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Integrated pest management for potato tuber moth -

end of year report

A report prepared for

Technology for Business Growth

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1 EXECUTIVE SUMMARY

A three year project to establish an integrated pest management programme for potato tuber moth (PTM) is being undertaken by the New Zealand Institute for Crop & Food Research Ltd in partnership with the Potato Sector of Vegfed, major potato processors and exporters, and the Technology for Business Growth Programme (TBG). This end-of-year report covers the first year of the project (1996/97). The three objectives set for the year were:

- to determine the most suitable pheromone trap, pheromone blend and trap placement for New Zealand conditions;
- to evaluate larval sampling techniques for identifying economically damaging PTM populations;
- to carry out a survey to assess the current practices of growers.

Pheromone traps

'DeSIRe' sticky traps were found to be the best pheromone traps for monitoring populations of PTM adults. While water traps caught more moths, these traps took much longer to service than the DeSIRe traps. It was found that traps sited on the top of the potato canopy could be easily located while the effects of adverse weather were minimised. A 1:1.5 blend of the two pheromone components is recommended for use in New Zealand. This blend was more effective than others tested and it is already in commercial use in New Zealand.

Assessing larval populations

Whole plant sampling in the field was the most efficient method for assessing larval populations in the foliage. Egg traps failed to collect any eggs and complete plant dissections in the laboratory were too labour-intensive to be of practical use (although they indicated that whole plant sampling found the majority of mines on the plants).

A question still remains: What is the relationship between foliar and tuber infestation of PTM? Data gathered over the next two seasons will help to answer this question, and should indicate the most suitable method for predicting likely infestation of tubers.

Grower Survey

Results of a grower survey indicated that while Ilam Hardy and Rua remain the most common potato cultivars grown in New Zealand (in terms of number of growers growing them), processing cultivars (Fianna, Draga, Agria, Delcora, Russet Burbank and Russet Ranger) dominate the the top ten cultivars grown. Crop rotations were six years long, on average, with pasture and broad acre crops commonly included in rotations.

A majority of growers either considered PTM to be a serious pest of potatoes or sprayed their crops to control it. Forty-four percent of growers monitored PTM in their crops but of these, most had no defined action thresholds and applied insecticides when they saw PTM life-stages in their crops. The small group of growers who already used pheromone traps used a wide range of action thresholds, e.g. an action threshold based on number of mines per length of row. Most growers applied insecticides on a calendar basis, while several growers used either crop growth stage or weather conditions to determine when to use insecticide.

Aphids were a problem for 90% of growers - in the early stage of crop growth for North Island growers and throughout the whole growth period for South Island growers. Wireworms were the next most common pest problem, and some North Island growers also reported cutworm, black beetle and white-fringed weevil as problem insects.

PTM populations

A common trend seen in pheromone trap catches in most of the potato crops sampled was for moth catches to peak at, or shortly after, crop senescence. Numbers of moths caught in the traps across three regions (Matamata, Opiki, Pukekohe) were similar while larval infestations of the foliage varied. One crop in Matamata had a severe foliar infestation, while the rest of the crops in this area did not. Three Opiki crops had much lower levels of foliar infestation than the Pukekohe and Matamata crops. Severe foliar infestations did not lead to severe tuber infestations. Data from the coming 1997/98 growing season will help to establish a better understanding of the correlations between PTM lifestages and the parts of the potato crop they infest.

Parasitoids of PTM

Two parasitoids of PTM, *Apanteles subandinus* and *Diadegma semiclausum*, were recovered in Pukekohe, Matamata and Hawke's Bay. No parastioids were recovered from the small larval collections in Opiki.

Cultivar susceptibility to PTM

In cultivar trials at Pukekohe and Hawke's Bay there was little evidence of differences in PTM infestation between the nine cultivars examined. However, early-maturing cultivars suffered greater tuber damage than late-maturing ones which had more severe foliar infestations. Of the late-maturing cultivars, those with greater soil cover (depth to first tuber) had lower levels of tuber infestation at Pukekohe.

2 INTRODUCTION

More than 10 600 ha of potatoes, with an annual retail value of $220 million, are grown in New Zealand each year, making them the country's largest vegetable crop. In a 1995 survey, New Zealand potato growers ranked potato tuber moth (*Phthorimaea operculella*) as a high priority for research (Potato Research and Development Grants Committee, 1995). A Technology for Business Growth (TBG) project was subsequently set up with the support of the potato growers (Potato sector, NZ Vegetable & Potato Growers' Federation (Vegfed)) and four potato processors (Heinz-Wattie, Bluebird Foods, Mr Chips, and Southern Fresh Produce).

The aims of the three year project are to develop and implement an integrated pest management (IPM) programme that will enable growers to assess PTM populations in their crops and determine if or when insecticides should be applied to avoid serious tuber infestations. Implementing an IPM programme should improve the efficiency of pest control and enhance the quality of yield. This report describes the results of the first year of the project. The objective for this year was to determine the most appropriate monitoring system for assessing the damage potential of PTM populations in potato crops. To achieve this the following work was planned:

- A series of experiments were carried out at Pukekohe Research Station to determine the most suitable type of pheromone trap (water, sticky, or cone and bucket); pheromone blend; trap placement and trap density for New Zealand conditions.

- Larval sampling techniques (foliage sampling and tuber sampling) were evaluated for identifying economically damaging PTM populations in potato crops in the Pukekohe and Manawatu regions.

- Growers and processors were surveyed to find out about their current practices, e.g. spray schedules, monitoring systems and spray used, average and acceptable tuber damage.

3 AN EFFECTIVE PHEROMONE TRAP

The work of defining the most effective pheromone trap for PTM in New Zealand potato crops was subcontracted to John Clearwater, Clearwater Research and Consulting. Chris Triggs (Department of Statistics, University of Auckland) statistically analysed the data obtained.

Four types of trap design, two trap heights and three ratios of the two identified pheromone chemicals were compared in two experiments carried out at the Pukekohe Research Station. The research established that the DeSIRe sticky trap ("delta" trap design) is the most suitable pheromone trap to use for monitoring PTM. The fluctuations in the moth catches in these traps reflect the fluctuating population of PTM in the crop and they are easy and quick to service. There is no clear difference between the 1:1 and 1:1.5 ratios of pheromone blends, but the latter is recommended as it is already in use in New Zealand commercial potato crops. Although there was no real difference in the effectiveness of traps placed at various heights, the traps are probably best located at the top of the canopy for ease of access and to minimise any adverse weather effects.

The full report of the work is in the Appendix.

4 LARVAL SAMPLING TECHNIQUES

A range of techniques for sampling egg and larval stages of PTM were tested to see if they were suitable for including in a system for monitoring PTM populations.

4.1 Eggs

PTM eggs are commonly laid on the soil surface around the base of plants. The few that are laid on plants are laid on dead leaves (Traynier 1975). Valencia (1984) concluded that although the soil around the base of plants is the main oviposition site for PTM, females did lay eggs on foliage and showed preferences for some potato cultivars.

Because PTM eggs are very small and difficult to find, they are not usually included in a monitoring programme. However, Valencia (1981) described an egg trap that could be used to monitor oviposition activity of PTM. Valencia's trap, which used black terylene and filter paper stretched over a plastic Petri dish, was suspended in the apical third of the crop. We used this design and modifications of it to try and monitor oviposition activity in the potatoes (cv. Rua) used for the pheromone trap experiments (Section 3.).

From late January to late February we tested six versions of the oviposition traps. Although the traps were left out for a week no eggs were recovered from them. In late March, a further trial was run. Again no eggs were recovered, although a couple of PTM larvae were found tunnelling in the potatoes in the Petri dish traps. The size of these larvae suggested that they had moved from elsewhere on to the potatoes in the traps.

4.2 Larvae

PTM larvae are commonly found mining the leaves of potatoes or tunnelling in tubers (Raman & Radcliffe 1992; Trevedi & Rajagopal 1992). The fact that larvae may be present in two separate areas of the plant restricts the type of sampling methods that can be used to monitor populations.

Foliage mining is more common on lower leaves and the outermost leaflets of these (Reed 1971). Observations in this research confirm Reed's conclusions. PTM larvae were most often found in larger mature leaves and only became common in younger leaves, higher on the plant, when the older leaves began senescing.

Tuber infestations occur late in the growth of potatoes. Foot (1979) reported that tuber infestation occurred only 2 - 4 weeks before harvest (98-126 days after planting) which concurred with Shelton and Wyman (1979a) who reported tuber infestation occurred 76-118 days after planting. Von Arx et al. (1987) observed that larvae preferred to feed on tubers once the haulms began senescing and tuber infestations increased as the soil dried and cracks opened, exposing the tubers. Foot (1979) found that tubers covered by 1 cm of soil were not infested by PTM larvae that had been forced to leave the foliage, and first instar larvae, hatching from eggs in the soil, were unable to locate and infest tubers covered with 0.5 cm of soil. A sampling plan should, therefore, consider foliar infestation by PTM larvae in the first instance, and tuber infestation in the second instance.

According to the literature, the most common method of assessing PTM larval populations in potato foliage is to carry out whole plant counts of randomly selected plants either weekly or fortnightly (Yathom 1968; Foot,1979; Shelton & Wyman 1979a; Lal 1987; von Arx et al. 1987; Lal 1989).

The sampling plan tested in this research project consisted of weekly counts of occupied PTM mines on 40 randomly selected plants throughout the insecticide-free potato crop used for the pheromone experiments. The efficiency of this crop scouting was assessed by harvesting five whole plants and dissecting them in the laboratory to determine absolute PTM larval infestations. Results are presented in Table 4.1. The larval infestation developed in the crop from the middle of January and peaked in late February. The growth stage of the potatoes over this period was early to late tuber bulking. There was little difference in the number of larvae found per plant by scouting in the field, or dissecting plants in the laboratory, apart from the one date in late February. This was mainly because two heavily infested plants in a small sample size distorted the average number of larvae found per plant by dissection.

Because PTM go through more than one generation a year, there was the problem of distinguishing between old empty mines and fresh, occupied mines once there had been one generation of larvae. Mined leaves had to be removed and held up to the light to look for occupying larvae. Some instances were found of more than one larvae per mine and young larvae occupying vacant mines.

Table 4.1: Comparison of two sampling methods to assess infestation of PTM larvae on potatoes.

