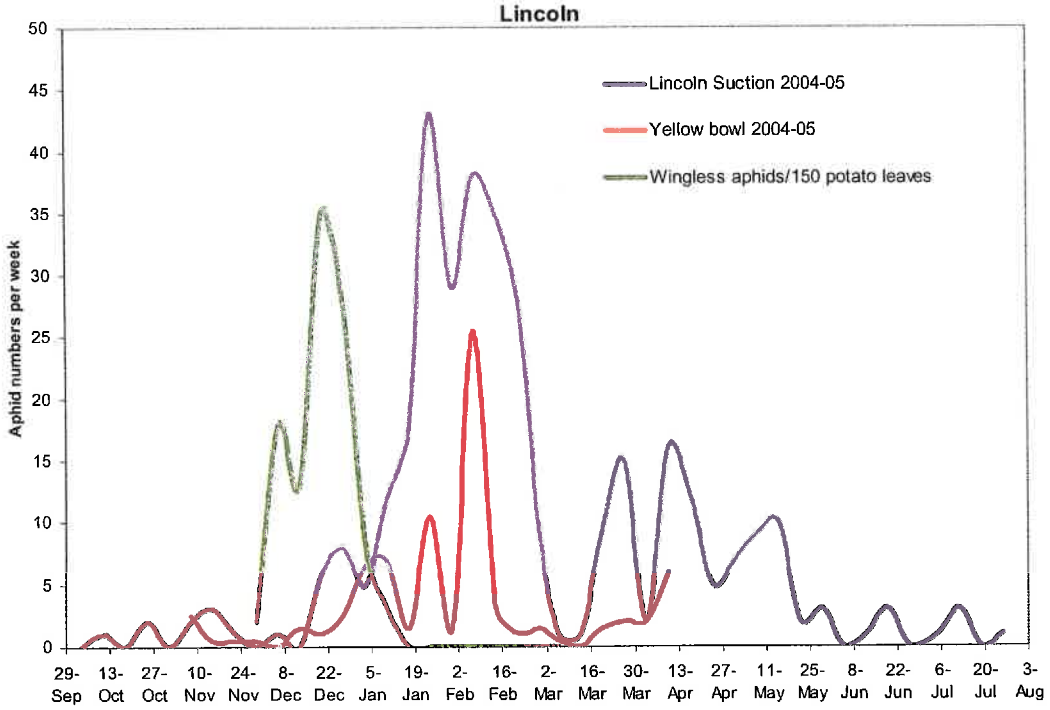


*Figure 9: Comparison of numbers of winged aphids (*A. solani, M. persicae, A. gossypii, M. euphorbiae*) caught in the suction trap at Lincoln, and in a yellow-bowl trap 1 km away. The numbers of wingless aphids colonising 150 potato leaves near the yellow-bowl trap are also shown*

At Courtenay, there was a large difference in the timing and numbers of winged aphids of potatoes in the suction trap and in the yellow-bowl traps located 0.5, 4 and 8 km away (Figure 9). The difference in trap catches probably reflected local variation in aphid flights between trap locations. This suggests that a yellow-bowl trap in a potato paddock would provide a more accurate indication of aphid flights in the paddock than the closest suction trap.

