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Benchmarking pesticide use in potato crops in Canterbury, New Zealand

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Contents

1 Executive summary

The aim of this study was to describe pesticide use patterns in Canterbury, New Zealand, for potato seed crops grown for the establishment of process potato crops and potato crops grown for processing in order to assist in the development of sustainable pest management systems. Benchmarking of industry agrichemical use has been important in the successful development and implementation of integrated pest management programmes in New Zealand. Key results of pesticide use surveys carried out over seven growing seasons are presented in this report along with a discussion of pesticide use in relation to sustainable pest management.

The study is part of the Human Dimensions programme of research funded by the Foundation for Research, Science and Technology to better identify and understand pesticide use patterns and grower best practice.

Pesticides for the control of weeds, insects and diseases in potatoes in Canterbury were assessed via spray diaries tabulated using SprayView Analyst (HortPlus©). Spray diaries for 17–30 seed potato crops in each of seven growing seasons (1999–2006) were examined. They represented pesticides that were applied to 13% of the area grown for seed for the establishment of processing crops in New Zealand. Spray diaries for 71–100 processing potato crops in each of four growing seasons (2003–07) were examined. They represented pesticides that were applied to 28% of the area grown for the production of process potatoes in New Zealand.

Seed crops were generally treated with the herbicide metribuzin, the fungicides pencycuron, mancozeb/metalaxyl-M, azoxystrobin and propineb, and the insecticides methamidophos, pymetrozine and pirimicarb. Total pesticide use on seed crops fluctuated between 8.8 and 13.1 kg(L) ai/ha over all seven growing seasons surveyed. Process crops were mostly treated with the herbicides cyanazine, glyphosate, linuron and metribuzin, and the fungicides pencycuron azoxystrobin, chlorothalonil, copper hydroxide, fluazinam and mancozeb/metalaxyl-M. Weeds, pathogens causing early blight and late blight, and aphids were presumed to be the primary pest targets. Total pesticide use on process crops fluctuated between 11.5 kg(L) ai/ha to 17.4 kg(L) ai/ha in the four growing seasons.

Pesticide resistance strategies were followed surveyed in half of seed crops (2005-06) and most of the process crops in the survey.

The data presented in this report provide a benchmark for future analysis of pesticide use in potatoes in New Zealand. Key findings from this report follow:

1. More than 90% both of seed and process crops received a seed treatment to control *Rhizoctonia solani* prior to planting, although process crops received more foliar-applied fungicides than seed crops, but with recommendations to prevent fungicide resistance generally adhered to by growers.
2. Most seed crops received a single insecticide seed treatment (imidacloprid) as well as 1–12 (but averaging 5.5) foliar applications of insecticides from four insecticide classes, while process potato crops were also mostly seed treated with insecticide in 2003, but not in subsequent years, and received considerably fewer foliar applications of these chemicals (usually 1–2 but occasionally up to 6) than seed crops.

3. Prior to the 2005–06 growing season, most seed crops received more than three sequential applications of organophosphates, a practice that may have selected aphid populations that are resistant to insecticides from this and other chemical classes, but this practice declined somewhat in the 2005–06 season, coinciding with the release of the Sustainable Farming Fund (SFF) potato aphid virus report on sustainable insecticide management.

4. This study has benchmarked insecticide use patterns before the predicted incursion into Canterbury of the potato psyllid (*Bactericera cockerelli*), which is likely to have a large impact on potato production in New Zealand and result in changes to established insecticide use patterns.

2 Introduction

Benchmarking of industry agrichemical use has been important in the successful development and implementation of integrated pest management programmes in New Zealand. In the fruit sector, for example, assessments of individual spray diaries have led to the identification of high or unnecessary use of pesticides, improved timing of applications and identification of inappropriate product choices, particularly relating to the management of resistance development in target pest populations (Manktelow et al. 2005). Benefits that may come from recording and analysing pesticide use data include identifying the proportion of an industry sector using best practice for pest control, predicting future pest resistance issues or non-target impacts on beneficial insects, grower education, improved market access, understanding the reasons for pest outbreaks, responses to invasive organisms, formulating biosecurity policy and planning for the introduction of new pesticides. Analysis of pesticide use is especially worthwhile when linked to analysis of any pest scouting or disease forecasting, as well as pest, disease and weed control outcomes achieved as a result of particular use patterns.