Date	Mean no. of larvae/plant)	
1996-97	scouting	plant dissection
9/12	0.05	0
16/12	0	0
23/12	0	0
3/1	0	0
6/1	0	0
13/1	0.05	0
20/1	0.50	0.60
27/1	0.65	0
3/2	0.43	0
11/2	1.38	0
18/2	3.78	3.60
25/2	5.45	11.20
3/3	0.93	ns
13/3	4.08	2.20
17/3	2.73	3.60
25/3	2.10	5.00

Observations during this research confirmed Foot's observations (1979) that tubers must be exposed or very close to the soil surface before they become infested by PTM. Moths can lay eggs on exposed tubers and larvae can tunnel directly into them. Larvae can also tunnel through exposed green tubers and infest marketable tubers underneath.

4.3 Discussion

Whole plant scouting is the accepted method for monitoring PTM overseas (Yathom 1968; Foot 1979; Shelton and Wyman 1979a; Lal 1987; von Arx et al, 1987; Lal 1989). Our research confirms that this method is suitable for use in New Zealand as our data indicate that scouting monitors a consistent proportion of the PTM larval population.

Two issues that were not fully investigated in this work were:

- dispersion of PTM through a crop;
- the relevance of foliar PTM infestations to tuber infestations.

Foot (1979), in the only reference found relating to dispersion of PTM through a potato crop, found that the dispersion of foliage-mining tended to be non-random, but the dispersion in the trial block she sampled was influenced by a 1.5 m hedge on the upwind side of the block. Foot also observed the incidence of high foliage mining concentrated in headlands and in the lee of wind obstacles in commercial crops. Reed (1971) reported greater PTM infestation of potato foliage on the margins of a crop planted 110 m windward of a previous crop, compared to samples from within the crop. Yathom (1968) reported that all dry plants, but not all the more succulent plants, were infested with PTM larvae in trials in Israel.

Lal (1989) found a positive, linear correlation between moth catches, foliar larval counts and percent plant infestation and concluded that pheromone traps could be used to predict foliar damage, negating the need for 'cumbersome, time consuming' larval counts. However, various researchers have noted that foliar infestations are not necessarily an important factor in tuber infestations. Foot (1979) and others have reported that PTM larvae do not migrate from senescing foliage down potato stems into tubers, but they can leave senescing foliage and infest exposed tubers or tubers only lightly covered with soil, e.g. <10 mm (Foot 1979). Once an exposed tuber is infested the larvae can tunnel right through the tuber and infest other unexposed white tubers. Moths may also oviposit on exposed tubers. Therefore, the longer a crop is left before it is harvested, the greater the tuber infestation is likely to be. An increase in tuber infestation was observed in sequential harvests after foliage senescence in the crops in this research.

Bacon (1960) and Foot (1974) considered that because foliar infestations of PTM larvae were not directly related to tuber infestations, insecticide control of foliar infestations would not necessarily prevent or control tuber infestations. Foot (1974) did note that insecticide control of foliar infestations would be beneficial only if foliar infestation was the only source of PTM to infest the tubers, i.e. if there were any self-set potatoes in the surrounding crops insecticide control of foliar infestation would be less effective.

Shelton and Wyman (1979a) and Laksanawati (1986) both advocated using pheromone traps to monitor moth populations. However, the pheromone traps only catch male moths. Foot (1979) noted that the sex ratio of PTM adults at Pukekohe varied from 50:50 in the spring to a dominance of males (80:20) later in the season. For this reason care is needed in predicting possible tuber infestations on the basis of the number of males caught in a trap.

The threat of damage to a potato crop by PTM is greatest during the period from tuber bulking through to harvest. Seasonal variation in PTM populations in terms of calendar date is a factor in the size of the threat to the crop.

5 GROWER SURVEY

A survey was sent to all the potato growers on the VegFed mailing list in mid-August 1997. Growers were asked to return completed surveys by the end of August to be eligible for a prize draw to win 10 litres of Tamaron™ (courtesy of Bayer NZ Ltd). The majority of the 73 surveys returned arrived by this date.

While there was a even split of responses from the North Island and the South Island, over 40% of the responses were from Canterbury (Fig 5.1). The percentage of responses from the other major potato growing regions were: Horowhenua/Opiki/ Manawatu/ Rangitikei/Wanganui 18%; Pukekohe/Waikato 13%; and Hawke's Bay/Waiarapa 13%. Ken Fraser of Hawke's Bay won the Tamaron™.

The survey was split into three parts: the crop, PTM, and other pests.

5.1 The crop

The average area of early crop potatoes, grown over the past five years, was 13.8 ha (32 growers); the average area of main crop potatoes grown was 32.9 ha (50 growers). However the area grown ranged from 0.2 ha to 142 ha for early crops, and from 0.8 ha to 330 ha for main crops. Sixteen growers grew an average of 20.4 ha of seed potatoes (ranging from 3 ha to 40 ha).

Ilam Hardy and Rua were the most popular cultivars grown over the past five years; 40 growers planted Ilam Hardy and 39 growers planted Rua. The top ten cultivars and the market they are grown for are shown in Fig 5.2 (note that some growers grow a cultivar for more than one market). While fresh market varieties take the top three places (Ilam Hardy, Rua, Desiree), process varieties dominate the top ten cultivars grown in New Zealand (in terms of the number of growers growing each variety).

The average length of crop rotation used was 6 years (ranging from 2 to 14 years). Some growers grew more than one crop of potatoes in each rotation making 5.6 years the average number of years between potato crops. Pasture and broad acre crops were the most common crops used in the potato rotation, but a range of 23 crops were rotated between potato crops (Fig 5.3).

5.2 PTM

Forty-two percent of the growers who responded considered PTM to be a serious pest; 57% of growers sprayed their crops to control PTM.

Tamaron/Monitor (methamidophos) was the most commonly used insecticide for control of PTM (Fig 5.4). Karate (lambda-cyhalothrin) was the next most common; the other insecticides registered for PTM control were less preferred. There was a marked difference in the way that North Island and South Island growers used insecticides (Fig 5.5). Sixty-seven percent of South Island growers did not use any insecticides for PTM control, while only 11% of North Island growers did not use insecticides to control PTM.

Eighty-one percent of growers (56 out of 69 responses) reported no PTM damage to their potatoes in the 1996/97 season. The damage that was reported ranged from 5% of tubers in the North Island to 1% of tubers in the South Island. Seventy percent of growers (56 responses) had zero tolerance to tuber damage by PTM, but tolerance levels ranged up to 10% for North Island growers and 5% for South Island growers.

Fifty-three percent of growers (35 out of 66 responses) did not monitor PTM in their crops. Forty-four percent of growers (29 responses) carried out some form of crop scouting for PTM in their crops, and 12% of growers also used pheromone traps. However, of the 29 growers who monitored their crops for PTM, 59% had no action thresholds and 28% would apply an insecticide if they saw PTM moths or mines in the foliage of their crops. Of the few growers who used action thresholds, three had thresholds based on moths caught in pheromone traps (ranging from 4.3 moths per day to 25 moths per day); one grower had a threshold of any mines on two plants in 10 m of a crop row. Twenty-four percent of the growers who monitored their crops also applied insecticides on a calendar basis.

There were 38 responses on insecticide timing. Forty-two percent of these growers applied insecticides on a regular calendar basis to control PTM. Twenty-one percent based their insecticide applications on stage of crop growth and 18% on the weather. The remaining 18% used a combination of the three methods.

The spray interval of the 19 growers who regularly applied insecticides ranged from 7 to 21 days, with a 14 day interval being common. Almost a third of these growers did not vary the length of the interval, while other growers varied the interval by an average of 5 days.

Nine growers used stage of crop growth to time insecticide applications for PTM control. The actual timing varied from planting to maturation of the crop, but the majority of responses indicated that growers applied insecticides at later rather than earlier stages of crop growth.

The consensus of the 21 responses to the question on the influence of weather conditions on insecticide use for PTM control was that warm and/or dry conditions led to shorter spray intervals and/or higher insecticide rates.

A few growers reported spray failures but these appeared to be the result of errors made in applying the insecticides rather than insecticide resistance in PTM.

5.3 Other pests

Ninety percent of growers (55 out of 61 responses) listed aphids as another insect pest that required control in their potato crops, while 34% listed wireworm. There was very little difference between North Island and South Island growers on the importance of these two pests (Fig. 5.6). North Island growers also considered that cutworm (16%), black beetle (8%) and white-fringed weevil (5%) were pests that required control in their potato crops.

Aphids were commonly considered to be a problem early in the growth of North Island potato crops, while the majority of South Island growers considered aphids to be a problem over the whole period of crop growth. Wireworm was considered to be a problem throughout the growth of a potato crop, while black beetle was a problem in new ground or after the foliage had been burnt off. White-fringed weevil was a problem early in crop growth.

Twenty-nine percent of growers (51 responses) used crop checks to determine if an insecticide should be applied to any of the 'other pests' of their potato crops. Fourteen percent of these growers applied sprays on a calendar basis and 19% used a combination of the two methods. Four percent used some form of monitoring and action thresholds to control 'other pests'. One grower used both monitoring with action thresholds and calendar spraying to control 'other pests', and another used all three methods.

Granular insecticides (Disyston 19%, and Phorate 15%) and insecticides for seed-treatment (Gaucho, 7%) were the most common insecticides used (42%) for control of 'other pests'. The use of the granular insecticide, Miral, by one grower was an off-label use (it is registered for beetles and cutworms in pasture, corn and carrots). Tamaron or Monitor (30%), Metasystox and Pirimor (both 19%) were the most commonly applied foliar insecticides, probably for aphid control (Fig. 5.7). Two growers said they used the insecticides, Karate and Gusathion, against other pests. Again, these were off-label uses.

5.4 Discussion

Growers in Canterbury returned more surveys than growers from other areas. Richard Falloon's powdery scab survey earlier this year showed a similar trend. This response pattern did not bias the results unduly, since when necessary, we were able to split the responses into North Island/South Island.

The area of potatoes grown varied widely. This reflects the varied nature of the industry which includes small fresh market growers growing for the local market, and export growers and process growers growing under contract to processing companies.

PTM can be considered a serious pest in potatoes as the majority of growers sprayed their crops with insecticides to control it. Growers alternated between chemical groups when choosing which insecticide to use—Tamaron/Monitor (organophosphate group) and Karate (synthetic pyrethroid group) were the two most commonly used insecticides. The amount of damage to tubers by PTM larvae varied but, not surprisingly, it was greater in the North Island than in the South Island. The majority of growers did not tolerate any damage from PTM in tubers, because as little as one infested tuber per bin of potatoes can taint the end-product made from those potatoes. However, North Island growers are more tolerant of PTM damage to tubers than South Island growers. This may be, in part, because many Canterbury growers, grow seed potatoes and are therefore more concerned about potential late season virus infections.

