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Integrated pest management for potato tuber moth

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A report prepared for
New Zealand Vegetable &
Potato Growers Federation

Contents

1 Executive summary

This report presents the results from the final year of a three year project to develop an integrated pest management (IPM) programme for potato tuber moth (PTM). An overview of the whole project is also presented.

A flow chart has been developed to enable growers to assess the threat of potato tuber moth infestation in their crops.

The objective for the third year was to integrate the IPM technology developed and implement the IPM programme commercially by:

- testing proposed spray thresholds;
- combining the monitoring system with biological and cultural controls strategies;
- training exemplar growers and assisting them to implement the IPM programme in their crops;
- demonstrating the IPM programme to other growers;
- developing an IPM reference manual.

Although an efficient monitoring system was developed earlier in the project further research showed that it was not feasible to define at what level a PTM population was likely to cause economic damage. This is because several other factors such as stage of crop growth and prevailing weather are also important in determining the likelihood of tuber damage.

A risk assessment concept was therefore tested during the season with the aim of enabling growers to assess when the risk of damage was high enough to require an insecticide application. However, results from the crops monitored this season did not support the concept. Some crops had severe tuber damage even though no larvae had been found in the foliage. In contrast, in other crops where relatively high larval populations developed late in the growth of the crop, there were very low levels of tuber damage.

Flow chart developed

After -depth discussions with the exemplar growers it was decided to develop a flow chart which combined various control strategies with factors that were identified as important in determining the likelihood of tuber infestation. Crop growth stage, time of year, and current weather conditions are considered the most important of these factors. Also important is the condition of the moulds over the tubers because intact moulds help to protect tubers from larval attack.

This PTM management flow chart enables growers to evaluate the threat of tuber infestation and, therefore, potential economic loss. After working through the variables listed on the flow chart they can decide if an insecticide application is necessary. Although the flow chart has not yet been tested in the field, the issues it covers and its underlying concept were discussed with growers as it was developed.

Biological control is not considered in the flow chart because *Apanteles subandinus*, the only PTM-specific parasitoid in New Zealand, failed to make a significant contribution to the control of PTM. Further research in this area should aim to achieve higher levels of *A. subandinus* parasitism and seek other parasitoids that could be introduced to New Zealand.

Grower education

Throughout the project, exemplar growers were trained in the principles of IPM technology. Grower seminars were held in Pukekohe, Manawatu and Hawke's Bay to present project results to potato industry personnel in those regions. Useful discussions were held with those who attended, and the IPM programme was well received.

An IPM manual has been prepared to transfer the technology developed in the project to the potato industry. The manual covers the identification and control of most potato pests and diseases. Crop monitoring systems are detailed for PTM, aphids and major diseases, and a 'Quick Reference' section contains a range of sample sheets and flow charts to help growers implement the programme. A draft of the manual was circulated to the exemplar growers, potato industry personnel and fellow scientists for comment. Their feedback is now being incorporated into a final version. A range of options for publishing and distributing the manual are outlined in this report, with the favoured one being a formal training programme to teach growers and consultants how to use and implement the IPM programme.

It is recommended that the release of the IPM manual is delayed for two years until a new project that recently gained funding is completed. This project will field test the IPM programme more widely and enable further refinements to improve its effectiveness.

2 Introduction

Potatoes are New Zealand's largest vegetable crop. Over 10 000 ha are planted each year with a retail value of approximately $235 million. Potato tuber moth (*Phthorimaea operculella*) is a major insect pest of potatoes and is consistently ranked by growers as a high priority for research.

A Technology for Business Growth (TBG) project was set up with the support of potato growers (Potato Sector, NZ Vegetable & Potato Growers Federation (Vegfed)), two potato processors (Heinz-Wattie Australasia and Bluebird Foods) and an exporter (Southern Fresh Produce). The aims of the three year project were to develop and implement an integrated pest management (IPM) programme that would enable growers to assess the potato tuber moth (PTM) populations in their crops and determine if or when insecticides were required to avoid economically damaging tuber infestations.

Earlier reports have described the results of the first two years of the project (Herman 1997; 1998). This report describes the results of the third and final year of the project. The objective for this year was to integrate the IPM technology developed and implement the IPM programme commercially by:

- testing proposed spray thresholds

- combining the monitoring system with biological and cultural control strategies to produce an IPM programme for PTM
- training the exemplar growers to use the IPM programme and assisting them to implement it in their crops
- demonstrating the programme to other growers
- developing an IPM reference manual for PTM control in potatoes

3 Testing proposed thresholds

3.1 Methods

Thresholds for PTM population levels, proposed from data collected in the previous two seasons, were to be trialled on a large scale this season. However, it proved difficult to clearly define a population level that would discriminate between PTM populations that cause economic damage and those that don't. Several other factors relating to crop husbandry and cultural control must also be assessed together with the size of the PTM population to determine the risk of tuber damage. Insecticide applications can then be recommended when there is a high risk of damage.

To develop and test the concept of using integrated methods of control we proceeded with our planned large scale IPM sites. These were substantial areas within the potato crops of the five exemplar growers participating in the project. Pheromone traps and crop monitoring were used to monitor PTM populations in both areas of the crops. The grower made PTM management decisions for the conventional block and Tim Herman made decisions for the IPM block, with the grower having the right to override decisions.

In the Matamata region, A.S. Wilcox & Sons (ASW) provided an early season crop of cv. Draga (split in two) and two early plantings of cv. Delcora (one under each management regime). Chapman Onion Exports Ltd (COEL) provided one main season crop of cv. Fianna, an area of which was placed under IPM management.

In Opiki, Tony Moleta (cv. Kiwitea), Danny Fraser (cv. Fianna) and John Miers (cv. Fianna) each provided a main season crop with an area under IPM management within each crop.

The pheromone traps were set up in early November in the Matamata crops and in early December in Opiki crops. Weekly crop scouting started at the same time if there was foliage present (ASW Draga and Delcora) or when the foliage emerged (all Opiki crops and COEL Fianna).

In both regions any larvae found were collected and taken back to the laboratory to determine levels of parasitism. The method differed from the previous two seasons in that the larvae from each crop at each sample were bulked together in one large container. Each container had a layer of vermiculite covering the base as a substrate for pupation and some potato tuber to provide extra food for the larvae. The containers were checked twice weekly and any moths or adult parasitoids were removed and counted.