In New Zealand, as indicated in the *New Zealand Novachem Agrichemical Manual* (Anon. 2008), fungicides are applied to potatoes primarily to control the diseases early blight (caused by *Alternaria solani*) and late blight (caused by *Phytophthora infestans*). Insecticides are used to control potato tuber moth (*Phthorimaea operculella*) and several species of virus-transmitting aphids, especially the green peach aphid (*Myzus persicae*) (Stufkens & Teulon 2001). Herbicides are used to control weeds, which act both as competitors for crop plants and as reservoirs for potato viruses transmitted by aphids. Weed control, and the requirement to keep potatoes free from fungus and virus diseases, requires thorough and exacting control programmes, often resulting in multiple pesticide applications. Pesticide control programmes that rely on the multiple use of the same or related pesticides can lead to the development of pesticide resistance in pest populations in the absence of pesticide resistance management strategies (Martin et al. 2005). Resistance to metalaxyl (including metalaxyl-M) in *Phytophthora infestans* was recorded in New Zealand in the 1980s (Hartill et al. 1983), and is common in countries with both A1 and A2 mating types of the pathogen (Lehtinen et al. 2008). Resistance to strobilurin fungicides in *Alternaria solani* has been reported in the US (Rosenzweig et al. 2008), although not yet in New Zealand. Insecticide resistance to aphids that colonise potatoes has already been documented in New Zealand (Cameron & Walker 1988; Fellowes & Fergusson 1994; Martin & Workman 1997; van Toor et al. 2008). The development of weed resistance to herbicides is relatively uncommon, and has not been recorded in potato crops (Anon. 2008).

The study is part of the Human Dimensions programme of research funded by the Foundation for Research, Science and Technology, Contract C02X0303 Objective 1, to better identify and understand pesticide use patterns. This report describes research undertaken for Milestones 3 and 4, which are designed to benchmark pesticide use and grower best practice. In this report pesticide use patterns in Canterbury, New Zealand, are outlined for potato seed crops (which are grown for the establishment of process potato crops) and crops grown for processing. Spray use was established by examining growers' spray diaries. These data provide a benchmark for future analysis of pesticide use in potatoes in New Zealand. Pesticide use is also discussed in relation to sustainable pest management.

3 Methods

Spray diaries from Canterbury potato growers (permission from each obtained) were accessed through Alex McDonald Merchants, Darfield, Canterbury, for seed crops, and McCain Foods Ltd, Washdyke, South Canterbury, for process crops. Spray data from seed crops (6–11 growers representing 17–30 crops) and process crops (11 growers representing 71–100 crops) were obtained and examined. The seed crops were grown for propagation from cut seed for the establishment of process crops, in contrast to propagation from whole seed, which is used for crop establishment to produce potatoes for sale as fresh potatoes. Crops are defined here as comprising a single potato cultivar to which a discrete pesticide programme was applied in one field. Data from seed potatoes were obtained for seven seasons, 1999–2006, and from process potatoes for four seasons, 2003–07. Data were entered into a database using SprayView Log (HortPlus©) to standardise grower and pesticide names and the amounts of pesticide applied.

Cursory summaries of the data were produced using SprayView Analyst (HortPlus©), and the data tabulated using Microsoft Excel. Sequential applications of three or more pesticides from the same chemical class were noted because this practice has the potential to induce resistance in fungal pathogens and insect pests, and in weeds to a lesser extent (Martin et al. 2005). We assumed that growers used these pesticides to control the appropriate target pests for which individual products are registered (www.novachem.co.nz). For agrichemicals with one or two active ingredients, the amount of active ingredient per hectare was calculated by multiplying the active ingredient concentration in a product by the rate at which the product was applied per hectare. Agrichemical classifications were those categorised by the Resistance Action Committees for fungicides, insecticides and herbicides (www.frac.info/; www.irac-online.org/; www.plantprotection.org/hrac/).

4 Results

4.1 Seed potato crops

4.1.1 Pesticides used and numbers of applications

Crop areas of seed potatoes averaged 6.3 ha, ranging from 1 to 20 ha. The pesticides that were applied to these crops are listed in Table 1 and summarised graphically under pesticide classes in Figure 1.

Seventeen different fungicide active ingredients (including those in mixes) from 11 fungicide classes were applied to potato seed crops during 1999–2006. Pencycuron was the only pre-planting seed tuber treatment used, for the control of black scurf and stem canker (caused by *Rhizoctonia solani*) in most (over 90%) of the crops. Most (at least 80%) of the foliar-applied fungicides were for the control of early and late blight (caused by *Alternaria solani* and *Phytophthora infestans* respectively). Mancozeb or mixtures of mancozeb and metalaxyl made up more than half of the fungicide applications to control these two diseases, with the other fungicides propineb, azoxystrobin, difenoconazole, chlorothalonil, dimethomorph and iprovalicarb/propineb all being applied in 2005–06. Fluazinam was applied in some crops during 2003–05 to control *Sclerotinia sclerotiorum* and early and late blight. Dithiocarbamates (mancozeb, propineb) were applied sequentially three or more times to 5–60% of crops during the survey period. The strobilurin azoxystrobin was applied to 11% of crops in 2001. The triazole difenoconazole was applied to 10% of crops in 1999 only. Thiabendazole was applied to between 0% (2005–06) and 40% (2002–03 and 2003–04) of harvested tubers to control *Fusarium* spp., which cause dry rot, and to control *Phoma* spp., which cause gangrene, in stored tubers. This indicates that the use of postharvest thiabendazole treatment varies considerably from year to year.