Although many of the growers claim to use some form of monitoring, seeing any life stage of PTM in their crop is the most common action threshold used to determine when to start a regular spray programme. Among growers who did use pheromone traps and a predetermined action threshold of x moths per night, there was a wide range in the action threshold used, indicating a lack of knowledge in defining the threshold. However, the fact that 44% of growers carry out some form of monitoring for PTM indicates a desire to limit insecticide applications to the most appropriate times.

Most growers know that periods of warm, dry weather favour the development of PTM populations and they modify their spray programmes accordingly (e.g. higher rates of insecticide and/or shorter intervals between applications).

Aphids are the other major insect pest of potatoes. They are a problem throughout all growth stages of South Island potato crops, while they are only a problem in the early stages of North Island crops. This difference in aphid management probably reflects differences in the market for the crops. Canterbury growers grow the majority of seed potatoes and these crops must be protected from aphids which transmit potato virus diseases. North Island growers are more tolerant of late season infestations of aphids as they have a minor impact on the yield of their crops.

Wireworms are a problem for almost a third of growers. The larvae of wireworm feed on potato seeds and young shoots, affecting the vigour of a crop at establishment, or bore into tubers as they are bulking later in the season (Ferro & Boiteau 1993). The growers are therefore correct in considering this pest a problem throughout the growth of a crop. It is possible that the soil-dwelling pests listed by growers as a concern are not correctly identified and any one of the three (wireworms, black beetles and white-fringed weevils) could be causing damage. Correct identification would assist in selecting the most appropriate management strategy for the control of that pest.