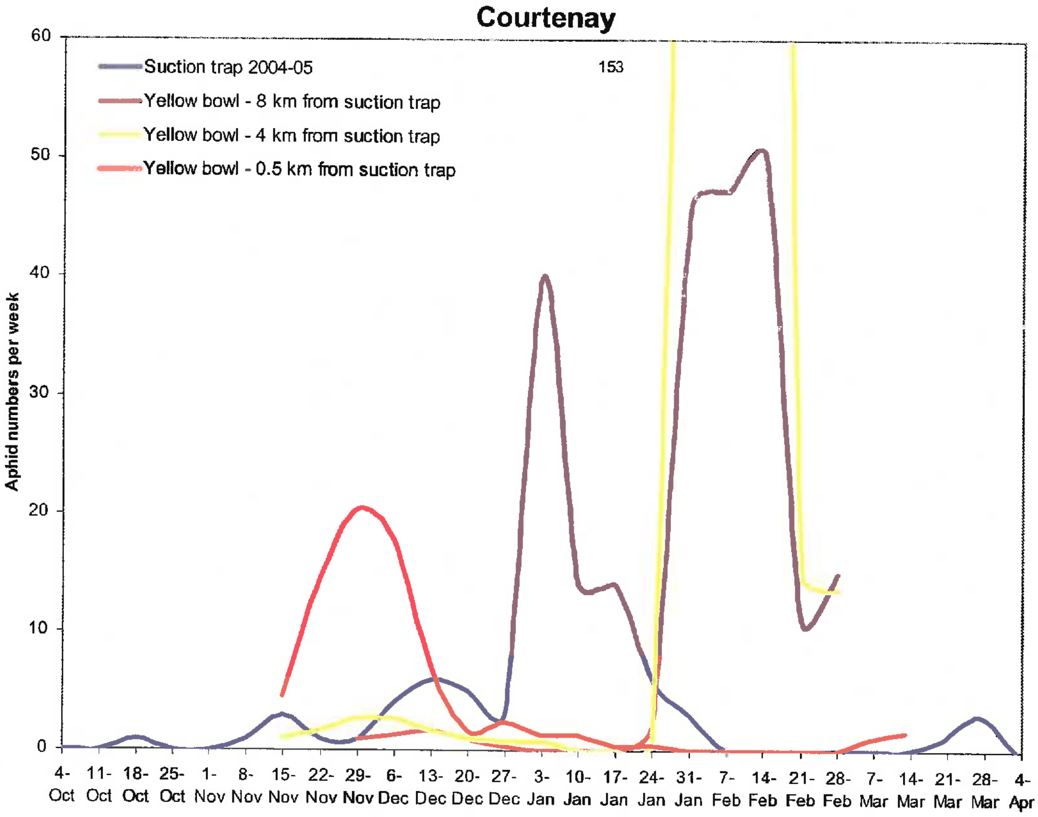


Figure 9: Comparison of numbers of winged aphids (A. solani, M. persicae, A. gossypii, M. euphorbiae) *caught in the suction trap at Courtenay, and in the yellow-bowl traps located 0.5, 4 and 8 km away.*

At Rokeby, a yellow-bowl trap located at each end of a potato paddock adjacent to the suction trap indicated that aphid flights in the paddock differed from those detected in the suction trap (Figure 10). Peak aphid flights in the paddock were later than those indicated by suction trap catches. Furthermore, the yellow-bowl trap at the west end of the paddock collected much larger numbers of aphids during mid-February and March than the trap at the east end, which had frequent foliar applications of methamidophos. The aphid catch in the yellow-bowl trap at Rokeby differed markedly from that at a trap 20 km south-east in Dorie, reflecting the ability of the traps to record local aphid flights (Figure 11).