3.2 Results

3.2.1 Matamata

Draga (ASW)

Moth catch in the two pheromone traps gradually increased to a peak in late January of around 20 moths per day for both the IPM and conventionally managed areas of the crop (Fig. 1). The catches then dropped sharply to around 5 moths per day before slowly increasing again.

Only two larvae were found in the foliage of the conventional side on one date in early January. An insecticide was applied to this side of the crop in mid January. The first harvest sample was taken in mid January when the moth catches were peaking. The remaining foliage was sprayed off in late January and a second insecticide was applied to the conventional side of the crop and the majority of the IPM side of the crop (first application) at the same time. Harvest samples were taken fortnightly until the crop was harvested. Three harvest samples were taken in the IPM side of the crop. The first was taken across the whole site, before the defoliant and insecticide were applied, and two samples were taken in the small strip that remained unsprayed. Four harvest samples were taken in the conventional side of the crop.

PTM infestation of white tubers increased over time under both crop management regimes (Table 1). The percentage of infested white tubers increased more quickly in the IPM side of the crop, with 12.6% of the white tubers infested in the third sample, compared to 2.8% infested tubers from the conventional side. The percentage of infested white tubers in the rest of the crop (comprising the conventional side which received two insecticide sprays and the bulk of the IPM side which was sprayed once) was highest (17.6 %) in the fourth sample, just before harvest.

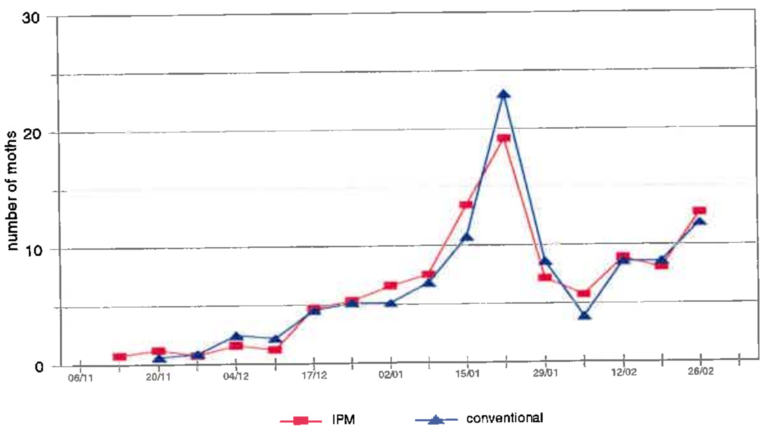

Figure 1: Mean moth catch per day and the mean number of larvae per plant in a potato crop (cv. Draga) in Matamata.

Delcora (ASW)

The pattern of moth catch in the Delcora crops was similar to the pattern in the Draga crop (Fig. 2). Moth catch increased to a peak of 20 - 27 moths per day in late January and then dropped sharply to about five moths per day, followed by a gradual increase until harvest in late February.

No larvae were found in the foliage of either Delcora crop. Two insecticides were applied to the conventional Delcora crop as they had been to the Draga crop. The IPM Delcora crop was not sprayed off and no insecticide was applied. The first harvest sample in both Delcora crops was taken before the foliage of the conventional crop was sprayed off.

Infestation of white tubers increased over time under both crop management regimes (Table 1). There were more infested white tubers in the conventional side of the crop (7.2 %) compared to the IPM side of the crop (2.7 %) at the third harvest sample. There was no significant difference in the proportion of infested white tubers in the IPM and conventional sides of the crop at the fourth harvest sample, but there was a significant difference at the fifth and final sample with 19.1% tubers infested in the IPM side compared to 12.2% in the conventional side.

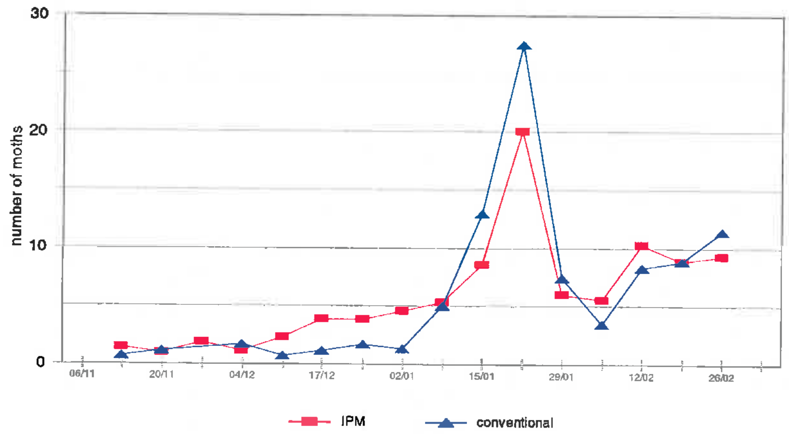

Figure 2: Mean moth catch per day and the mean number of larvae per plant in a potato crop (cv. Delcora) in Matamata.

Fianna (COEL)

The pattern of moth catch in the Fianna crop was similar to the moth catch in the Delcora and Draga crops, but fewer moths were caught (Fig. 3). Moth catch peaked at 11 moths per day in late January for both the IPM and conventionally managed areas of the crop. Moth catch then dropped sharply to about five moths per day for a period, before increasing to around 14 moths per day in late March. No larvae were found in the foliage.

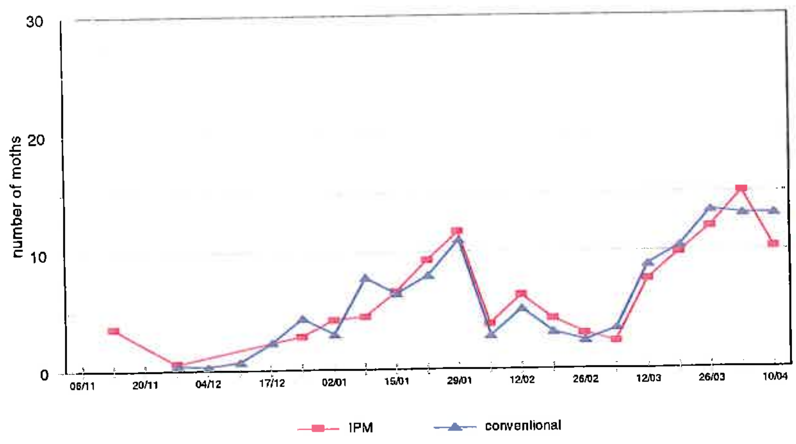

Figure 3: Mean moth catch per day and the mean number of larvae per plant in a potato crop (cv. Fianna) in Matamata

Fortnightly harvest sampling started after the foliage had been sprayed off in early March. Only a small number of infested white tubers were found in the four samples taken (Table 1).