Ten insecticide active ingredients from five insecticide classes were used against potato tuber moth and/or aphids, along with oils, to prevent transmission of potato viruses. In the seven growing seasons, most crops (81–100%) were sown with seed tubers treated with imidacloprid to provide control of aphids in spring, and the other crops were sown with seed tubers to which no insecticide had been applied. Phorate granules were broadcast after planting on one crop in 2004 only, in addition to the imidacloprid seed treatment. The four most commonly used foliar-applied insecticides (λ-cyhalothrin, methamidophos, pirimicarb and pymetrozine) comprised 97% of the 856 insecticide applications made during the survey period. Mineral oil was applied to foliage at the same time as an insecticide in the majority of crops to disrupt feeding by aphids and to limit virus transfer to plants. Three or more sequential applications of organophosphates (mostly methamidophos but also acephate and dimethoate), and occasionally pymetrozine and λ-cyhalothrin, were applied to 59–100% crops planted in 1999–2004, but to only 53% of crops planted in 2005.

Eight herbicides, applied singly or in herbicide mixes, comprising six chemical classes, were applied in the seven growing seasons from 1999 to 2006. Metribuzin comprised 58–83% of the herbicides applied. Carfentrazone-ethyl was used in the later years, representing 26% of herbicides applied in the 2005–06 season. Diquat was used as a desiccant to aid harvesting of tubers on 56–100% of crops, on between one and four occasions, depending on growing conditions and cultivar for individual crops.

Table 1: Pesticides applied to seed potato crops during 1999–2006, showing total number of crops surveyed for each year, those treated (T), and the average (A) and maximum (M) number of applications per crop that received pesticides.

	1999–00			2000–01			2001–02			2002–03			2003–04			2004–05			2005–06		
Total no. crops	21			17			27			23			21			30			19		
Mean crop area (ha)(range)	6.9 (1–13)			7.6 (2–14)			6.8 (1–14)			4.5 (2–13)			7.6 (1–20)			5.6 (2–14)			6.7 (2–13)		
	T	A	M	T	A	M	T	A	M	T	A	M	T	A	M	T	A	M	T	A	M
Fungicides																					
Azoxystrobin	10	**1.2**	2	1	1.0	1	16	1.5	3	5	1.0	1	10	1.0	1	9	1.3	2	9	1.2	2
Carbendazim	0	**0.0**	0	1	1.0	1	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0
Chlorothalonil	1	**2.0**	2	0	0.0	0	4	1.5	3	6	1.3	3	2	2.5	3	8	1.0	1	1	1.0	1
Copper hydroxide	0	**0.0**	0	1	1.0	1	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0
Copper oxide	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	4	1.0	1	0	0.0	0
Difenoconazole	13	**1.5**	3	1	1.0	1	4	1.3	2	1	2.0	2	3	1.0	1	• 1.	1.0	1	0	0.0	0
Fluazinam	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	7	1.4	2	7	1.0	1	0	0.0	0
Iprovalicarb/propineb	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	5	1.4	2
Mancozeb	19	**2.2**	4	15	2.8	4	19	3.9	6	11	3.6	6	12	3.6	6	18	3.1	8	15	2.9	5
Mancozeb/benalaxyl	1	**2.0**	2	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0
Mancozeb/dimethomorph	0	**0.0**	0	1	1.0	1	3	1.0	1	0	0.0	0	5	1.0	1	0	0.0	0	0	0.0	0
Mancozeb/metalaxyl	2	**1.0**	1	8	1.0	1	0	0.0	0	1	1.0	1	0	0.0	0	0	0.0	0	0	0.0	0
Mancozeb/metalaxyl-M	15	**1.5**	2	10	2.1	4	12	1.4	2	19	1.5	2	16	1.6	3	22	1.2	3	13	1.0	1
Pencycuron treated seed	17	**1.0**	1	16	1.0	1	22	1.0	1	22	1.0	1	18	1.0	1	30	1.0	1	19	1.0	1
Propineb	0	**0.0**	0	1	4.0	4	6	3.2	4	12	3.6	5	10	2.7	4	12	4.5	7	9	2.0	6
Thiabendazole	2	**1.0**	1	5	1.0	1	6	1.0	1	10	1.4	2	8	1.5	2	6	1.0	1	0	0.0	0