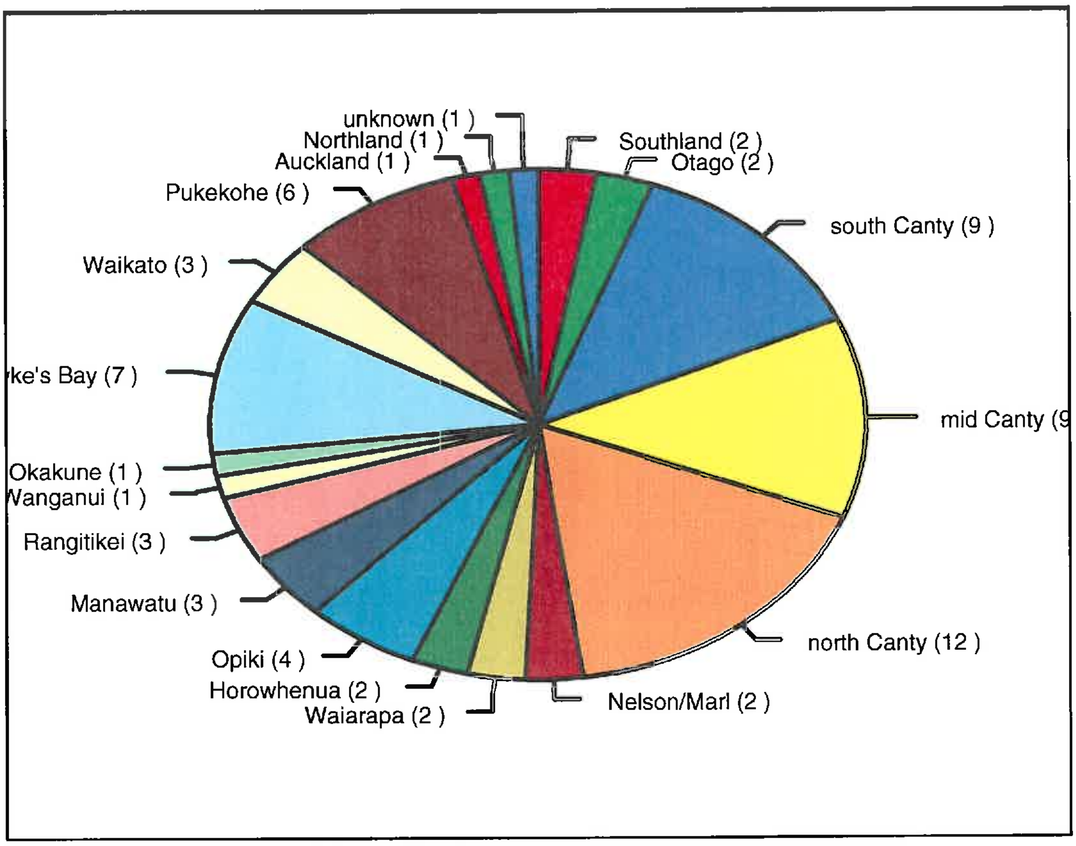

Fig. 5.1: **Potato grower survey responses from regions of New Zealand**

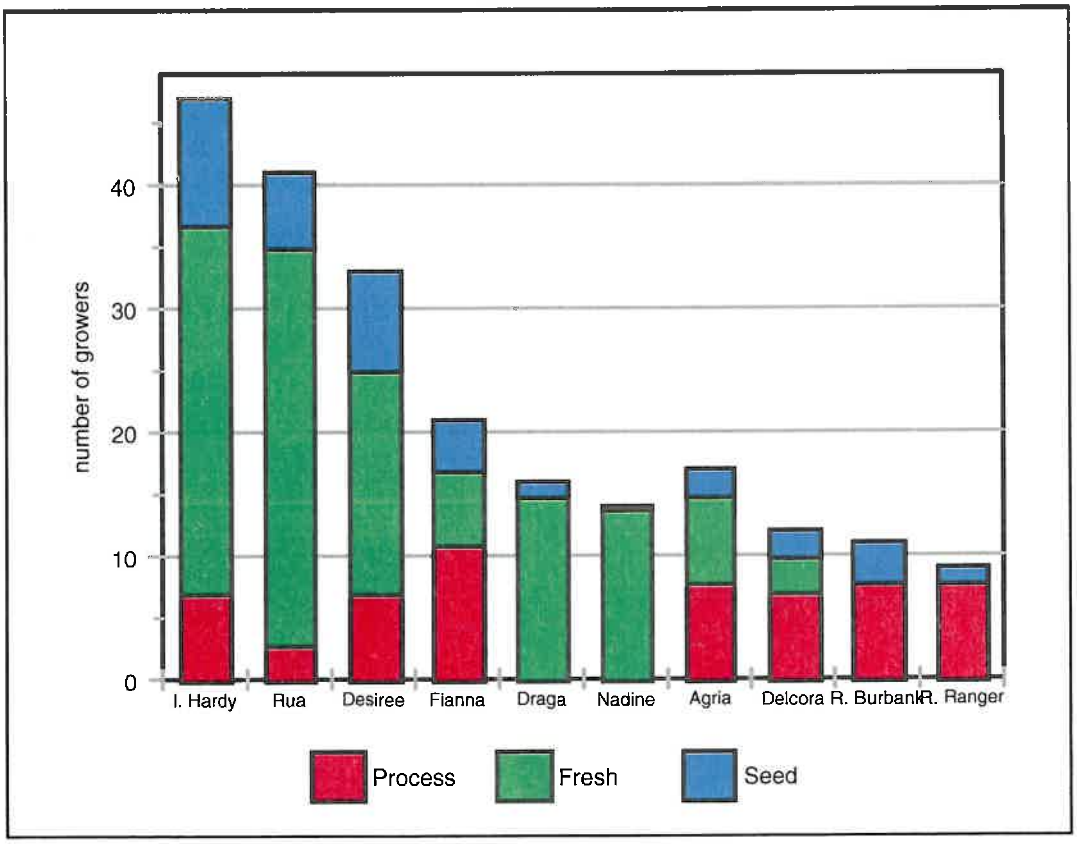

Fig. 5.2: **Top ten varieties of potatoes grown by New Zealand potato growers.**

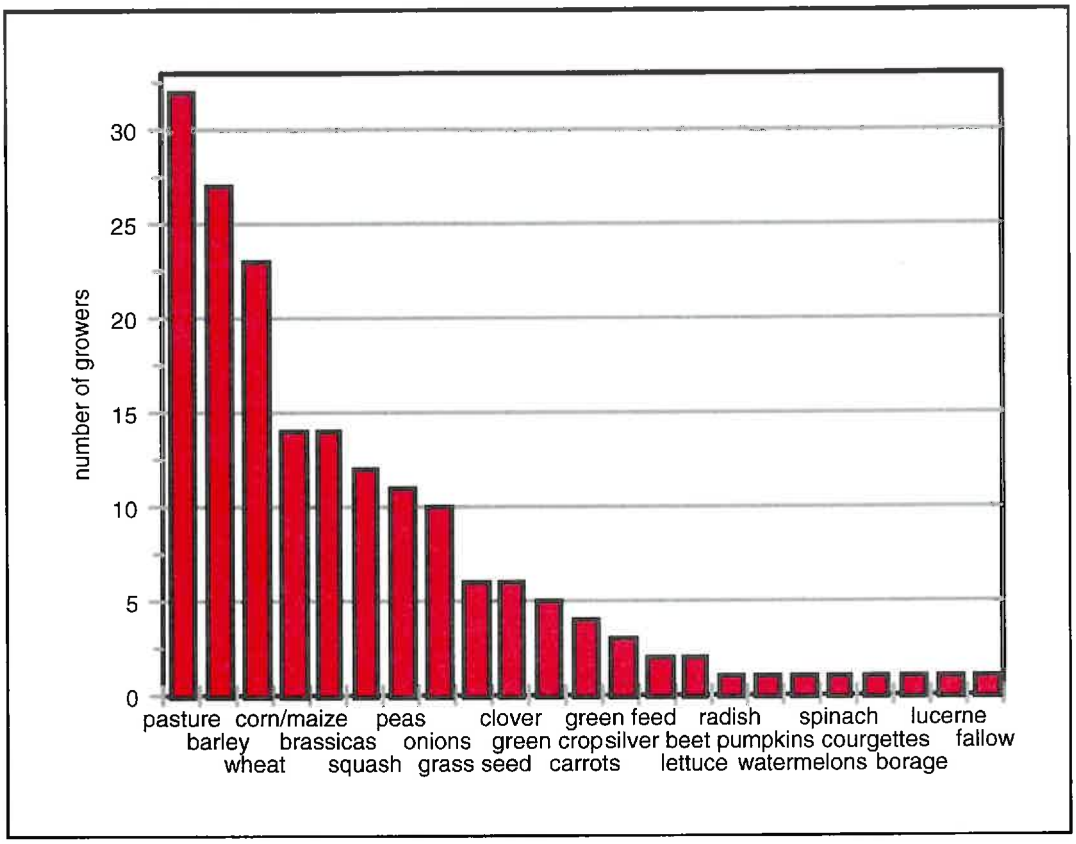

Fig. 5.3: **Crops included in rotations with potatoes in New Zealand.**

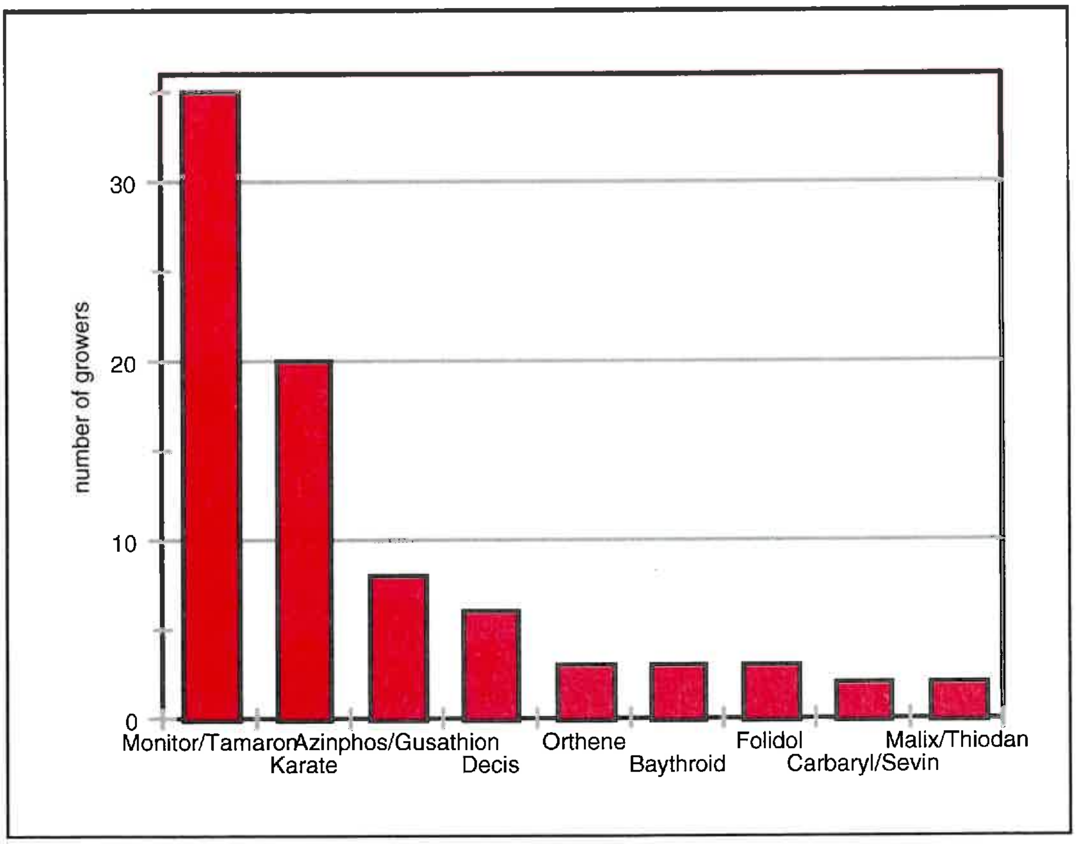

Fig. 5.4: **Insecticides used against potato tuber moth in New Zealand.**

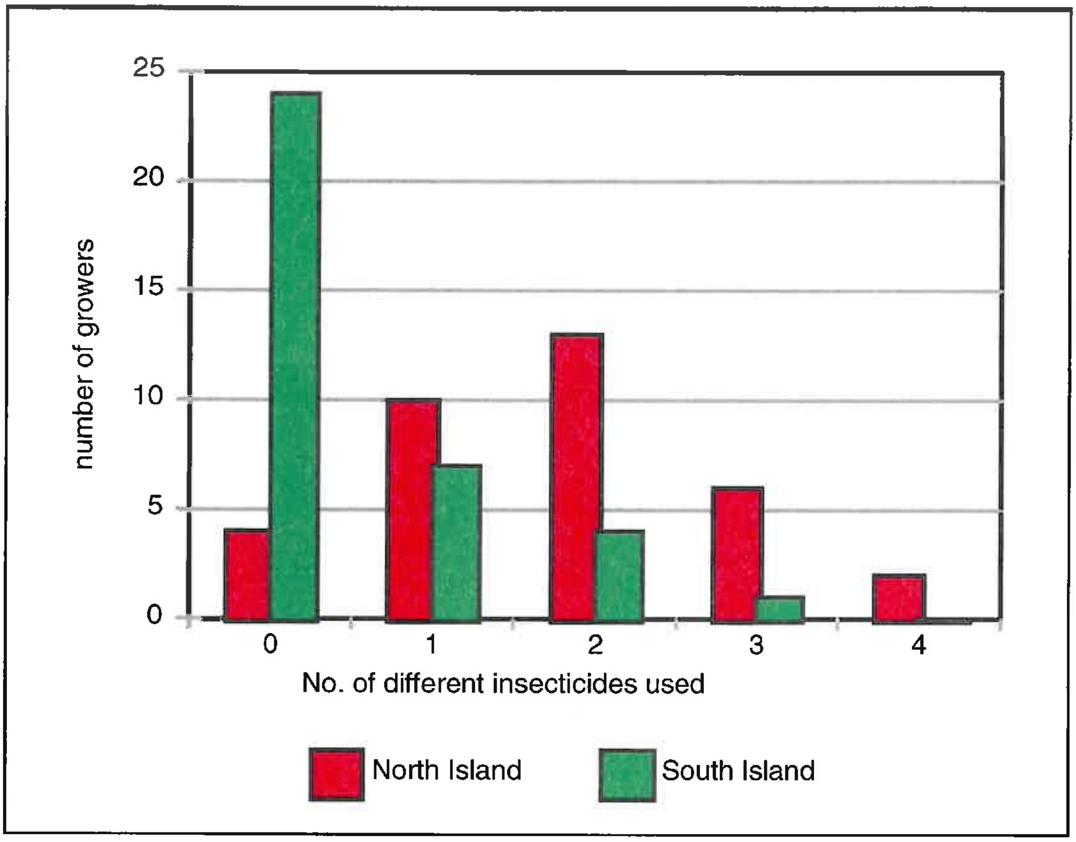

Fig. 5.5: **Number of different insecticides used for potato tuber moth control by North Island and South Island potato growers.**

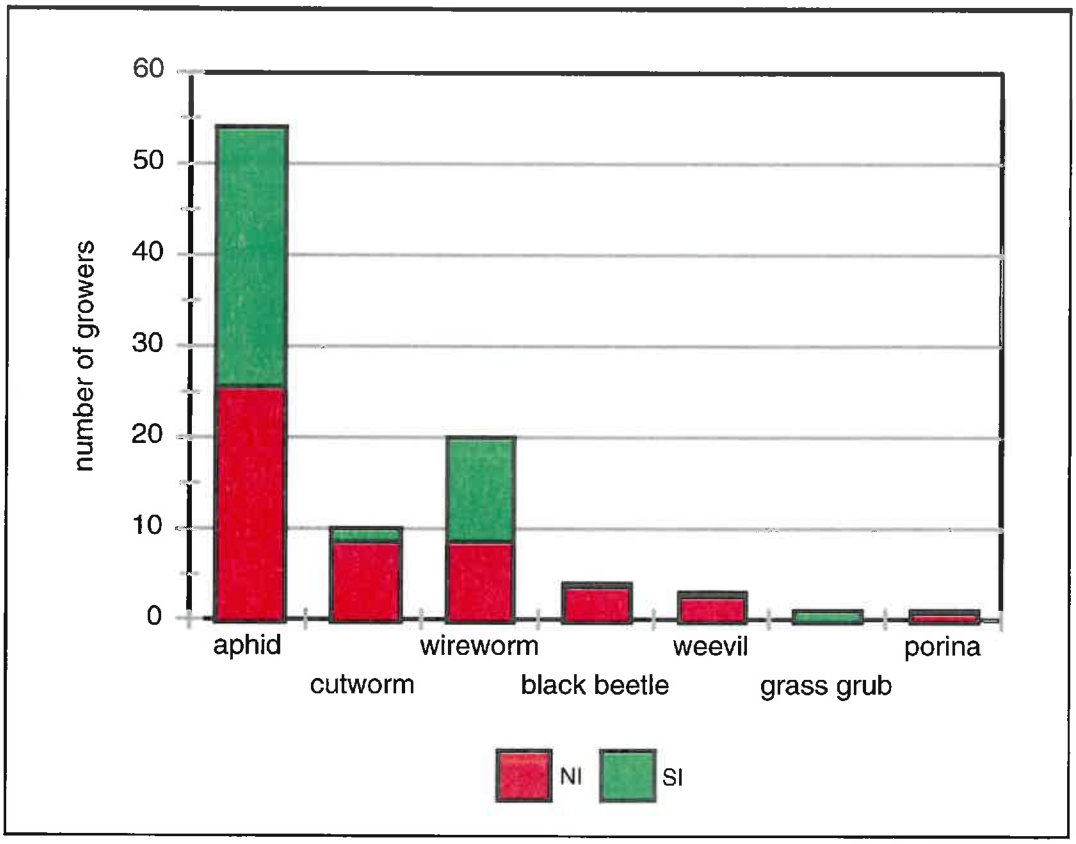

Fig. 5.6: **Other insects considered pests in potato crops by North Island and South Island potato growers.**