Table 1: Percentage of white tubers infested by PTM larvae in areas under conventional and IPM management in three Matamata potato crops.

	Crop/management					
	Draga		Delcora		Fianna	
Harvest date	IPM	conv	IPM	conv	IPM	conv
22/01/99	0	0	0	0		
29/01/99						
05/02/99	0.9	0.4	0	1.1		
12/02/99						
19/02/99	12.6	2.8	2.7	7.2		
26/02/99						
05/03/99		17.6	17.4	17.6		
12/03/99					0	0
19/03/99			19.1	12.2		
26/03/99					0	0
04/04/99						
10/04/99					0.3	0
16/04/99						
23/04/99					0	0.3

Parasitism of PTM larvae by *Apanteles subandinus* again made little impact on the control of PTM in Matamata (data not presented). The parasitism rate was rarely more than 20% throughout the season.

3.2.2 Opiki

Kiwitea (Moleta)

Moth catch was very low during December (Fig. 4), before climbing in January and February to reach a peak of around 21 moths per day in mid March. Moth catch fell to about five moths per day in late March then slowly increased to about 20 moths per day by the end of sampling in late May.

The first larvae were found in the foliage in early February, but these were only at low levels until March, when they rapidly increased to a peak of 3.4 larvae per plant in late March. An insecticide was applied to the conventional side of the crop about this time. Two further foliage samples found less than half a larvae per plant for the conventional part of the crop and 1.7 larvae per plant for the IPM part of the crop. An insecticide was applied to the IPM side of the crop just as the remaining foliage died off in early April.

The proportion of infested white tubers increased over the three fortnightly harvest samples taken during late April and into May (Table 2), peaking at 1.3% in the conventional part of the crop in early May and reaching 1.6% in the IPM part of the crop in mid May. The proportion of infested white tubers was similar for both management regimes.

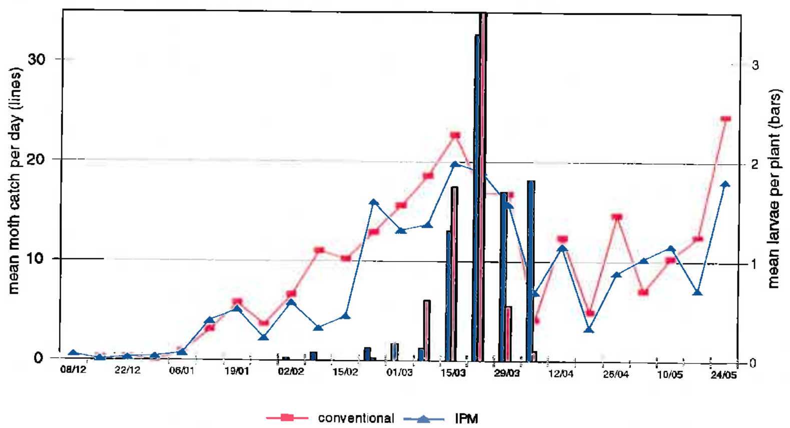

Figure 4: Mean moth catch per day and the mean number of larvae per plant in a potato crop (cv. Kiwitea) in Opiki.

Fianna (Fraser)

Moth catch in this crop mirrored that in the Kiwitea crop, with low catches in December, then increased numbers in January and February, peaking at about 30 moths per day in mid March (Fig. 5). Moth catch then fell quite sharply to about five moths per day and fluctuated around 10 moths per day during April and into May. Moth catch rose again to about 24 moths per day at the final sample in late May.

The first larvae were found in the foliage in late January, but numbers did not increase until late February and into March. The number of larvae per plant peaked at about 2.4 in late March.

Infested white tubers decreased from 1.5% to 0.6% over the three harvest samples (taken fortnightly from late April to late May) in the IPM part of the crop (Table 2), while the percentage of infested white tubers in the conventional part of the crop peaked at the second harvest sample (1.0%). There was no significant difference in infestation levels of tubers in the IPM and conventionally managed areas of the crop.

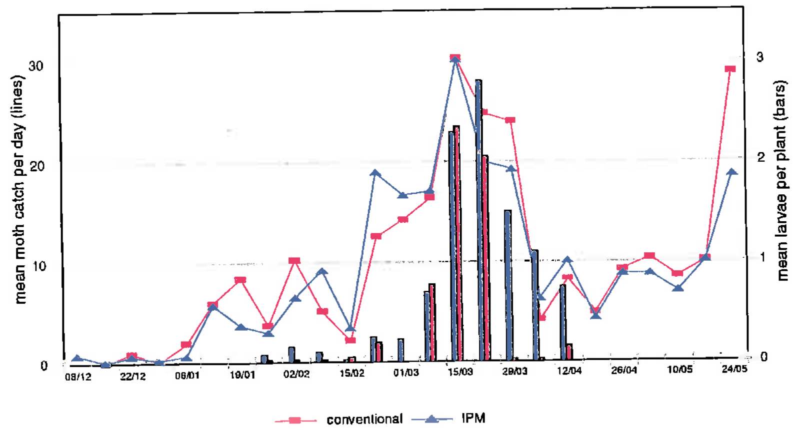

Figure 5: Mean moth catch per day and the mean number of larvae per plant in a potato crop (cv. Fianna (Fraser)) in Opiki.

Fianna (Miers)

The pattern of moth catch in this crop was different from the pattern in the other two Opiki crops (Fig. 6). Moth catches were initially low in December, then increased to a low peak in mid January and dipped in early February before climbing to a peak of about 23 moths per day in late February. A sharp, one week dip in moth catch following the peak was probably the result of an insecticide application to both areas of the crop (insecticide was mistakenly applied to the IPM area). After a third peak of around 21 moths per day, moth catch declined again and the pattern of moth catch in the two parts of the crop then diverged from late March. In the conventionally managed areas the catch peaked for a fourth time at about 23 moths per day and climbed to a final peak of almost 30 moths per day by the end of sampling in late May. Moth catch in the IPM area of the crop fell to less than 10 moths per day in late April/early May before climbing to 27 moths per day by the end of sampling.