	1999–00			2000–01			2001–02			2002–03			2003–04			2004–05			2005–06		
Total no. crops	21			17			27			23			21			30			19		
Mean crop area (ha)(range)	6.9 (1–13)			7.6 (2–14)			6.8 (1–14)			4.5 (2–13)			7.6 (1–20)			5.6 (2–14)			6.7 (2–13)		
	T	A	M	T	A	M	T	A	M	T	A	M	T	A	M	T	A	M	T	A	M
Insecticides																					
Acephate	4	**3.8**	4	0	0.0	0	1	1.0	1	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0
Chlorpyrifos	0	**0.0**	0	0	0.0	0	2	1.0	1	0	0.0	0	0	0.0	0	0	0.0	0	1	1.0	1
Dimethoate	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	1	5.0	5	0	0.0	0	0	0.0	0
Imidacloprid treated seed	17	**1.0**	1	16	1.0	1	22	1.0	1	22	1.0	1	19	1.0	1	30	1.0	1	19	1.0	1
λ-cyhalothrin	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	6	2.0	3	13	2.3	6	6	2.0	3
Methamidophos	17	**3.1**	6	17	4.5	7	25	3.8	7	23	4.4	7	20	5.6	10	29	4.0	10	17	3.7	7
Mineral oil	2	**2.0**	2	1	5.0	5	8	3.8	6	15	4.7	6	5	4.0	6	5	7.0	7	15	3.0	7
Phorate (broadcast)	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	1	1.0	1	0	0.0	0
Pirimicarb	0	**0.0**	0	4	1.0	1	0	0.0	0	0	0.0	0	1	1.0	1	8	2.6	3	8	1.9	3
Pymetrozine	5	**2.6**	3	5	2.0	3	0	0.0	0	0	0.0	0	12	1.2	3	27	2.0	3	14	1.8	2
Taufluvalinate	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	3	1.7	2	0	0.0	0
Herbicides																					
Carfentrazone-ethyl	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	6	1.2	2
Cyanazine	1	**1.0**	1	1	1.0	1	1	1.0	1	1	1.0	1	1	1.0	1	3	1.0	1	1	1.0	1
Glyphosate	0	**0.0**	0	0	0.0	0	2	1.0	1	3	1.0	1	1	1.0	1	0	0.0	0	1	1.0	1
Linuron	1	**1.0**	1	0	0.0	0	1	1.0	1	1	1.0	1	2	1.0	1	0	0.0	0	0	0.0	0
Metribuzin	7	**1.0**	1	5	1.0	1	6	1.0	1	4	1.8	2	7	1.0	1	12	1.0	1	16	1.0	1
Paraquat	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	2	1.0	1
Terbutryn/terbuthylazine	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	1	1.0	1	3	1.0	1	2	1.0	1
Desiccants																					
Diquat	11	**1.2**	2	10	1.6	4	17	1.3	2	19	1.2	2	21	2.0	3	28	2.2	4	12	2.2	3
Endothal	0	**0.0**	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	4	1.8	3	3	2.0	2