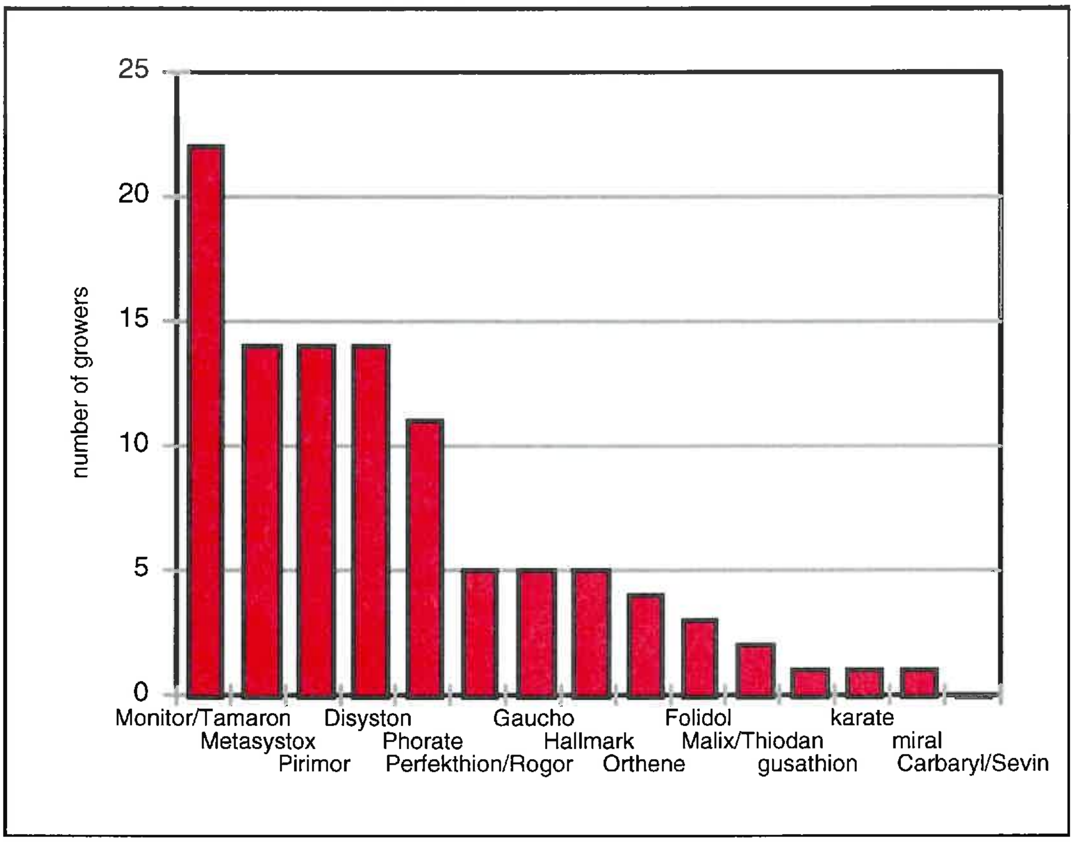

Fig. 5.7: Insecticides used against other insect pests of potato crops in New Zealand.

6 PTM POPULATIONS DURING THE SEASON

PTM populations in the three regions in which we sampled crops (seven crops in total) are shown in Figures 6.1 to 6.3. The moth catches in all of the crops gradually built up during the growth of the crop and, in general, did not decline until the foliage of the crop had senesced. Larval populations in the foliage frequently peaked just before foliage began to senesce.

6.1 Pukekohe

Moth catches in this crop (Fig 6.1) were disrupted by the two pheromone experiments that were carried out in mid-February and late March. Moth catches remained below 25 moths per day and peaked in May almost a month after the crop was harvested. Larval numbers in the foliage peaked at about 5.5 larve per plant in late February as the crop was senescing. Two harvest samples showed that about one tuber per plant was infested. However, infested tubers included green tubers. The actual loss of yield (infested white tubers/total white tubers) was about 3%.

6.2 Matamata

Average moth catches and larval foliage populations for the three exemplar grower crops in Matamata are presented in Fig 6.2. Moth catches were less than 15 moths per day during the growth of the crops, and about 20 moths per day after the foliage had senesced in mid-April. Larval populations in the foliage of the potato crops averaged less than one per plant for most of the growth of the crops. There was a sudden increase in mean larval numbers to nine larvae per plant in mid-March in one crop.

The size of PTM populations varied widely between the three exemplar grower crops. Pheromone traps in two of the crops caught less than 20 moths per day over the whole time they were running and there were very small populations of larvae in the foliage (less than one larva per plant). The pheromone trap in the third crop, while catching less than 20 moths per day during the growth of the crop, caught about 47 moths per day after the foliage had senesced. Populations of PTM larvae in the foliage peaked in early February; a second peak occurred in mid-March.

Tuber infestation reached 7% in two of the crops. One of these crops was left in the ground for more than two months, while there had been a large population of PTM larvae in the foliage of the other crop. About 1% of tubers in the third crop were infested. In all three exemplar grower crops all the infested tubers were uncovered and green. No marketable tubers were infested.

6.3 Opiki

The average moth catch in pheromone traps in the three exemplar growers' crops in Opiki steadily increased throughout the growth of the crops (Fig 6.3), reaching a peak of 37 moths per day in late April just after the crops had senesced. Moth catches then steadily declined until July.

Numbers of larvae in the foliage were initially low, but a series of peaks from early February indicated a developing population which peaked in early April. However, this larval population was much smaller than those in the other two regions.

Tubers infested with PTM larvae increased from an average of 0.25% in mid-April to 3.5% in mid-August. In one crop, tuber infestations reached 10%, but these results were influenced by one plant sample, in which 50% of tubers were uncovered and infested. All the infested tubers in these three crops were uncovered and green. No marketable tubers were infested.

6.4 Discussion

The numbers of moths caught in pheromone traps in each of the three regions were on the same scale and showed similar trends during the growth of a crop. This finding verifies the results of the two pheromone trap experiments (Section 3) which showed that the pheromone trap catches were a useful indicator of changes in PTM populations.

An increase in moth numbers after the foliage senesced, followed by a decline in numbers towards winter, was observed in all the crops in this project. A similar phenomenon has been observed by others. Von Arx et al. (1987) noted a continued high level of moth catches after harvest. Shelton and Wyman's (1979a) data showed an increase in moth catches one week after vine kill (trapping ended then). In another study, Shelton and Wyman (1979b) reported that moth catches declined after harvest across four consecutive crops of potatoes spanning 1.5 years. Raj (1988) reported decreasing moth catches after the harvest of one crop (spring harvest) and increasing moth catches after the harvest of another (autumn harvest) and related this to seasonal changes in relative humidity.

Shelton and Wyman (1979a) noted a correlation between moth catch in pheromone traps and larval populations in the foliage a week later. Foot (1979) found a correlation between larval numbers and temperature (positive) and rainfall (negative). There was an eight and four week lag, respectively, in the response of larval numbers.

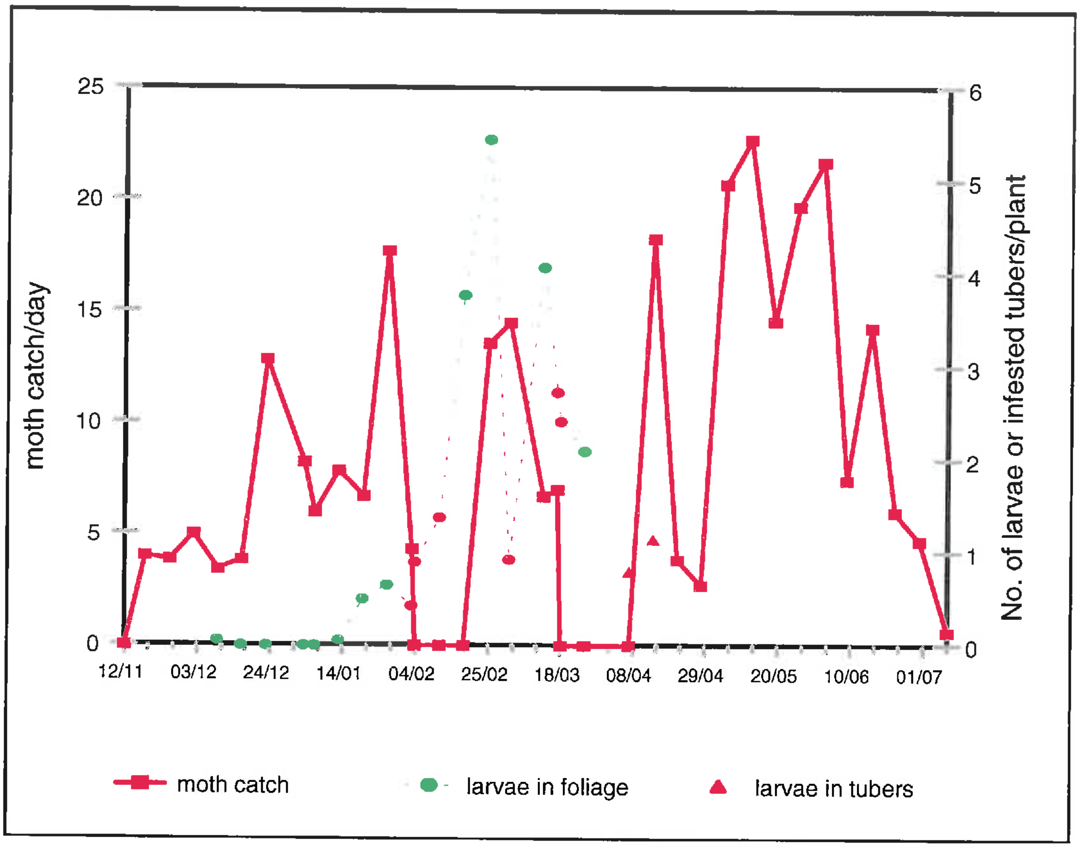

Fig. 6.1 Potato tuber moth populations (male moths and larvae) in a potato crop, cv. 'Rua', in Pukekohe.