Larvae were first found in the foliage in mid January, but weren't found again until early February. The number of larvae per plant increased to a peak in early March. This peak was higher in the IPM part of the crop (0.2 larvae per plant) than in the conventional part of the crop (0.08 larvae per plant), but still markedly lower than the peaks in the other two Opiki crops. The number of larvae in the crop declined until no larvae were found in a sample in mid March. Larval numbers then increased to 0.23 larvae per plant in the final foliage sample.

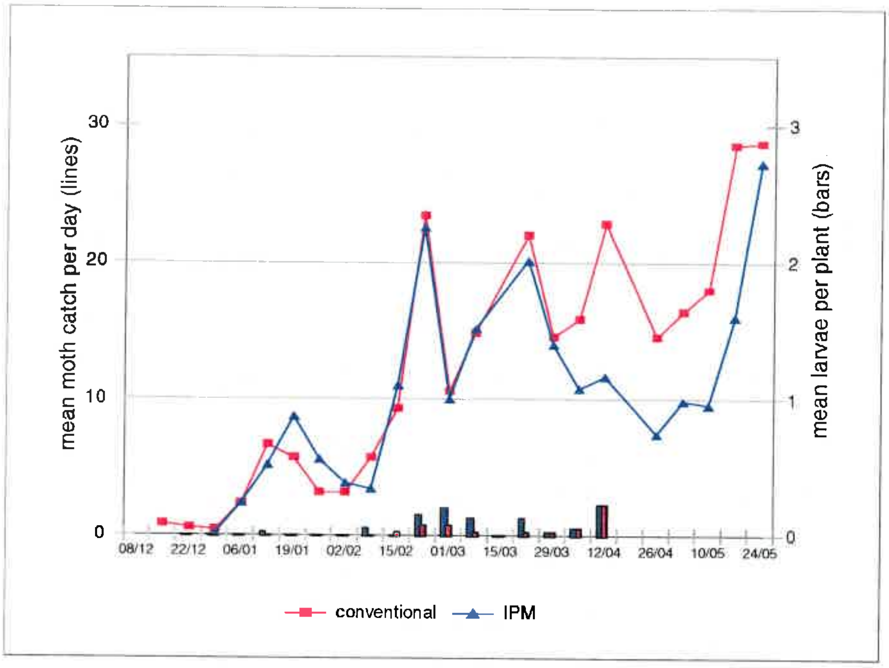

Figure 6: Mean moth catch per day and the mean number of larvae per plant in a potato crop (cv. Fianna (Miers)) in Opiki.

Significantly more white tubers were infested in the IPM part of the crop, reaching 3.5% in the final harvest sample, compared to 1.0% in the conventional part of the crop at the third harvest sample (Table 2).

Table 2: Percentage of white tubers infested by PTM larvae in areas under conventional and IPM management in three Opiki potato crops

Date	Crop/management					
	Kiwitea		Fianna		Fianna	
	IPM	Conv	IPM	conv	IPM	conv
19/04/99	0.6	0			0.5	0
26/04/99			1.5	0		
03/05/99	1.2	1.3			2.2	0.7
10/05/99			0.9	1.0		
17/05/99	1.6	1.0			3.5	1.0
24/05/99			0.6	0.3		

Parasitism levels in Opiki were frequently higher than 20% during the season and peaked at over 50% during the peak of larval infestations (data not presented). While *A. subandinus* was the dominant parasitoid (79% of total parasitism), the diamond-back moth parasitoid, *Diadegma semiclausen,* (21% of total parasitism) was a useful contributor when low numbers of PTM larvae were present in the crops (86% of parasitoids reared during February).

3.3 Discussion

Again this season PTM population data clearly show a correlation between number of moths caught in the pheromone traps and the number of larvae found in potato foliage. However, as we have previously noted, the size of the PTM population, particularly the larval population, did not relate directly to the amount of damage to white tubers.

No larvae were found in the foliage of the Delcora crops and only two were recorded in the foliage of the Draga crop. Yet the percentage of infested white tubers exceeded 10% for both management regimes of both cultivars. This was mainly because the harvest of both crops was delayed during the period when the PTM population was peaking. Another factor was the hot dry season, which favoured PTM, and the very dry soil which gave larvae easier access to the tubers. The delay in harvesting was beyond the grower's control although we had discussed the need to harvest the crops within 4 weeks of the foliage dying off to minimise tuber damage.

When the IPM side of crop, which received no insecticide, was compared to the conventional side, which received one or two insecticide applications, it appeared that insecticide delayed tuber infestation by about a week, but ultimately applying an insecticide did not prevent damage from occurring.

In Opiki there were similar PTM populations in the three crops, although regular insecticide applications to one crop (Miers' Fianna) held the PTM population of that crop in check.

In Moleta's Kiwitea and Fraser's Fianna crops one insecticide application, applied either at a peak in the larval population (conventional part) or late in the growth of the foliage (IPM part), was effective in holding white tuber infestation below 2% in the six weeks after the foliage died.

Miers' Fianna crop was the exception. The differences in larval populations between the conventional and IPM parts of this crop and the other two Opiki crops probably resulted from insecticide applications. Insecticides were frequently applied to the conventional part of the crop and mistakenly to the IPM part of the crop (mid March) and this held the PTM populations back. Irrigation was also applied to this crop and this is known to reduce PTM populations (Foot 1974; Shelton & Wyman 1979a).

Two spotted spider mite infested the two Fianna crops in Opiki in February and both crops were sprayed with a specific miticide. In the Miers' crop the infestation was more severe in the IPM part of the crop. The resulting defoliation of the IPM area of the crop may have encouraged PTM infestation of the tubers earlier than in the conventional area of the crop where the defoliation was less severe.

In general, parasitism levels during the 3 year project were not sufficient to contribute significantly to the economic control of PTM. However, there were indications that the parasites could be important contributors, e.g. in Opiki this season *A. subandinus* and *D. semiclausen* parasitised over 50% of the peak of PTM larvae during March.

Foot (1979) reported average parasitism levels of 45% in tubers left lying on the ground from March through to September at Pukekohe and although parasitism dropped to below 10% in the spring, Foot (1979) concluded that parasitism by *A. subandinus* may delay the build-up of PTM populations by 3-4weeks, through lowering the number of pests that survive overwinter.