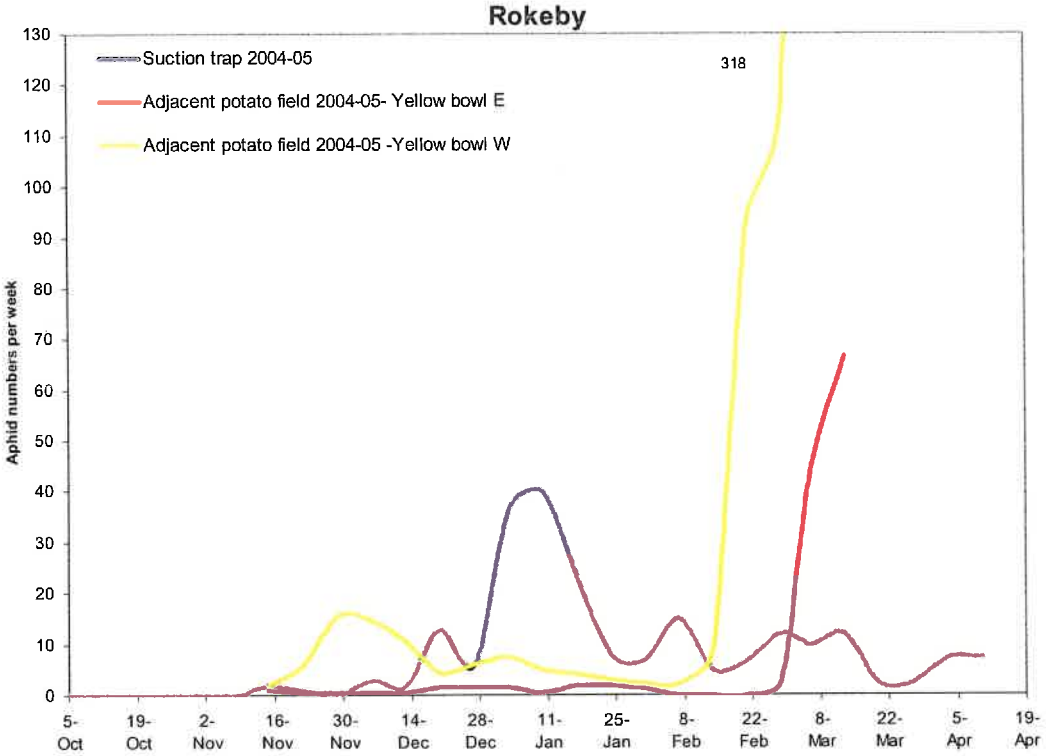


Figure 10: Comparison of numbers of winged aphids (A. solani, M. persicae, A. gossypii, M. euphorbiae) *caught in the suction trap at Rokeby, and in the yellow-bowl traps located at the east (A) and west (B) ends of a potato paddock adjacent to the suction trap.*