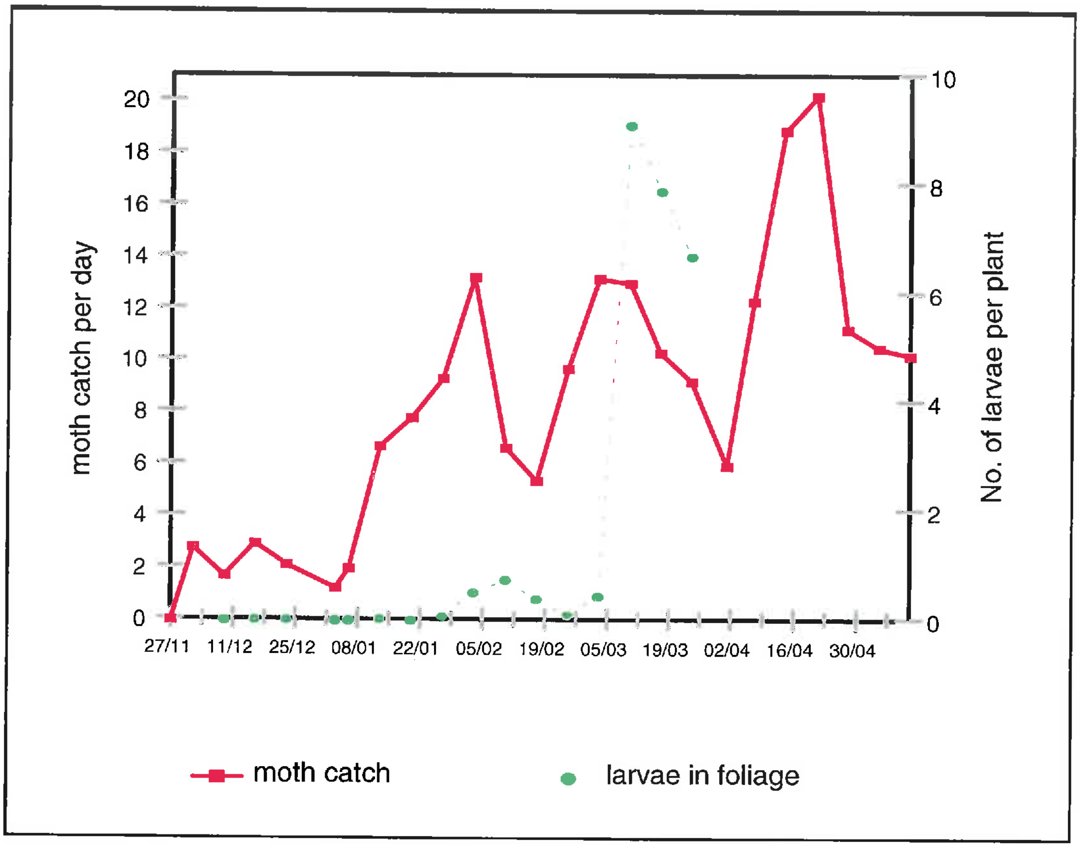

Fig. 6.2: Mean potato tuber moth populations (male moths and larvae) in three processing potato crops in Matamata.

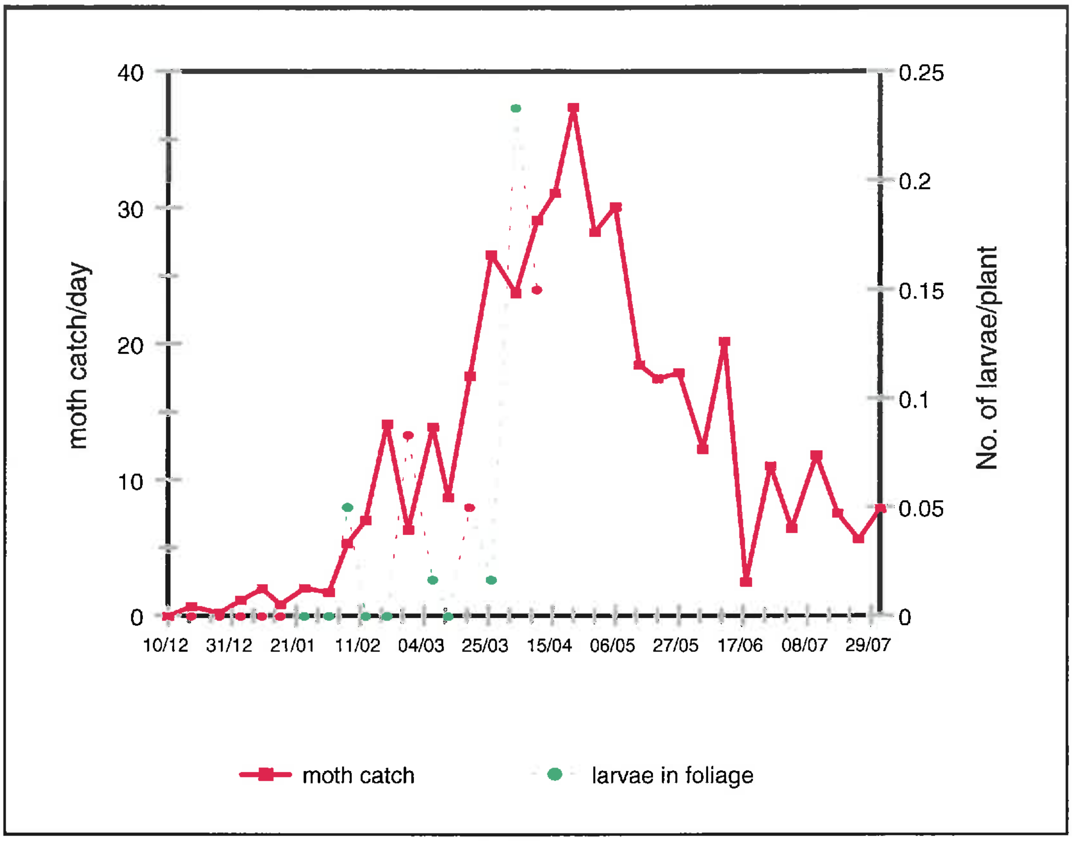

Fig. 6.3 **Mean potato tuber moth populations (male moths and larvae) in three processing potato crops in Opiki.**

7 NATURAL ENEMIES

Two larval parasitoids, *Apanteles subandinus* and *Diadegma semiclausum*, were recovered from field collections of PTM larvae. *A. subandinus* was found more often than *D. semiclausum* which was only recovered occasionally. This is not surprising as *A. subandinus* is a specific parasitoid of PTM and was introduced to control PTM (Ferguson 1989), while *D. semiclausum* was introduced to control diamondback moth (Thomas & Ferguson 1989).

The parasitoids were both recovered from larvae collected from crops in Pukekohe, Matamata and Hawke's Bay (variety trial). No parasitoids were recovered from the few larvae collected from the Opiki crops but, as noted in Section 6, the larval populations in Opiki were low.

The PTM larvae that had been collected were difficult to rear successfully. Approximately 50% of the larvae died for unknown reasons, without any feeding or further growth. The handling techniques and artificial diets used have been reviewed and improved procedures will be used in the coming season to accurately determine parasitism levels.

8 VARIETAL DIFFERENCES IN PTM INFESTATIONS

A small trial was added to this year's research programme (funded by Potato Sector, Vegfed) to look for any varietal differences in PTM infestations.

Single small plots of nine cultivars (Table 8.1) were planted on research stations at Pukekohe, Lawn Rd (Hastings) and Levin. Foliar infestations of PTM larvae were surveyed at least once at each site and a tuber sample taken after all the foliage had senesced.

At the Levin site, there was a very small PTM infestation that only established late in the growth of the potatoes. No PTM larvae were found in the foliage and only two infested tubers were found at harvest. The data for this site are not presented.

In mid-January, the level of PTM infestation in the foliage was similar for all nine cultivars at Pukekohe (Table 8.1), averaging 1.3 mines per plant. While the foliage of the earlier maturing varieties senesced, the foliar infestation in the late-maturing varieties increased over the next two months.

At harvest, in late April, tuber infestation averaged 2.1 infested tubers per plant, ranging from 0.6 infested tubers per plant (cv. Russet Burbank) to 4.3 infested tubers per plant (cv. Nadine). (Note that in Table 8.1 the cultivars are ranked in descending order of tuber infestation and that this ranking does not match that of the earlier foliar infestations; neither does it match the ranking of the cultivars with reference to infested white (marketable) tubers). When the tubers were graded to remove green tubers, Nadine remained the most infested cultivar (2.6 infested white tubers per plant) while cv. Rua had the least infested white tubers per plant (0.2 infested white tubers per plant). The average number of infested white tubers for all cultivars was 0.88 tubers per plant. Because the trial was unreplicated these are indicative results only, and do not show statistically significant differences between cultivars.

Table 8.1: Potato tuber infestation of nine potato cultivars at Pukekohe

Cultivar	20/1/97 mines/plant	18/2/97 mines/plant	25/3/97 mines/plant	24/4/97 infested tubers/plant	infested white tubers/plant
Nadine	1.0	-	-	4.3	2.6
Red Rascal	0	2.0	5.0	4.1	1.1
Fianna	1.2	1.6	-	2.5	0.9
Kiwitea	0.8	2.0	4.6	2.4	0.3
Ilam Hardy	0.4	-	-	1.8	1.7
Driver	3.0	5.4	-	1.3	0.3
Rua	1.8	6.0	6.8	1.1	0.2
Agria	0.6	-	-	0.8	0.4
Russet Burbank	2.6	4.6	-	0.6	0.4

The depth to the first tuber was also noted at harvest. These data, graphed against the number of infested tubers per plant for each cultivar, showed that tubers with less soil covering generally had more infested tubers per plant (Fig 8.1). The early cultivar, Nadine, had the highest infestation in spite of an 8 mm depth to first tuber.

In mid-March, the infestation of PTM larvae in the foliage of the nine potato cultivars at Lawn Rd (Table 8.2) averaged 5.4 mines per plant and ranged from one mine per plant (cv. Ilam Hardy) to 9.2 mines per plant (cv. Kiwitea). The foliage of cv. Nadine had senesced by this date.

At harvest in mid-April, tuber infestation averaged 0.4 infested tubers per plant, ranging from 0.1 infested tubers per plant (cv. Fianna and Rua) to 1.7 infested tubers per plant (cv. Nadine). (Note that the cultivars in Table 8.2 are ranked in descending order of tuber infestation and that this ranking does not match that of the earlier foliar infestations; neither does it match the ranking of the varieties with reference to infested white (marketable) tubers). As in the Pukekohe trial, Nadine was the most infested cultivar (0.8 infested white tubers per plant) when the tubers were graded to remove green tubers. However, the level of tuber infestation was lower than that found in Pukekohe and many cultivars had no PTM larvae in white tubers.