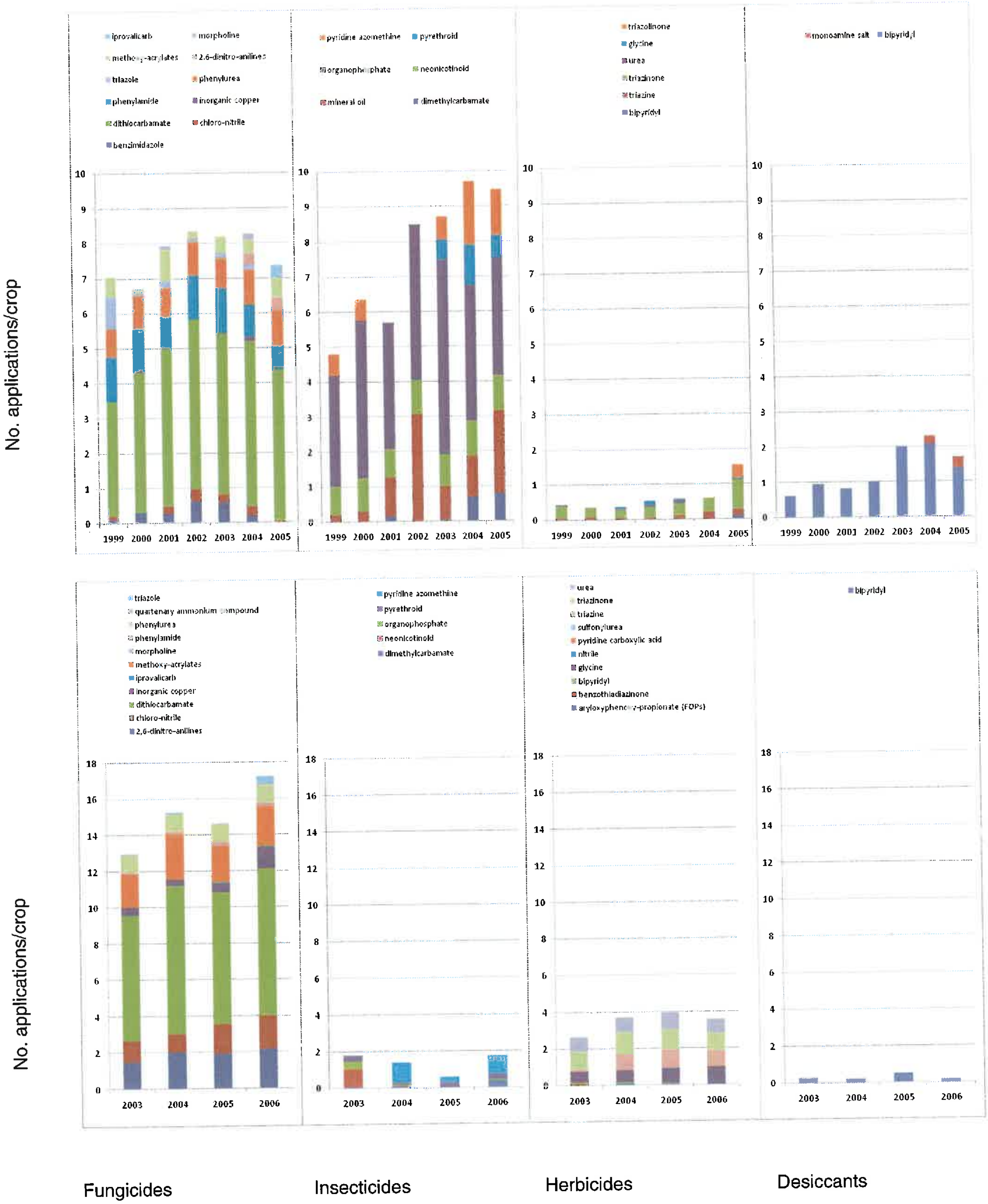

Figure 1: Numbers of agrichemical applications per year on seed (top) and process (bottom) potato crops during 1999–2007.

4.1.2 Total amount of pesticides applied

The total amount of pesticide active ingredient (excluding mineral oil) applied on average to each crop varied over the 1999–2006 survey period, ranging from 8.8 kg(L) ai/ha in 1999–2000 to 12.9 kg(L) ai/ha in 2005–06 (Table 2). The amount of desiccant used on crops tended to increase over the survey period due to an increase in the use of endothal. This product was withdrawn from the market in 2006 (Anon. 2008). The overall increase in pesticide use on seed crops across the seven years of this survey was reflected both in the average total amount of pesticides applied to crops and in the different types of pesticides used (fungicides, insecticides, herbicides and desiccants). Pesticide usage tended to increase across the seven seasons covered in this survey, with a total average increase in pesticide use between the two first seasons and the last four seasons of 28%.

Table 2: Average amount of pesticide (kg(L) ai/ha) applied to each seed potato crop for each growing season. (Blanks denote no chemical applied, 0.000 denotes less than a gram on average/ha.)

		Average kg or L ai/ha pesticide per crop						
		1999	2000	2001	2002	2003	2004	2005
Fungicides								
Benzimidazole	Carbendazim, thiabendazole	0.004	0.013	0.113	0.027	0.025	0.009	
Chloro-nitrile	Chlorothalonil	0.069		0.173	0.153	0.147	0.252	0.061
Dithiocarbamate	Mancozeb, propineb	4.083	5.219	5.709	6.277	5.846	5.988	5.580
Inorganic copper	copper hydroxide, copper oxide		0.021				0.150	
Iprovalicarb	Iprovalicarb							0.034
Methoxy-acrylates	Azoxystrobin	0.089	0.007	0.110	0.027	0.055	0.075	0.072
Morpholine	dimethomorph		0.007	0.012			0.021	
Phenylamide	metalaxyl, metalaxyl-M, benalaxyl	0.181	0.178	0.119	0.180	0.182	0.128	0.099
Phenylurea	Pencycuron	0.300	0.441	0.375	0.416	0.338	0.505	0.529
Triazole	Difenoconazole	0.111	0.007	0.023	0.011	0.018	0.017	
2,6-dinitro-anilines	Fluazinam						0.035	0.046
Total		4.836	5.894	6.635	7.091	6.611	7.178	6.421
Insecticides								
Dimethylcarbamate	Pirimicarb			0.023		0.012	0.175	0.191
Mineral oil	Mineral oil	1.848	0.285	1.078	2.994	0.924	1.132	2.502
Neonicotinoid	Imidacloprid	0.093	0.160	0.136	0.155	0.150	0.179	0.189
Organophosphate	Acephate, Chlorpyrifos, Dimethoate, methamidophos, Phorate	1.379	2.231	1.749	2.170	2.688	1.913	1.548
Pyrethroid	λ-cyhalothrin, Taufluvalinate					0.008	0.016	0.006
Pyridine azomethine	Pymetrozine	0.114	0.118			0.068	0.180	0.132
Total		3.434	2.793	2.985	5.320	3.849	3.595	4.567
Herbicides								
Bipyridyl	paraquat							0.032
Glycine	glyphosate			0.027	0.094	0.017		0.019
Triazine	cyanazine, Terbutryn, terbuthylazine	0.043	0.053	0.033	0.039	0.054	0.153	0.126
Triazinone	metribuzin	0.135	0.134	0.087	0.086	0.112	0.162	0.361
Triazolinone	carfentrazone-ethyl							0.022
Urea	linuron	0.048		0.037	0.043	0.083		
Total		0.225	0.187	0.184	0.262	0.266	0.315	0.560
Desiccants								
Bipyridyl	diquat	0.291	0.441	0.404	0.465	0.879	1.017	0.632
Monoamine salt	endothal TD-2335-2						0.480	0.758
Total		0.291	0.441	0.404	0.465	0.879	1.497	1.389
Total agrichemicals applied		8.788	9.315	10.208	13.138	11.605	12.584	12.938

4.2 Process potato crops

4.2.1 Pesticides used and numbers of applications

Crop areas of process potatoes averaged 13.7 ha, ranging from 2 to 92 ha. The pesticides applied to the crops are listed in Table 3 and summarised graphically under pesticide classes in Figure 1.