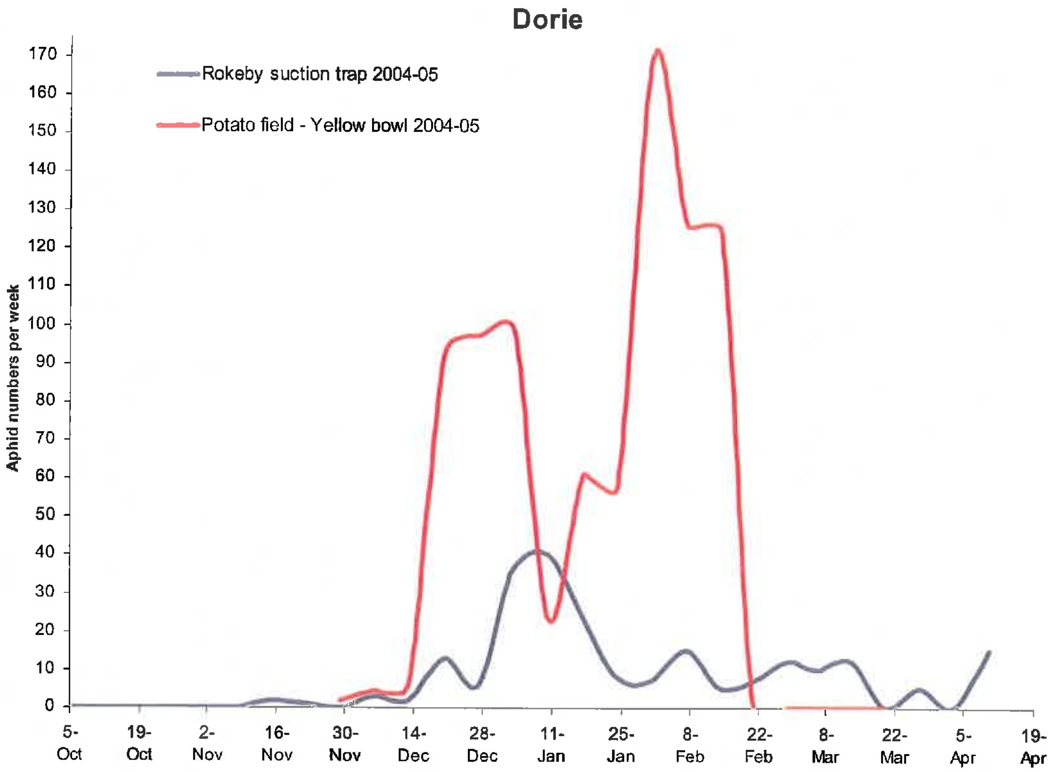


Figure 11: Comparison of numbers of winged aphids (A. solani, M. persicae, A. gossypii, M. euphorbiae) *caught in the suction trap at Rokeby, and in the yellow-bowl traps located in a potato paddock 20 km south-east at Dorie.*

At Rangitata, a yellow-bowl trap located at each of two potato paddocks 3 km apart also provided information on local flights (Figure 12). The number of aphids flying on to the paddocks increased just when protection from the imidacloprid (Gaucho®) seed treatment was expected to cease, about 55 days after planting.

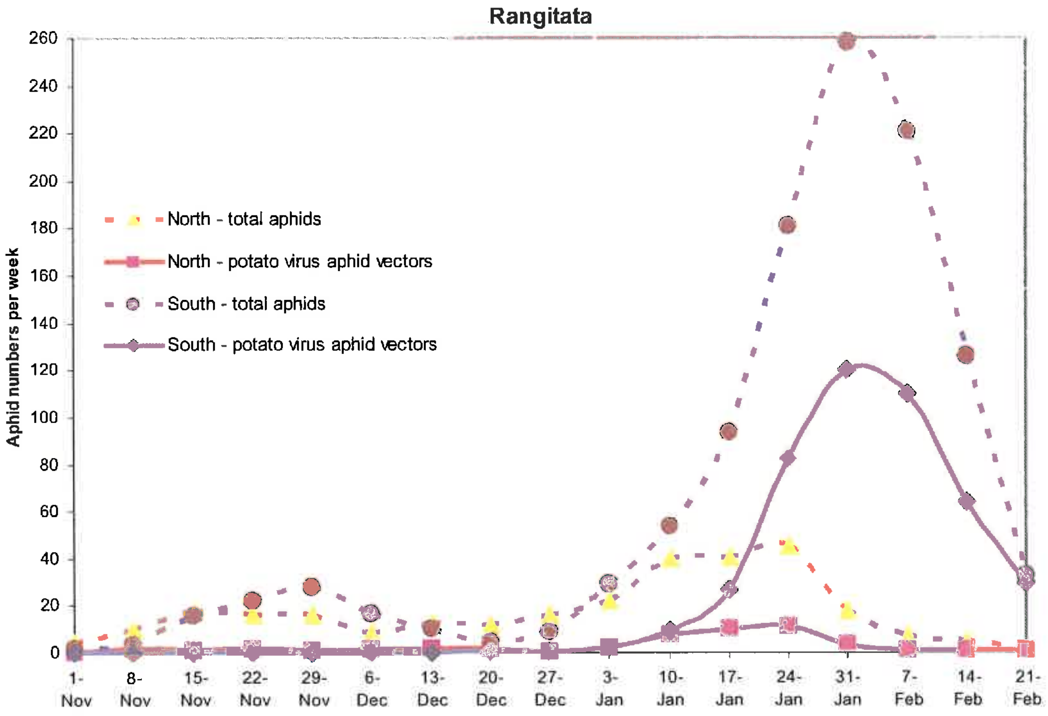


Figure 12: Comparison of numbers of winged aphids (A. solani, M. persicae, A. gossypii, M. euphorbiae) *caught in yellow-bowl traps located in two potato paddocks north and south of Rangitata, 3 km apart. The main aphid flights occurred when the protection from Gaucho® seed treatment had ceased (on 27 December 2005, 50 days after planting on 7 November).*

The yellow-bowl traps appear to offer a practical method of monitoring aphid flights specific to individual paddocks. Researchers in Scotland have shown that there is a very close relationship between the risk of transmission of PVY to potatoes and the number of aphids of specific species caught in yellow-bowl traps (King et al. 2004). We expect the same close relationship to occur in New Zealand. The traps also caught aphid predators such as lacewings, ladybirds, aphid parasitoids and Syrphid flies, and this information on when aphid predators were flying into the potato crop could assist in deciding on whether to use predator-benign insecticides or not.