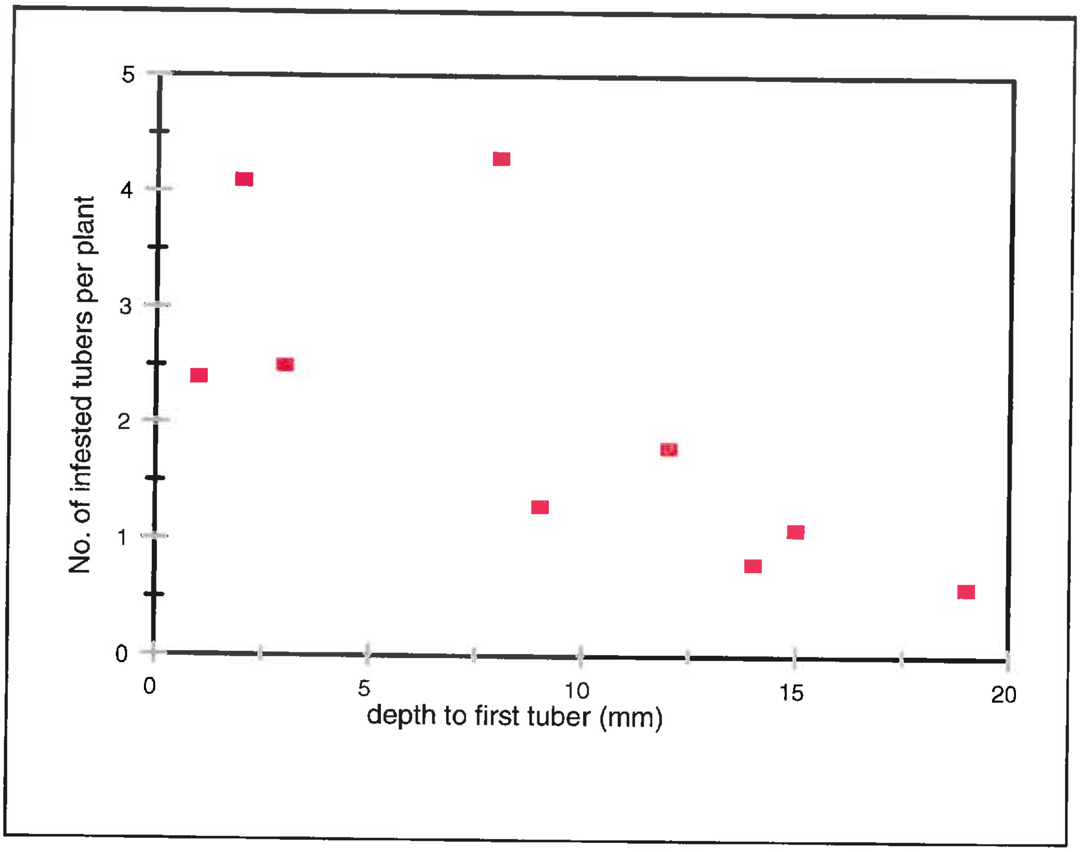

Fig. 8.1: **Mean depth of soil to the first tuber and mean number of tubers infested with potato tuber moth for nine potato cultivars at Pukekohe.**

Table 8.2: **Potato tuber infestation of nine potato cultivars at Lawn Rd, Hastings**

	13/3/97	17/4/97	
Cultivar	mines/plant	infested tubers/plant	infested white tubers/plant
Nadine	-	1.7	0.8
Russet Burbank	4.2	1.1	0.4
Agria	4.0	0.5	0
Kiwitea	9.2	0.4	0
Red Rascal	7.0	0.3	0
Ilam Hardy	1.0	0.2	0
Driver	7.2	0.2	0
Fianna	8.2	0.1	0.1
Rua	2.4	0.1	0.1

The ranking of the cultivars in Tables 8.1 and 8.2 are quite different. Nadine was ranked first in both trials, but the other cultivars did not show any consistency.

The results of the trial suggest that none of the potato cultivars tested have any resistance to PTM. Nadine appeared to be the most susceptible cultivar, but it was at a disadvantage in this experiment because the potatoes were harvested on a calendar date with no reference to the growth stage of the potatoes. Nadine, an early-maturing cultivar, lost its foliage earlier than other cultivars, so there was more time for the resident PTM population to infest the tubers. Foot (1976) found that tuber infestations were increased when harvest was delayed after foliage senescence.

Tuber infestations at harvest were not related to the larval infestations in the foliage. There were more larvae present on the foliage of the late-maturing cultivars, which had foliage present for longer, but this did not result in more infested tubers than in the early-maturing varieties. Foot (1979) suggested that PTM larvae that leave dying potato foliage are unable to infest soil-covered tubers.

The inverse relationship between depth to the first tuber and the number of infested tubers found in the Pukekohe trial confirms the conclusions of Foot (1979) that tuber depth is one of the most important factors in the ability of PTM larvae to infest tubers as they mature.

Foot (1976) tested a range of potato cultivars (Ilam Hardy and Rua were included in the 12 named cultivars) in the laboratory and field. All cultivars were 'seriously infested' and there was no evidence of resistance, although some significant differences were found between the cultivars. Many of the differences were attributed to varietal differences in growth habit, such as depth of tuber set or a lack of suitable oviposition sites, rather than inability of PTM larvae to penetrate or survive in tubers.

Fenemore (1980) inspected 21 potato cultivars for susceptibility to PTM. Ilam Hardy and Rua were among the 12 named cultivars. Fenemore did find significant differences between the cultivars tested in oviposition preference, larval development and adult moth fecundity and there was close correlation between cultivar rankings from these laboratory experiments and infestations in cultivars grown under field conditions.

Foot (1976) and Fenemore (1980) both noted that under normal commercial growing conditions, large areas of single cultivars are grown and it is likely that any cultivar grown could be expected to suffer heavy infestations (in the absence of control measures).

In the trial reported here, Ilam Hardy was more susceptible to PTM infestation than Rua which agrees with the results of both Foot (1976) and Fenemore (1980).

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10 APPENDIX I

Clearwater Report

Experiments to assess pheromone traps, pheromone blends, and trap placement. Report by John Clearwater, Clearwater Research and Consulting.

The sex pheromone of potato tuber moth (PTM) is known to consist of two chemicals: (E4,Z7)-tridecadienyl acetate (PTM 1) (Roelofs et al. 1975), and (E4,Z7,Z10)-tridecatrienyl acetate (PTM 2) (Persoons et al. 1976). Raman (1988) tested blends of PTM 1 and PTM 2 in ratios from 9:1 to 1:9. Blends of 9:1, 1:1.5 and 3:1 caught the most moths, in approximately equal numbers. The four blends in ratios from 3:1 to 1:3 were of similar effectiveness. Voerman and Rothschild (1978) reported similar results.

Raman (1988) also tested two designs of pheromone traps: a water trap and a funnel trap (tin lid, plastic funnel and plastic bag) and found no difference in moth catches. Tamhankar and Harwalkar (1994) tested the same traps and found that while the water traps caught fewer moths, the difference was not statistically significant. Raman (1988) also tested the funnel trap at a range of heights: on the ground, 0.4 m and 0.8 m above ground, but found no significant difference between these. Bacon et al. (1976) compared moth catches in water traps and sticky traps (at 0.3 m height) and found the water traps caught more moths than sticky traps. The type of trap used is important both because the trap must catch a consistent proportion of the PTM population present and because it must be easy to service.

Raman (1988) concluded that pheromones could be useful tools in IPM programmes for PTM. However, as the number of males caught has been shown to vary, the results obtained overseas for potato tuber moth may not hold good in New Zealand.

Four types of trap design, two trap heights, and three ratios of the two identified pheromone chemicals were compared in two experiments carried out at the Pukekohe Research Station.

Materials and methods

The experiments were conducted in a one hectare plot of main crop potatoes, cv. Rua, on the Pukekohe Research Station (Crop & Food Research). The crop, planted in early November, was managed according to normal practice, except that no insecticides were applied. Data were collected from two experiments, each of which ran for 12 days. The plants were in full growth at the first experiment (3 -14 February 1997), while many of the stems had senesced when the second experiment was run (18 -30 March).

Both experiments were laid out as a 12x12 Latin square. The "rows" of the square were the 12 days on which data were gathered and the 12 trap positions corresponded to the "columns" of the square. Each of two lines of traps were placed at right angles to the predominant wind direction (west). The traps were spaced 9 m apart, the complete line covering 99 m. The first and last traps were 2 m from the edge of the plot. The twelve treatments of each experiment occurred once in each of the two lines. Male moths caught on the preceding night were counted and removed each day. The position of each treatment was randomised again each day, with each treatment spending one night at each of the twelve positions in the line.

Weather data were retrieved from the daily records collected at the meteorological station on the Pukekohe Research Station.

Experiment I

In the first experiment a complete 3-way factorial design was used to test:

- two types of pheromone trap: DeSIRe sticky traps (Hort+Research) and funnel traps (Agrisense);
- three pheromone blends: 1:1, 1:1.5 and 1:4 (PTM 1 : PTM 2, total 0.2 mg loading) (Hort+Research);
- two trap heights: 0.3 m and 1 m (the level of the pheromone lure).

The number of males caught in each trap on each day was recorded. The base of the sticky trap was changed when 20 moths had been caught (cumulative or single catch). This is an important aspect of using sticky pheromone traps (J. Clearwater, pers. comm.).

Moth sexual behavior and responses to the traps were recorded during a 24 hour observation period (from 10:00 a.m., 11 February, to 10:00 a.m., 12 February (day 8/9)). Observations were made on a 3 h on, 3 h off cycle.

Experiment II

The second experiment tested:

- three types of pheromone trap (at a range of heights): DeSIRe sticky traps (0.3 m and 1 m), 'A-trap' sticky traps (Ciba) (0.3 metres) and a water trap (Bacon et al. 1976) on the ground;
- the same three pheromone blends that were used in the first experiment.

On one date, the time taken to service a water trap compared with a sticky trap was recorded.

The data from both experiments were analysed by Dr Chris Triggs, Department of Statistics, University of Auckland, in a generalised linear model. Values and standard errors were back-transformed from the log scale.

Results

Experiment I

The funnel traps were much less attractive to PTM than the DeSIRe traps ($p<0.001$) (Table 1).

Table 1: Mean moth catch per day for the DeSIRe trap and funnel trap, Experiment I

	Trap type		
	DeSIRe	funnel	SED
mean catch/trap/day	17.1	2.1	0.75

This difference was consistent for all ratios of chemical and both trap heights (Fig. 1). The funnel traps caught a total of 298 males and the DeSIRe traps caught a total of 2467 males during the 12 days of the trial.

There was a substantial difference in the effectiveness of the different ratios of chemical ($p<0.001$) and this was not consistent at both trap heights, ($p<0.01$) (Table 2). The 1:4 ratio of the two pheromone chemicals caught fewer moths than the 1:1 and 1:1.5 ratios. There was no difference in the moth catch for the 1:4 ratio at either trap height. In the traps at a height of 1.0 m there was no significant difference between the ratios 1:1, 1:1.5 ($p>0.05$), but at 0.3 m there was a significant difference, ($p<0.01$). Combining these two results gave the overall significant difference between the 1:1 and 1:1.5 ratios ($p<0.05$).