Horne (1990) reported that while *A. subandinus* was the most widely spread PTM parasitoid around Victoria (Australia), the relative importance of this species changes during the season due to competition from other PTM parasitoids. At an unsprayed site, parasitism peaked late in the season at 90%, just after the numbers of PTM larvae peaked in the foliage. Horne (1990) also documented the impact of a single insecticide application which suppressed the parasitoids, but did not completely suppress the PTM population, leading to a resurgence in PTM numbers. Multiple applications of insecticides at another site effectively reduced parasitism to zero.

Rearing parasitoids from PTM larvae collected in the field was difficult. Initially there was a large number of deaths from undetermined causes (Herman 1997) and changes in rearing methods in the second season failed to overcome this problem (Herman 1998). Further refinements in the third and final season seemed to work, but the bulking of samples for rearing may have hidden the problem.

4 Combining strategies for IPM

It was known at the outset of this project that cultural control strategies can play a major role in controlling PTM. Ridge spacing, depth of seed planting, moulding and irrigation can all influence the size of PTM populations and the amount of damage they inflict (Foot 1974; 1976; Shelton & Wyman 1979a). Most of these factors are taken into account in the growing practices of New Zealand's potato growers.

Biological control commonly plays an important part in IPM programmes. However, in New Zealand the level of biological control of PTM is at present too low to prevent PTM populations from inflicting economic damage.

The two elements missing from a practical IPM programme for PTM were a system for accurately monitoring PTM populations in crops, and a population threshold to determine if or when insecticides were required to prevent economic damage to the crop. Defining these elements has been a major focus of the research project.

Pheromone traps are widely used overseas to monitor PTM populations (Yathom et al. 1979; Ferro & Boiteau 1993; Fuglie et al. 1993; Raman 1994) and a survey indicated that 12% of New Zealand potato growers were already using pheromone traps to monitor PTM populations in their crops (Herman 1997). However, there are differences between countries in both the type of trap and blend of chemicals used (Raman 1988). Experiments within this project identified an appropriate pheromone trap and blend of pheromone components for use in New Zealand potato crops (Herman 1997).

Pheromone traps and crop scouting were used to monitor both moth and larval PTM populations in commercial potato crops during the three seasons of this project and this system was able to track fluctuations in PTM populations in the crops (Herman 1997; 1998; and Section 3 above). Peaks and troughs were seen in both daily moth catch in the pheromone traps and number of larvae per plant, showing that separate generations of the pest were present. Larval numbers peaked at the same time, or one to two weeks after a peak in moth catches.

Based on the data collected over the three years we propose a threshold of 10 moths per day to initiate crop scouting. A practical example of the application of the threshold is seen in Figures 4, 5 and 6. In each crop the moth catch reached 10 moths per day as the peak generation of PTM was building up in February and the first larvae were being found in the crops. Thus, applying the suggested threshold focuses labour intensive effort on a period when damage is most likely, minimising the costs of crop monitoring and maximising its usefulness.

The next step of producing a threshold at which an insecticide is necessary, has not been as easy. When we attempted to relate the population data gathered by monitoring to the amount of damage to tubers at harvest, we found that the relationship between the size of a PTM population within the crop and the damage to tubers in that crop was confounded by a range of other factors. The stage of crop growth, time of year, prevailing weather, and other crop husbandry factors all influence how accessible the tubers are to PTM larvae.

Because the problem was more than simply an issue of the size of the PTM population in a crop, a threshold based on population size was not appropriate. Instead, all the factors listed below need to be evaluated in turn to determine the need for an insecticide.

- *Crop growth stage*

  If there are no tubers present, or they are too small to be accessible to PTM larvae, there is very little chance of economic damage. Therefore an insecticide for PTM control should not be required before the crop is at the tuber bulking stage. As the tubers get bigger, the risk of tuber damage increases. Tubers are most at risk once the foliage has died.

- *Time of year*

  PTM populations peak during February and March. Crops at a susceptible growth stage (late tuber bulking or after the foliage has died) are more likely to suffer serious tuber damage at this time. Before February, PTM populations are not large enough to inflict serious tuber damage. PTM populations decline later in the season as the cooler, damper autumn weather sets in, and there is then less threat of damage.

- *Prevailing weather*

  Hot and/or dry weather favours the development of PTM populations so damage is more likely in hot, dry seasons.

- *PTM population*

  Tuber damage is not directly related to the size of the PTM population. However, the data gathered on PTM populations show peaks and troughs. An insecticide will be more effective if it is applied to a peak of larvae (numbers increasing weekly) rather than to a larval population in decline. In the latter case, cultural control strategies should be employed or renewed, if possible, to reduce the likelihood that PTM larvae will infest tubers. An insecticide could be applied to the next generation of larvae as the numbers increase if there is still a high risk of tuber damage.

- *Crop husbandry*

  Keeping the moulds intact and in good shape obstructs the access of PTM larvae to the tubers.

The factors outlined above are listed in order of importance, e.g. if there are no tubers present then time of year and size of PTM populations are irrelevant. A flow chart was drafted (Fig. 7), in which the factors are listed in the same order as above.