3.3.4 *Virus risk service*

Crop & Food Research can develop an aphid monitoring service, for example using yellow-bowl traps, to give growers an assessment of virus risk to their crops. This would involve an assessment of aphid species, virus load and aphid predators. In Scotland, a programme already exists where the virus risk is calculated by multiplying the number of each aphid species by their PVY virus efficiency transfer factor (Table 13) to obtain a PVY risk index. The higher the index, the higher the risk of PVY. The cost of the trap would be a separate charge. Whether the service goes ahead will depend on interest from growers. A cost-effective programme would require a significant number of growers to take part.

Table 13: Efficiency factors (King et al. 2004, Scotland) for aphid species common on potatoes in New Zealand as vectors of PVY.

Aphid species	PVY factor
Myzus persicae	1
Acyrothosiphon pisum	0.7
Rhopalosiphum padi	0.4
Metopolophium dirhodum	0.3
Brachycaudus helichrysi	0.21
Aulocauthum solani	0.2
Macrosiphum euphorbiae	0.2
Hyperomyzus lactucae	0.16
Brevicoryne brassicae	0.01

Alternatively, the amount of virus contained in each insect catch from the yellow-bowl trap or suction trap could be determined by quantitative PCR. Since the aphids will not need to be separated from the other insects caught in the trap, nor sorted into separate species, this technique offers a potentially much cheaper method of determining virus risk than the current method. However, the validity of quantitative PCR in detecting virus-carrying aphids in trap catches needs to be tested under New Zealand conditions.

3.3.5 *Selection of insecticides*

As soon as a period of high virus risk is evident, an insecticide can be applied to the potato foliage. The selection of the insecticide will depend on the timing of the virus risk, as per the reasons given for the calendar-based regime. Pymetrozine should be applied in spring; pirimicarb in mid-summer; methamidophos in early autumn; lambda-cyhalothrin in late autumn after a desiccant has been applied to the foliage.

This strategic insecticide application regime requires further evaluation under commercial paddock conditions to verify its effectiveness over calendar-based programmes in reducing virus incidence in seed potatoes.

4 Acknowledgements

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Appendix Insecticides registered for use in potatoes (New Zealand AgriChemical Manual, 2005, AgriMedia Ltd, Christchurch).