The 15 fungicide active ingredients used on crops comprised 11 chemical classes. Pencycuron was used as a seed treatment for the control of *Rhizoctonia solani* in all but five crops sown for processing between 2004 and 2007. Control of the pathogens causing early and late blight made up 80–86% of the total fungicide applications to foliage. Mancozeb and azoxystrobin made up 60–80% of the total applications. Chlorothalonil, copper, propineb, difenoconazole and mancozeb/metalaxyl mixture were used to a lesser extent. Iprovalicarb/propineb was used in the 2005–06 growing season and thereafter. Fluazinam was applied in 13–17% of crops during the survey period to control *Sclerotinia sclerotiorum* and pathogens causing early and late blight. Chloro-nitrile (chlorothalonil) was applied sequentially three or more times on 2–20% of crops during the survey period, Dithiocarbamates (mancozeb, propineb) were used on 90–96% of crops, while the pyridinamine fluazinam was used on 7–21% of crops; the strobilurin azoxystrobin on 1–4% of crops; and the triazole difenoconazole on 1% of crops in 2006 only.

Nine insecticide active ingredients from five chemical classes were used. Their use differed over the survey period. All potatoes planted in 2003 were treated with imidacloprid seed dressing to control aphids or with phorate in planting furrows to control aphids and grass grub, but in subsequent seasons little or no insecticide seed treatment was used. Of the foliar-applied insecticides, pirimicarb and pymetrozine were used to control aphids more frequently on potatoes planted in 2006 than in previous growing seasons, and λ-cyhalothrin was used for aphid and/or potato tuber moth control consistently throughout the survey period in 12–20% of crops per season. Three sequential applications of pyrethroids were applied to 2% of crops in the 2003–04 season, and organophosphates to 1% of crops and carbamates to 2% of crops in the 2004–05 season, but none of these compounds were used in subsequent seasons.

Cyanazine, glyphosate, linuron and metribuzin comprised 86–95% of the 15 herbicides or herbicide mixes applied in the four growing seasons from 2003 to 2007. Diquat was used as a desiccant to aid harvesting of tubers on 18–46% of crops, usually once and rarely twice in a season. The common pre-emergence or emergence residual herbicides (cyanazine, linuron and metribuzin) were used for weed control in crop establishment in accordance with accepted agricultural practice.

Table 3: Pesticides applied to process potato crops during 2003–07, showing the total number of crops surveyed for each year, those treated (T), and the average (A) and maximum (M) number of applications per crop that received pesticides.