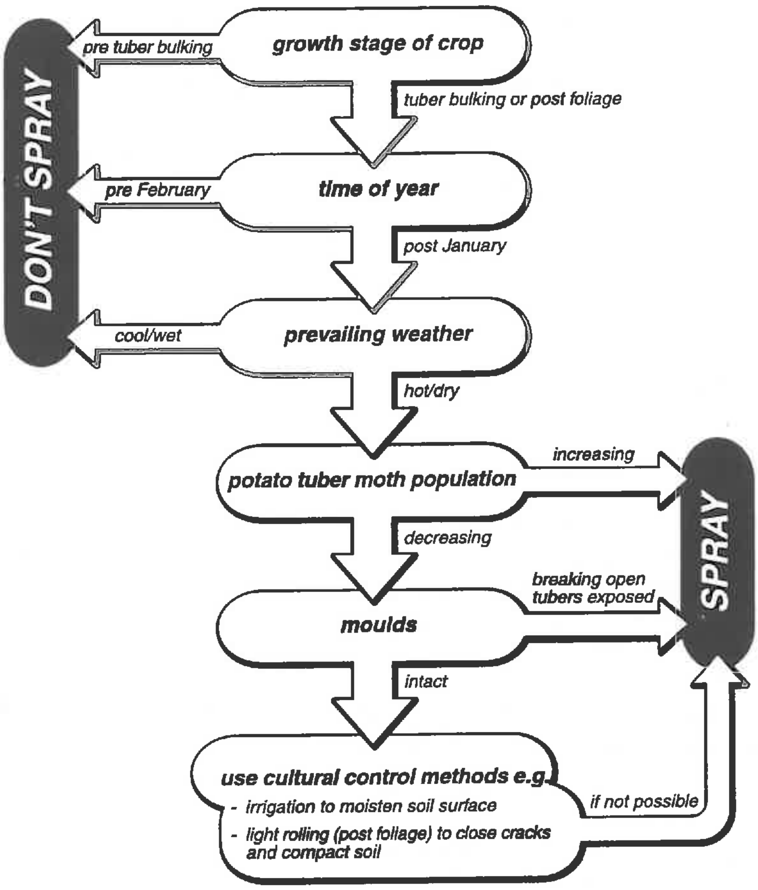

Figure 7: Potato tuber moth management flowchart.

After a grower has scouted his crop he should run the resulting information through the flow chart. If any of the first three factors are low risk then a spray is probably not warranted. The information gathered from scouting the crop is then considered. If the PTM population (larval counts in particular) is increasing then an insecticide application will have a maximum controlling effect. However, if the population is naturally declining, an insecticide application will kill a smaller proportion of the larvae and be less effective. In the latter instance, the use of cultural practices where possible, is recommended rather than an insecticide.

The two cultural control methods suggested in the flow chart are strategies used by potato growers in Victoria, Australia, in the period between defoliation and harvest to reduce potentially damaging PTM populations and avoid tuber infestation. Another option that is sometimes used by these growers is an application of a synthetic pyrethroid to kill any moths hiding in dead foliage and any first instar larvae hatching from eggs laid in the crop debris. The pyrethroid also repels moths immigrating to the crop.

The flow chart is a guide rather than a definitive procedure. There is scope for growers to use their experience to override or alter the flow of the chart or the outcome at the end because of other important local factors. However, the flow chart was developed after discussions with the exemplar growers involved in this project and other potato industry contacts and it is unlikely that any major factors have been omitted.

Using a risk assessment system instead of applying a threshold was considered, but this needed a scoring system to give each factor a weighting and then a threshold value. If the total score exceeded this value then an insecticide would be applied. The PTM population database that has been accumulated during this project is not suitable for this purpose and further research and testing of the weightings would be required to develop the risk assessment concept.

5 Grower education

5.1 Training exemplar growers

There has been close liaison between Tim Herman and the exemplar growers during this project, which has resulted in Tim gaining a better overview of potato crop management, while the growers have received a good grounding in the entomology underlying pest control and IPM.

The flow chart, which was partly based on information contributed by growers, has been presented to the exemplar growers in the draft IPM manual and they have provided feedback. Because the project has finished, implementing the flow chart and the programme as a whole now depends on potato growers applying the programme in their crops and demonstrating its benefits to the wider industry. Tim Herman will provide the necessary support for growers by telephone.

5.2 Demonstrating the programme to growers

5.2.1 Field walks

Two field walks were planned to demonstrate the programme to other local growers in the Pukekohe/Matamata and Opiki/Manawatu regions. These were scheduled for February/March as the foliage in the crops began to die off. However, the Pukekohe/Matamata field walk was cancelled on the advice of the local Vegfed Potato Sector representative, as most growers were busy with onion harvesting.

The field walk in Opiki/Manawatu was held in early March in Tony Moleta's Kiwitea crop (adjoining Danny Fraser's Fianna crop) in conjunction with a gathering of Heinz-Wattie growers. Tim Herman did not attend because of ill health, but Graham Bunckenburg read a brief on his behalf, outlining the aims and results of the project.

5.2.2 Seminars

The IPM programme was presented to growers, along with other results from the project, at a series of grower seminars held in late September and early October in Pukekohe, Hawke's Bay and Manawatu. Each grower seminar included a number of speakers.

Pukekohe

The theme of this seminar, organised by Richard Wood (Vegcon Services), was control of onion thrips in onions. As most of the onion growers are also potato growers, the PTM project was relevant. The seminar was well attended (80-100 growers and industry personnel) and although PTM was not the main topic of the evening, individual growers had useful discussions with Tim Herman after the talk.

Hawke's Bay

Potatoes were the theme of this seminar. In addition to Tim Herman, Peter Stone (Crop & Food Research) talked about the growth and development of potatoes and Graham Bunckenburg (Heinz-Wattie) reported on his recent trip to potato producing regions in Idaho, Oregon and Washington State. The seminar was attended by five of the main growers in the region (some industry personnel who were unable to attend this seminar attended the Manawatu seminar).

Manawatu

This seminar was an expanded version of the Hawke's Bay seminar and was organised by Barney O'Connor (Morgan Laurenson). As well as the speakers above, two chemical companies gave short presentations on new products. The seminar was attended by about 40 local growers and industry personnel.

6 IPM manual

A draft IPM manual for potatoes has been prepared. It follows the format of the existing series of Crop & Food Research IPM manuals, e.g. IPM for Processing Tomatoes (Herman 1995). The manual explains the concept of IPM and describes pests and diseases of potatoes (including colour photos of key stages and symptoms of damage), their life cycle, and current methods of control. It also outlines details of crop monitoring for PTM, aphids and diseases in potatoes, and includes a 'Quick Reference' section with sample monitoring and record sheets and flow charts to assist growers to implement the programme in their crops.

The draft manual was circulated to the exemplar growers, key industry personnel and Crop & Food Research scientists for comment, and where possible Tim Herman worked through the manual on a one-to-one basis with individual growers or industry personnel. The feedback received will be incorporated into the final version of the manual.

Distributing the manual

Once the manual is completed we need to address the issue of publishing and distributing it. These costs are not covered by the project. There are two options available: give each potato grower a voucher to purchase one copy at cost (approximately $15 + GST per copy), or provide a Vegfed-funded copy (at cost) to all potato growers.

The voucher option will mean that growers who want to implement IPM to control PTM will buy a copy and probably implement the programme successfully. The downside of this option is that growers who don't purchase a copy are likely to be the less progressive growers who spray on a regular basis. They are the ones who would benefit most from implementing the programme.