		Active ingredient concentration		Minimum product label rate		Minimum water label rate				
Product	Active ingredient	Amount	Unit	Amount	Unit	Amount	Unit	Chemical class	Control purpose	Mode of action
Carbaryl 50 F	carbaryl	500	g/litre	2.4-4.8	litre/ha	-	-	carbamate	potato tuber moth	Contact
Chess$^{®}$ WG	pymetrozine	500	g/kg	200	g/ha	350	litre/ha	pyridine azomethine	aphids	Translaminar, systemic
Crop Care Phorate	phorate	200	g/kg	11	kg/ha	-	-	organophosphate	aphids, wireworm	Systemic, contact, fumigant
Decis$^{®}$ Forte	deltamethrin	2.75	g/litre	450	ml/ha	500	litre/ha	synthetic pyrethroid	potato tuber moth	Contact
Deltaphar 25 EC$^{®}$	deltamethrin	25	g/litre	450	ml/ha	500	litre/ha	synthetic pyrethroid	potato tuber moth	Contact
Dimezyl$^{®}$ 40 EC	dimethoate	400	g/litre	800	ml/ha	500	litre/ha	organophosphate	aphids	Translocation in sap
Flavylan$^{®}$ 350 EC	endosulfan	350	g/litre	2.0	litre/ha	500	litre/ha	organochloride	aphids, potato tuber moth, looper caterpillar	Translocation in sap
Folidol$^{®}$	parathion methyl	600	g/litre	40-80	ml/100 litre	500	litre/ha	organophosphate	sucking and chewing insects	Translocation in sap
Gaucho$^{®}$	imidacloprid	600	g/litre	200	ml/ha	-	-	chloronicotinyl	aphids	Translocation in foliage
Ground Zero	phorate	200	g/kg	11	kg/ha	-	-	organophosphate	aphids, wireworm	Systemic, contact, fumigant
Karate$^{®}$ Zeon	lambda-cyhalothrin	250	ml/litre	40	ml/ha	500	litre/ha	synthetic pyrethroid	potato tuber moth	Contact
Lancer$^{®}$ 750 DF	acephate	750	g/litre	250	g/ha	-	-	organophosphate	aphids, potato tuber moth	Contact, systemic
Metafort$^{®}$ 60 SL	methamidophos	600	g/litre	800	ml/ha	500	litre/ha	organophosphate	aphids, potato tuber moth	Translocation in sap
Monitor$^{®}$	methamidophos	600	g/litre	800	ml/ha	500	litre/ha	organophosphate	aphids, potato tuber moth	Translocation in sap
Nemacur$^{®}$	fenamiphos	400	g/litre	20	litre/ha	100	litre/ha	organophosphate	potato cyst nematode	Translocating, systemic
Nufarm Phorate	phorate	200	g/kg	11	kg/ha	-	-	organophosphate	aphids, wireworm	Systemic, contact, fumigant
Orthene$^{®}$ Liquid	acephate	195	g/litre	1.0	kg/ha	-	-	organophosphate	aphids, potato tuber moth	Contact, systemic
Perfekthion$^{®}$ S	dimethoate	500	g/litre	650	ml/ha	500	litre/ha	organophosphate	aphids	Translocation in sap
Pirimor$^{®}$ 50	pirimicarb	500	g/kg	500	g/ha	200	litre/ha	carbamate	aphids	Contact, partially systemic, fumigant
Primisect	pirimicarb	500	g/kg	500	g/ha	200	litre/ha	carbamate	aphids	Contact, partially systemic, fumigant

		Active ingredient concentration		Minimum product label rate		Minimum water label rate				
Product	Active ingredient	Amount	Unit	Amount	Unit	Amount	Unit	Chemical class	Control purpose	Mode of action
Prohive™	pirimicarb	500	g/kg	500	g/ha	200	litre/ha	carbamate	aphids	Contact, partially systemic, fumigant
Sevin® Flo	carbaryl	500	g/litre	2.4-4.8	litre/ha	-	-	carbamate	potato tuber moth	Contact
Sumi-Alpha®	esfenvalerate	50	g/litre	250	ml/ha	300	litre/ha	synthetic pyrethroid	cutworm	contact
Sunspray®	mineral oil	970	ml/litre	0.5	%	-	-	mineral oil	aphids, mites, thrips	Narrow distillation range spray oil that coats insects and interferes with their metabolic processors
Tamaron®	methamidophos	600	g/litre	800	ml/ha	500	litre/ha	organophosphate	aphids, potato tuber moth	Translocation in sap
Thimet® 20 G	phorate	200	g/kg	11	kg/ha	-	-	organophosphate	aphids, wireworm	Systemic, contact, fumigant
Thiodan® 35 EC	endosulfan	350	g/litre	2.0	litre/ha	500	litre/ha	organochloride	aphids, potato tuber moth, looper caterpillar	Translocation in sap
Peptoil™	paraffinic petroleum oil	100	%	0.5	litre/ha	-	-	mineral oil, end capped polyalkoxylate polyol fatty acid ester	antifoam agent	general purpose crop oil concentrate with excellent emulsifying properties
Rainguard™	poly-1-p-methene	1000	ml/litre	200	ml/ha	-	-	terpenic polymer non-ionic surfactant	chemical wetting & adhesion; UV protection; reduced volatilisation	