	2003–04			2004–05			2005–06			2006–07		
Total no. crops	85			100			71			90		
Mean crop ha (range)	18.2 (2–92)			10.7 (4–17)			22.1 (1–69)			19.9 (1.5–60)		
	T	**A**	M	T	A	M	T	A	M	T	A	M
Fungicides												
Azoxystrobin	73	**2.2**	4	95	2.6	4	65	2.2	4	86	2.3	4
Chlorothalonil	41	**2.4**	5	45	2.2	7	43	2.7	5	51	3.1	7
Copper hydroxide	20	**2.0**	5	24	1.5	4	20	1.8	4	38	2.8	7
Copper oxychloride	1	**1.0**	1	0	0	0	0	0	0	0	0	0
Didecyldimethyl-ammonium chlorine	0	**0**	0	0	0	0	0	0	0	2	1.0	1
Difenoconazole	5	**1.0**	1	8	1.0	1	1	1.0	1	19	1.8	3
Difenoconazole/chlorothalonil	0	**0**	0	0	0	0	0	0	0	5	1.0	1
Fluazinam	66	**1.9**	3	90	2.2	3	63	2.2	4	82	2.4	4
Iprovalicarb/propineb	0	**0**	0	0	0	0	3	1.3	2	4	1.3	2
Mancozeb	68	**5.6**	10	99	7.3	15	71	7.0	10	89	7.7	15
Mancozeb/dimethomorph	0	**0**	0	0	0	0	2	1.0	1	0	0	0
Mancozeb/metalaxyl-M	4	**1.0**	1	16	1.0	1	12	1.0	1	20	1.1	2
Pencycuron treated seed	84	**1.0**	1	97	1.0	1	70	1.0	1	90	1.0	1
Propineb	51	**3.9**	9	39	2.0	6	0	0	0	8	2.4	5
Insecticides												
Diazinon	0	**0**	0	0	0	0	0	0	0	1	1.0	1
Dimethoate	11	**1.1**	2	1	1.0	1	0	0	0	0	0	0
Imidacloprid treated seed	82	**1.0**	1	3	1.0	1	0	0	0	0	0	0
λ-cyhalothrin	17	**1.8**	3	10	1.0	1	14	1.2	2	15	1.7	5
Methamidophos	21	**1.0**	2	2	2.0	3	0	0	0	1	6.0	6
Phorate	2	**1.0**	1	0	0	0	0	0	0	0	0	0
Pirimcarb	4	**1.0**	1	3	2.3	3	0	0	0	19	1.7	5
Pymetrozine	0	**0**	0	85	1.3	3	20	1.2	2	70	1.3	2
Taufluvalinate	0	**0**	0	0	0	0	0	0	0	1	1.0	1
Herbicides												
Bentazone	5	**1.0**	1	0	0	0	0	0	0	0	0	0
Cyanazine	0	**0**	0	85	1.0	1	61	1.0	2	74	1.0	1
Fluazifop-P-butyl	1	**1.0**	1	3	1.3	2	0	0	0	2	1.0	1
Fluroxypur/ioxynil	0	**0**	0	0	0	0	0	0	0	1	1.0	1
Glyphosate	48	**1.0**	1	59	1.1	2	49	1.2	2	60	1.3	2
Haloxyfop	0	**0**	0	4	1.0	1	2	1.0	1	6	1.2	2
Linuron	65	**1.0**	2	84	1.0	1	64	1.0	2	70	1.0	1
Metribuzin	81	**1.1**	3	99	1.2	3	69	1.2	3	81	1.1	2
Paraquat	0	**0**	0	0	0	0	3	1.0	1	0	0	0
Paraquat/diquat	7	**1.0**	1	6	1.0	1	0	0	0	0	0	0
Terbuthylazine	1	**1.0**	1	3	1.0	1	0	0	0	0	0	0
Terbutryn/terbuthylazine	8	**1.0**	1	3	1.0	1	3	1.0	1	0	0	0
Tribenuron methyl	0	**0**	0	0	0	0	1	1.0	1	0	0	0
Desiccant												
Diquat	19	**1.1**	2	18	1.1	2	33	1.0	2	16	1.0	1

4.2.2 Total amount of pesticides applied

The total amount of pesticide active ingredient applied to each process crop fluctuated between 11.5 kg(L) ai/ha and 17.4 kg(L) ai/ha in the four growing seasons (Table 4). Although the fluctuations in pesticide use were across all of the pesticide categories, much more fungicide was used on processing crops than the other types of pesticides, and the between-year variation in total pesticide use largely reflected the variation in fungicide use.

Table 4: Average amount of pesticide applied to each process potato crop for each growing season. (Blanks denote no chemical applied, 0.000 denotes less than a gram on average/ha.)

Resistance action group classification	Agrochemical	Average ai kg or L/ha pesticide per crop			
		2003	2004	2005	2006
Fungicide					
chloro-nitrile	chlorothalonil	0.544	0.751	0.745	1.048
dithiocarbamate	Mancozeb, propineb	8.482	12.188	7.398	11.518
inorganic copper	copper hydroxide, copper oxychloride	0.206	0.166	0.293	0.526
iprovalicarb	Iprovalicarb			0.004	0.005
methoxy-acrylates	Azoxystrobin	0.224	0.358	0.227	0.294
morpholine	Dimethomorph			0.003	
phenylamide	Metalaxyl, methalaxyl-M	0.007	0.026	0.024	0.035
phenylurea	Pencycuron	0.352	0.697	0.360	0.582
quartenary ammonium	didecyldimethyl-ammonium chlorine				0.001
Triazole	Difenoconazole	0.005	0.011	0.001	0.057
2,6-dinitro-anilines	Fluazinam	0.170	0.275	0.196	0.280
Total		9.991	14.471	9.251	14.348
Insecticide					
dimethylcarbamate	Pirimicarb	0.006	0.016		0.057
neonicotinoid	Imidacloprid	0.124	0.003		
organophosphate	Diazinon, dimethoate, methamidophos, phorate	0.210	0.023		0.033
pyrethroid	λ-cyhalothrin, taufluvalinate	0.003	0.001	0.001	0.002
pyridine azomethine	Pymetrozine		0.129	0.027	0.105
Total		0.343	0.173	0.028	0.198
Herbicide					
aryloxyphenoxy-propionate (FOPs)	fluazifop-P-butyl, haloxyfop-R-methyl	0.003	0.016	0.002	0.014
benzothiadiazinone	Bentazon	0.015			
bipyridyl	Paraquat, diquat	0.035	0.028	0.011	
glycine	Glyphosate	0.328	0.337	0.424	0.584
nitrile	loxynil				0.000
pyridine carboxylic acid	Fluroxypyr				0.000
sulfonylurea	tribenuron methyl			0.000	
triazine	Cyanazine, terbuthylazine, terbutryn	0.053	0.913	0.665	0.710
triazinone	metribuzin	0.313	0.573	0.405	0.407
urea	linuron	0.559	0.759	0.630	0.585
Total		1.306	2.625	2.138	2.300
Desiccant					
bipyridyl	diquat	0.089	0.088	0.132	0.065
Agrichemical total		11.728	17.358	11.549	16.911