The second option of providing a copy to all growers would have the advantage of ensuring the IPM technology was circulated to all corners of the potato growing regions of New Zealand. However, this would not necessarily mean that all growers would implement the technology. It is likely that only those who would have purchased a copy (first option) would implement the programme. The second option could be detrimental to the IPM programme in the long run, as some of the less enthusiastic growers might implement the programme half-heartedly. Experience, both here and overseas, has shown that in this situation, the pest concerned (PTM) will be inadequately controlled and the programme will be blamed. The resulting negative publicity lowers the overall uptake of the new technology.

With either option there is some risk that many growers might not implement the programme correctly or successfully with only the aid of the manual. IPM is a relatively complex technology that demands considerable attention and resources to implement (Wearing 1988).

Ideally a training programme should be established to teach growers how to effectively implement the programme. The current grower training programme for the brassica IPM programme is a good example of constructive implementation of the technology.

A benefit of this is that a feedback loop is created that helps to maintain flexibility in the programme through continued monitoring and adaptation after the programme is implemented (Hollings 1978, in Stoner et al. 1986). Any problems encountered or changes in the pest/disease complex are rapidly communicated back to the scientists which allows the programme to be modified quickly, if necessary, to maintain its effectiveness.

7 Review of the project

The project has been successful in achieving its main objectives. The monitoring system that was defined effectively identifies fluctuations in PTM populations and is practical for growers to use. The relationship between moth catch, larval counts in the foliage and tuber infestation was studied throughout the three years. While there was a relationship between the timing of peaks in moth catches and the timing of peaks in foliar larval counts, there was no clear relationship between larval populations in the foliage and tuber infestations. However, other factors that influenced the infestation of tubers were identified and have been included in a flow chart to assist PTM management decisions.

Pheromone traps

Earlier studies (Shelton & Wyman 1979b; Lal 1989) concluded that pheromone trap data could be used to predict foliage damage, negating the need for 'cumbersome and time consuming' larval counts. However, the data from this project suggest otherwise. The peak of moth catch ranged between 20 and 30 moths per day, both between regions and between seasons, throughout this project, and although this peak coincided with, or occurred immediately before a peak in the number of larvae found in foliage, it did not relate to the size of the larval population in the foliage. Therefore pheromone trap data cannot be used as a substitute for larval data.

The sticky bases of the pheromone traps used in this project may become saturated with moths, limiting the total number they can catch. Dust might also reduce the effectiveness of the sticky bases. However, these problems do not preclude the use of pheromone traps as monitoring tools in this IPM programme, but mean that traps are not wholly reliable predictors of larval numbers in the foliage.

This problem could be overcome by changing the sticky bases more often (twice weekly) or using a water trap design. Traps that gave a more accurate estimate of moth numbers might enable us to define a closer relationship between moth catch and foliar larval counts, but there would be more work associated with running the pheromone traps.

Relationship between larval population and tuber damage

The results from this project also show that the size of larval populations in the foliage do not directly relate to larval infestation of tubers. Both Bacon (1960) and Foot (1974) also noted that larval populations in the foliage were not directly related to levels of tuber infestation.

So, why monitor the larval population?

Information on the larval population in the foliage is used to optimise the timing of any insecticide applications. That is, insecticides are applied to an increasing larval population, hitting a greater proportion of the population, rather than to a declining larval population when many larvae have formed pupae, which are largely unaffected by insecticide applications.

An effective crop monitoring programme includes observations of all potato pests and diseases in the crop and other management issues, e.g. the state of moulds or irrigation requirements. The IPM programme developed in this project recommends that these observations are included in a monitoring programme along with sampling for PTM larvae in the foliage.

Natural enemies of PTM

The natural enemies of PTM, particularly the specific larval parasitoid, *A. subandinus* rarely had a major impact on PTM populations. Overseas, parasitoids can control 80-90% of PTM larvae in a crop (Horne 1990) and applications of a naturally occurring virus pathogen are being used instead of insecticides to reduce potentially damaging PTM populations both in the field and in storage (Raman & Radcliffe 1992).

There were indications that *A. subandinus* could provide greater levels of control, and research to promote this would be warranted if insecticide use could be minimised. Parasitoids that are effective overseas, particularly those successfully established in Australia, should be investigated to ascertain if they could be introduced to New Zealand to augment the control provided by *A. subandinus*.

Crop monitoring

Using the number of moths trapped as a basis for initiating monitoring minimises the amount of effort devoted to the labour intensive monitoring of larval populations. Data collected over the years indicate that larval populations are not found in large numbers until average daily moth catch in the pheromone traps exceeds 10 moths per day. Weekly larval monitoring then continues until the foliage has died. Tuber sampling can then be initiated to monitor the level of PTM infestation until the crop is harvested.

The PTM monitoring system has been tested and shown to be suitable for monitoring PTM populations in commercial potato crops. The system is explained in detail in the IPM manual and a flow chart helps growers to run the monitoring system in their crops. A similar flow chart has proven useful in other IPM programmes, e.g. IPM for processing tomatoes (Herman 1995).

Testing the flow chart

On the other side of the programme, the decision-making process has not yet been rigorously tested in the field. The concept for the flow chart was worked on during the season as we endeavoured to construct a prototype IPM programme, but it needs testing in the field to ensure its effectiveness. Insecticide applications cannot be timed solely on PTM populations. A range of other factors, and the interactions between them and their influence on the accessibility of potato tubers to PTM larvae, must also be considered. Considerable effort has been devoted to untangling the interactions between the factors and aligning them in order of priority. The result is a decision management flow chart which works through each factor in order before a decision is reached on applying an insecticide.

A characteristic of the flow chart is that the lower the risk of tuber damage, the more rapidly a decision can be made, e.g. if the crop is at an early growth stage and there are no tubers present, there is no risk of tuber damage. Conversely, as you move down the flow chart the risk of tuber damage increases as more of the factors favour tuber damage. There is already a relatively high risk of tuber damage at the point where PTM populations are considered. Crop growth stage, time of year and the prevailing weather conditions are important factors in tuber damage. Taking PTM population trends into account enables the likely effectiveness of an insecticide application to be determined. This allows further opportunity for other alternative control methods to be used, reserving insecticides for when they are likely to be most effective.