Table 2: Mean moth catch per day for three ratios of PTM pheromone chemicals and two trap heights

	Ratio of pheromone (PTM1:PTM2)			
Trap height (m)	1:1	1:1.5	1:4	Mean
0.3	8.4	12.9	8.7	10.0
1.0	10.9	11.4	5.4	9.2
mean	9.7	12.2	7.0	

The differences in the numbers of moths caught per day (Fig. 2) was significant ($p<0.001$). Numbers of moths caught per day in the DeSIRe trap dropped from a peak of 400 moths per day to a plateau of less than 100 moths per day. Moth catch in the funnel traps increased less than 10 moths per day to catch 20 to 30 moths per day late in the experiment. Moth catch showed a sudden drop in both funnel traps and the DeSIRe trap at 1.0 m on day 9. This coincided with relatively strong winds (4.5 m/s average wind speed, 11 February 1997).

There were also significant differences ($p<0.001$) between trap positions across the line (data not presented). However, these differences were consistent for all traps.

There were no significant differences resulting from trap height. The high and low DeSIRe traps maintained a catch rate of 40-100 males/day over most of the 12 days of the trial. The high traps captured fewer moths than the low traps on days 2 and 9.

There were six minor rainfalls during the experiment, all of less than 9 mm of rain over a 24 hour period. The wind was from the prevailing westerly quarter (between 225° and 315°) on 8 of the 12 days.

Moth behaviour was observed for a 24-hour period from 10 a.m. 11 February to 10 a.m. 12 February. Conditions were overcast, there was slight drizzle and it was moderately windy. It was noted that the wind was strong at dusk. During this time (7:00 p.m. to 9:45 p.m.), small numbers of males were observed approaching low traps. They remained within the cover of the foliage of the potato plants. No moths were observed approaching the high (1.0 m) traps. The approach flights of the moths to both trap types were short "hopping" flights from leaf to leaf. While moths readily entered the DeSIRe traps and were caught on the sticky base, those drawn to the funnel traps tended to land near the prominent rim of the trap where the funnel and bucket parts clip together. The moths then tended to make slow progress to the top of the funnel and less than a third entered and were caught in the trap.

A group of 20-30 males were observed during a short (10 minute) period of intense activity at 11 a.m. on 14 February (day 12). Conditions were sunny and hot. The activity began just as the light breeze dropped to calm conditions. A high funnel and a high DeSIRe trap had been moved into the area during the randomisation process. Males were seen approaching from a 10 m x 10 m area, hopping from leaf to leaf. Males only flew up to the edge of the traps when 1-2 m from the trap. Both traps appeared to engage the attention of equal numbers of males. Three were caught by the DeSIRe trap, none by the funnel trap. Some males first contacted the funnel trap below the rim. The prominent edge of the rim prevented males from moving past up to the trap entrance.

Experiment II

In the second trial, the DeSIRe traps were again placed at the high and low positions and water trap, and A-traps replaced the funnel traps. Moth catch in the three types of trap: DeSIRe (at 0.3 and 1.0 m), water (on ground) and A-trap (0.3 m), was significantly different ($p<0.001$) (Table 3). The water traps caught the most moths and the A-trap the least (Fig. 3).

Table 3: Mean moth catch per day for the DeSIRe trap, water trap and A-trap, Experiment II

	trap type		
	DeSIRe	water	A-trap
mean catch/trap/day	29.3	124.0	8.3

Trap height did not significantly affect moth catch in the DeSIRe trap. The data for the two heights of the DeSIRe traps are combined in Table 4. The 1:4 ratio was again the least effective in catching moths but no significant difference was seen between the 1:1 and 1:1.5 ratios.

Table 4: **Mean moth catch per day for three ratios of potato tuber moth pheromone chemicals and three types of pheromone traps**

	ratio of pheromone (PTM1:PTM2)			
trap type	1:1	1:1.5	1:4	SED
DeSIRe	33	34	22	3.4
water	128	127	117	9.7
A-trap	8.9	8.0	7.5	2.4
mean	56.6	56.3	48.8	

Again there was a significant difference ($p<0.001$) in the moth catch on each day of the experiment (Fig. 4), with the numbers of moths caught each day declining over the duration of the experiment. The dip in moth catches in all traps on day 5 coincided with 17 mm rainfall. A significant differential effect of trap position ($p<0.01$) was observed in this experiment and was consistent across all trap types (data not presented).

There were three minor rainfalls (< 2 mm) and two major rainfalls during this experiment. The two major rainfalls of 17.2 mm and 14.6 mm occurred on consecutive days (days 5 and 6). The wind was from the prevailing westerly quarter (between 225° and 315°) on 4 of the 12 days and the opposing easterly quarter (between 45° and 135°) on two days.

The sexual behavior of male moths was observed in the course of the trial. The act of setting out or randomizing the traps appeared to stimulate a response from groups of up to 30 males even in the middle of the day.

It took longer to count the catch in the water traps. An average of six minutes was required to count and remove the moths caught in a water trap compared with 8 to 10 seconds to count moths caught in a DeSIRe trap. (Note: the water traps caught more than six times as many moths as the DeSIRe traps on that day (153 vs 23).

Discussion

The pattern of moth catches in an efficient pheromone trap should reflect changes in the moth population in the crop in which the pheromone trap is situated. It is essential that such a pheromone trap is used in IPM programmes to monitor pest populations so that management decisions can be based on the data gathered.

The high (1.0 m) and low (0.3 m) DeSIRe traps had a similar pattern of moth catches over the duration of the first experiment. The initial peak of moth catches declined from the first day to a plateau. A similar pattern of moth catch was seen in the water traps and two types of sticky trap (DeSIRe and A-trap) in the second experiment. The pattern of catches observed, in both experiments, was also observed by Voerman and Rothschild (1978) who reported high initial numbers of PTM catches when the traps were first placed in a field. This peak in moth catch on the first day is not uncommon as the traps harvest the "standing crop" of available males.

The similar pattern of trap catches provided a consensus result from a group of different types of pheromone trap, although the actual numbers of moths caught in each trap differed. This agreement between different types of trap provided evidence that a real measure of fluctuations in the PTM population was being made.

A different pattern of moth catch was seen in the funnel traps. There appeared to be two levels of moth catches. This may have been because paper towels, which had been initially included as a substrate for the captured moths, were removed from the buckets of the funnel traps. Overall, the lower number of moths caught in the funnel traps was due to the design of the trap; many moths landed on the prominent rim and only one third of these were actually caught in the trap. The funnel traps are more effective at catching larger moths, e.g. noctuids (Herman et al., 1994) and are not suitable for smaller gelechiids (PTM family).

The water traps captured four moths for every one taken by the best sticky trap (DeSIRe). This result is very similar to the results of Bacon et al. (1976), Keerati-Kasikorn (1981) and Salas et al. (1991). Tamhankar and Harwalkar (1994) found that 'dry' traps (Raman's funnel trap) on average caught more moths than water traps, although the difference was not significant. The variation in trap catch was also greater for the water traps.

Experience has shown that the sticky bases are less effective after 20 or more moths have been caught on them (J. Clearwater, unpublished data). If the bases are not changed at this point, the trap catch of the sticky traps declines. While the water trap has a high saturation point in terms of the number of moths it can catch, the efficiency of the water trap may decline in periods of hot dry weather through evaporation of the water. Tamhankar and Harwalkar (1994) found, in laboratory studies, that water level was a critical factor in the efficiency of water traps.

Of the two sticky traps evaluated in this research, the DeSIRe traps caught more moths than the A-traps. These results are similar to those of Kennedy (1975) who evaluated a range of sticky traps for catching PTM in California. Sticky traps of a design similar to the DeSIRe trap, were generally better at catching moths than cylinder traps with a design similar to the A-traps.

The water trap is the better trap to use if the aim is to deplete the number of males in the field (mating disruption). However, the water trap was labour intensive in that it took a long time to remove and count the moths drowned in the water. If the aim is to observe the pattern of rise and fall of the population then the DeSIRe trap, with a shorter service time, would be a better choice. The low moth catch in the A-trap lowers the sensitivity of this trap in identifying changes in the PTM population and makes it less suitable for monitoring purposes.

The preference of PTM for the 1:1 and 1:1.5 ratio over the 1:4 ratio seen in these two experiments reflects the results reported by Voerman and Rothschild (1978) in Australia. Their traps captured a mean of 932 males with the 1:1 ratio, 1041 with the 1:1.5 and 658 with the 1:4 ratio, but these differences were not statistically significant. Raman (1988) found a very similar pattern when testing these ratios in Peru but, like the above authors, was unable to show statistical significance. Voerman and Rothschild's (1978) trial in Cyprus found that the number of males caught increased with ratios from 1:1 to 1:4. The finding that the Cyprus PTM males were equally attracted to PTM 2 alone as to the mixtures of PTM 1 and PTM 2, while only a third as many Australian PTM males are caught with PTM 2 alone, makes it probable that distinct differences exist between Cyprus and other regions. The New Zealand results unsurprisingly resemble the results from Australia.

Both trap heights (0.3 and 1.0 m) were equally effective in capturing males. Kennedy (1975) found that traps baited with unmated PTM females caught more males when placed at a height of 0.3 m in preference to 1.0 m, but also reported wide variation in the data. Raman (1988) found no differences between three heights: ground level, 0.4 m or 0.8 m when using synthetic baits.

The occasional sudden dip in moth catches observed in the 1.0 m traps appeared to be related to significant rainfall (17 mm) or strong wind (4.5 m/s average wind speed). This needs further research using hourly weather data rather than daily averages. Krambias (1976) found a weakly positive correlation between wind speed (0.1 - 4.7 m/s) and moth catch, while Foot (1979) noted that flight activity of PTM moths was inhibited by wind speeds greater than 3 m/s.

The observed differences in trap position (data not presented) in both experiments is not of great concern as it was consistent across all treatments. However, the existence of these effects should be investigated further. The existence of both day and trap position effects and their consistent effect for all treatments justifies the use of the Latin square design.

In conclusion, the DeSIRe sticky trap ("delta" trap design) is the preferred type of pheromone trap to use in a PTM monitoring system. The fluctuations in the moth catches in these traps reflect the fluctuating population of PTM in the crop and they are easy and quick to service. There is no clear difference between the 1:1 and 1:1.5 ratios of pheromones blends, but the latter is recommended as it is already in use in New Zealand commercial potato crops. Although there is no real difference in the effectiveness of traps set at various heights, the traps are probably best located at the top of the canopy for ease of access and to minimise any adverse effects of weather on the efficiency of the trap.

Declaration of interest: J. Clearwater has a business relationship with the American supplier of the Ciba "A-traps".