5 Discussion

Spray diaries from potato growers in Canterbury in the past seven years showed that pesticides were used in seed potato crops over an average of 157 ha/year and in process potato crops over an average area of 1679 ha/year. Overall, there were approximately 1200 ha of certified seed potatoes and 5900 ha of certified process potatoes grown per year in New Zealand during the survey period (R Gall, pers. comm.). Most of the remaining area grown for seed, about 1050 ha certified and about 200 ha not certified, is grown from whole seed for the fresh potato market, and since pesticide diaries were generally not kept by growers for this market segment pesticide use on these crops is not recorded (K Hughes, pers. comm.). However, since whole-seed crops mature more quickly than cut-seed crops, the foliage of whole seed crops is likely to receive significantly less pesticide than that of crops grown from cut seed.

The number of applications of agrichemicals are summarised in Figure 1. More than 90% both of seed and process crops received a seed treatment to control *Rhizoctonia solani* prior to planting. Process crops received more fungicides than seed crops, with some crops from both markets receiving three or more sequential applications of fungicides from chloro-nitrile (chlorothalonil,) dithiocarbamate (mancozeb), pyridinamine (fluazinam), strobilurin (azoxystrobin) and/or triazole (difenoconazole) chemical groups. Fungicide resistance recommendations for the number of fungicides applied sequentially in a potato growing season vary depending on the chemical group (Martin et al. 2005). In a season no more than four applications of morpholine (dimethomorph) fungicides should be applied per crop. For DMI fungicides (difenoconazole, thiabendazole) and phenylamides (metalaxyl-M) a maximum of three applications per crop is advised. *Alternaria solani* isolates resistant to strobilurin fungicides have already appeared in the USA (Rosenzweig et al. 2008). Strobilurins should make up no more than one-third of the total fungicides applied to each crop (Martin et al. 2005). These recommendations were generally adhered to by growers included in the present survey. The repeated applications of dithiocarbamates used by the growers, though, have not resulted in fungal pathogens resistant to this chemical class, although variation in sensitivity to mancozeb has been reported in *P. infestans* populations in the USA (Daayf & Platt 2002).

Over the survey period, most seed crops received a single insecticide seed treatment (imidacloprid) as well as 1–12 (but averaging 5.5) foliar applications of insecticides from four insecticide classes. Prior to the 2005–06 growing season, most crops received more than three sequential applications of organophosphates. This result matches that reported previously (van Toor & Teulon 2006). Multiple organophosphate applications may have selected aphid populations that are resistant to insecticides from this and other chemical classes. van Toor et al. (2008) found that 22 of 45 *M. persicae* aphids collected on potatoes in autumn 2005, within the regions where the crops were grown, carried multiple copies of genes producing high levels of carboxylesterase that conferred resistance to organophosphate, carbamate and pyrethroid insecticides. However, the practice of three or more sequential applications of methamidophos declined somewhat in the 2005–06 season, coinciding with the release of the Sustainable Farming Fund (SFF) potato aphid virus report on insecticide management. This recommended that alternating applications of insecticides from different chemical classes should be used (van Toor & Teulon 2005). This result highlights the impact of these recommendations on insecticide use patterns. Process potato crops were also mostly seed treated with insecticide in 2003, but not in subsequent years, and received considerably fewer foliar applications of these chemicals (usually 1–2 but occasionally up to 6) than seed crops.

This study has benchmarked insecticide use patterns before the predicted incursion into Canterbury of the potato psyllid (*Bactericera cockerelli*). This new pest may have a large impact on potato production in New Zealand, and insecticide use patterns are likely to change if this pest becomes widely established.

This survey has indicated that pesticide use in potato may be increasing. Reasons for this are not clear, but the overall increase is, generally, across all of the pesticide groups (fungicides, insecticides, herbicides and desiccants). Increased pesticide use may indicate that potato production is becoming more "intensive" and specialised, rather than suggest that pathogens, pests and weeds are causing increasing problems. Growers are possibly willing to apply more pesticide inputs as their operations become more specialised, and they become more dependent on potatoes to maintain the economic viability of their operations.

The Canterbury region is an important potato-growing area in New Zealand, particularly for seed potatoes but also for the supply of processing factories. However, the climate in this region is different from in other important New Zealand potato-growing areas (South Auckland/Waikato and Manawatu/Wairarapa), and this may cause differences in pesticide requirements. For example, the warm, moist climate of South Auckland/Waikato is likely to be more conducive to the development of late blight epidemics than the drier conditions generally experienced in Canterbury. Nevertheless, our survey indicates that large amounts of fungicide are applied to Canterbury crops for late blight control, possibly as preventative insurance applications rather than in response to epidemic threats. This suggests that there may be considerable scope to reduce fungicide use in Canterbury if growers were prepared to use disease prediction systems rather than preventative approaches to disease management.

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