Technology transfer

There were several elements of technology transfer in this project. Working with the exemplar growers was one of the main elements. Brough et al. (1995) considered the involvement of farmers in the research, development and implementation of IPM programmes as one of the most important aspects in the long term maintenance of established IPM programmes.

Working closely with growers has helped to overcome many of the potential obstacles to adopting IPM programmes. The exemplar growers contributed significantly to the development of this programme, discussing results and providing feedback to a greater degree as the project progressed and the research went from small scale plots to larger scale testing of prototypes.

The process has enhanced the usability of the programme and promoted the 'horizontal phase' of technology transfer, i.e. spreading the technology from innovative farmers who are leaders in implementing new technology to more conservative farmers who see new technology as risky and wait to see the results of its implementation (Garforth 1993).

It was noted during this project that the exemplar growers were taking on key aspects of the research, as it developed, and extrapolating the information to other potato crops. While this is rewarding to the researcher, indicating that the research is progressing in the right direction, this was not always successful as what was happening in one crop did not necessarily translate directly to another. However, Tim Herman's regular site visits enabled these issues to be dealt with as they occurred when they might otherwise have been blamed on the technology rather than the misapplication of the data.

Popular articles in the New Zeland Commercial Grower were used to publicise aspects of the results that were of immediate benefit to growers, and to bring the project as a whole to growers' attention. One article on the results of the pheromone trap experiments (Herman & Clearwater 1998) led to numerous enquiries from growers wanting to obtain the traps.

The other main form of technology transfer is the IPM manual which presents the IPM programme and associated information (identification and control of other pests and diseases) in user friendly language.

Educating the users is often a key to the successful implementation of IPM programmes and verbal communication is the most effective means of education (Wearing 1988). Wearing's survey rated one-on-one consultations between extension workers and growers as the most effective form of training followed by courses, field days and grower-scientist contact (the latter relating to the commercial practicality of the programme). The IPM manual would be an excellent teaching resource in one-on-one consultations and courses.

The IPM programme is not yet at the stage where it can be commercially implemented. Further field-scale testing and refinement of the PTM management decision flow chart is required first to identify any weaknesses because a new IPM programme must be technically and biologically feasible (Stoner et al. 1986) if growers are to have confidence in it. It is essential that the programme does not conflict with grower goals such as profit, income stabilisation, meeting cosmetic and quality standards and controlling other pests (Stoner et al. 1986).

Incentives for adopting a IPM programme

Cost advantage is one of the common incentives for implementing IPM (Wearing 1988). Carlson (1978, in Stoner et al. 1986) reported that IPM increased profit stability (decreased variance) compared with the profits of farmers using calendar spray programmes. This is because timing pesticide applications to periods of intense pest pressure maintains quality of yield better than calendar spray programmes (Herman 1994). The period of intense pest pressure may lower product quality in the market, which may increase the returns for quality product and thus cover any extra costs of pest control incurred. Produce grown under IPM programmes can also gain a market advantage through the associated low pesticide input and environmentally friendly/sustainable claims that can be made. IPM research in brassicas has also shown that more effectively timed insecticide applications improve appearance and quality of produce (Herman 1994).

Minimising insecticide applications and using insecticides with a narrow activity (i.e. they target the pest and not other insects) can help avoid the development of insecticide resistance or manage resistance if it is present.

Finally, other pests are included in IPM programmes, where possible, and the potato IPM manual prepared as part of this project, includes notes on all pests and diseases of potatoes so that growers can monitor them as well as PTM. Reducing insecticide use against the main pests of a crop commonly leads to the minor pests and their natural enemies being seen more frequently in the crops.

Refining the technology

The need for further field-scale testing and refinement of the PTM management decision flow chart will be accommodated in a new project that has just received funding (AGMARDT, Vegfed and Heinz-Wattie). This two year project, IPM for PTM in the Hawke's Bay, will continue the commercial development of the IPM programme while validating it for use in the drier Hawke's Bay climate. At the end it is expected that the IPM programme will have been thoroughly tested and the advantages of the programme quantified and documented so that widespread implementation of the programme can proceed. The grower group involved will be trained to use the technology, and the implementation of the programme in their crops will be carefully monitored so the IPM programme can be fine-tuned to ensure it achieves economic control of PTM.

There is a need for discussion within the potato industry on how the programme will be implemented. One recommendation would be a formal training course similar to the current brassica IPM training programme being run by Crop & Food Research. Brassica growers and commercial scouts have been trained in implementing the IPM programme using an IPM handbook and manual. The course involves one-on-one training in the field as well as group instruction and laboratory work and ends with a practical assessment of each trained scout in the field. Such training would ensure all users of the programme are properly trained in using the IPM programme, maximising its success.

8 Conclusions

- The IPM programme developed for PTM during this project is practical and should be able to provide New Zealand potato growers with a tool to maximise the effectiveness of PTM control in their crops and minimise the damage inflicted.

- The system developed for monitoring PTM populations in potato crops is effective at identifying peaks and troughs in the populations, but population size in the foliage does not relate directly to infested tubers because a number of other factors are also involved. A flow chart was developed so that all factors involved in PTM infestation of potato tubers could be assessed to determine the risk of tuber infestation. Where appropriate, cultural control strategies are used or reinforced to reduce the risk of tuber infestation. Insecticide applications are recommended when PTM populations are peaking and the risk of tuber damage if high.
- *Apanteles subandinus*, the only specific PTM parasitoid present in New Zealand, rarely makes a significant contribution to PTM control. Further research is needed to improve parasitism levels and investigate whether other parasitoids used overseas could be introducted into New Zealand.
- An draft IPM manual for potatoes has been prepared. The manual includes information on the pests and diseases of potatoes as well as instructions on systems for monitoring PTM and other pests and diseases. Two flow charts help growers to decide if an insecticide application is needed. Feedback from exemplar growers involved in the project, other key potato industry personnel and Crop & Food Research scientists is now being incorporated into a final version of the manual.
- A new project, recently started, aims to further test the results of this project and make refinements to the IPM programme for its implementation in the Hawke's Bay region.
- It is recommended that the release of the IPM manual is delayed until this two year project is completed. This will allow the extension of the IPM programme to all growers and associated industry personnel to be well planned, ensuring the commercial success of the IPM programme. The IPM manual should be used as a teaching tool which will become a key reference for growers once they are adequately trained to implement the programme in their crops.

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