



Know-how for Horticulture™

**Advancing the
integrated
management of
diamondback moth
(DBM) in brassica
vegetables (July 1997
– June 2000)**

National Diamondback Moth
Project Team

Project Number: VG97014

VG97014

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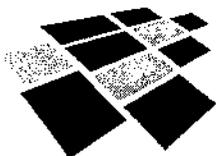
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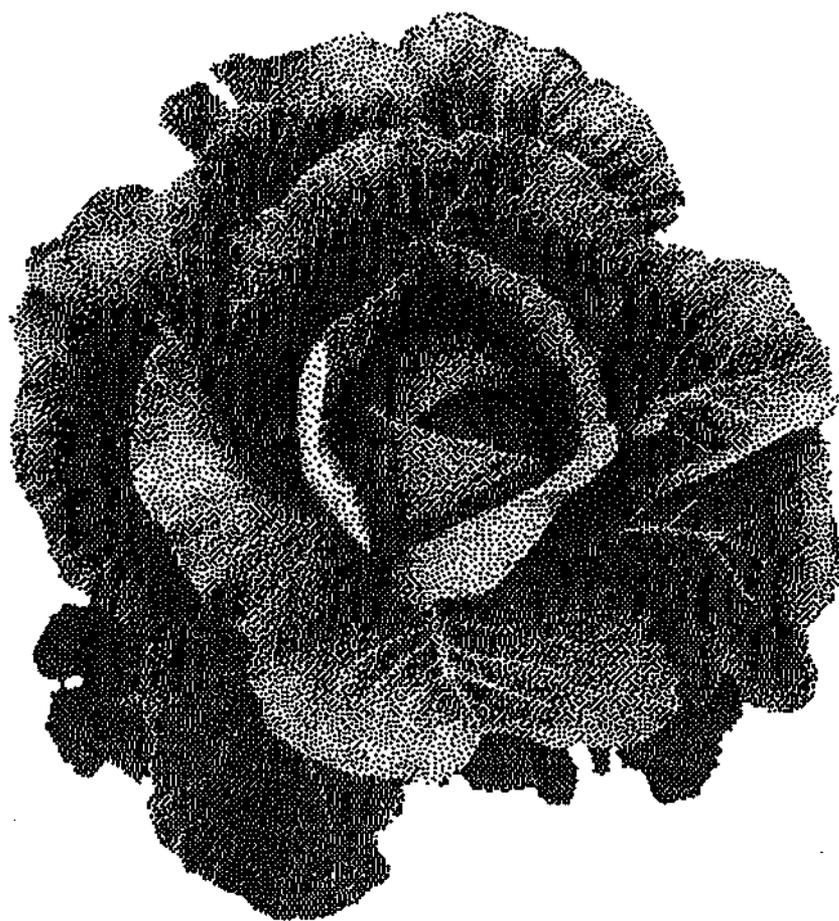


Horticulture Australia

Horticultural Research and Development Corporation

Project VG97014 (30 June 2000) – FINAL REPORT

**Advancing the integrated management of
diamondback moth (DBM) in *Brassica* vegetables
(July 1997-June 2000)**



National Diamondback Moth Project Team

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This report details the research and development undertaken in Project VG97014 on management of diamondback moth, *Plutella xylostella* (L.). Main findings, industry outcomes and suggested areas of future research are discussed.

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July 2001

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APPENDIX 3

Report of Second Project Workshop, Waite Campus, Adelaide, 28th-29th July 1999

MEDIA SUMMARY

Diamondback moth (DBM) is a key *Brassica* vegetable pest with a marked ability to rapidly become resistant to insecticides.

The aims of this project were to improve current insecticide-based DBM control, to limit the development of insecticidal resistance by all *Brassica* pests, and to work towards the development of cost-effective alternative controls. The perceived benefits at the outset were: improved production economics, an increased lifespan for new insecticides and a reduced reliance on frequent spraying.

The key outcomes (and conclusions) are:

- An improved awareness of good pest management and insecticide resistance management (IRM) principles and practices by Australian *Brassica* vegetable growers, and a significant increase in the adoption of these practices, in particular an adherence to a “two-window” IRM strategy. The means of achieving these changes included:
- The production and distribution of the *Brassica Integrated Pest Management (IPM) Handbook*, a modular compendium of practical IPM guidelines, to growers throughout Australia.
- Numerous **other communication outputs**, including DBM websites, a DBM developmental rate calculator, numerous newsletters and articles and the holding of field days in each State.
- The demonstration of “best-practice” boom-spray use in *Brassica* crops at **spray application roadshows** in each State.
- The development and industry-wide promotion of a “two-window” IRM strategy. (Adherence to this strategy is likely to increase the effective life of the new DBM insecticides by at least 2 to 2.5 times.)
- Fostering the uptake of **crop scouting** with a pilot training program and the development of a time-saving scouting technique.
- The independent assessment and publicizing of the effectiveness of 5 **new insecticides** against DBM and their impact on natural enemies.
- Important groundwork towards the development of alternative control tactics:
- Findings about **DBM dispersal** suggest that (i) alternative control tactics and the “2-window” IRM strategy can be successfully implemented independently on individual farms, and (ii) for transgenic crops containing toxins of the insect pathogen *Bacillus thuringiensis*, refuge crops to help manage resistance will need to be grown close by.
- The **mating-disruption** control tactic using a new DBM pheromone blend was assessed.

Future R&D is required to foster the wider adoption of crop scouting, to monitor resistance levels in DBM populations on commercial properties in all States, and to take advantage of the availability of the new “softer” DBM insecticides by developing practices that foster the beneficial role of natural enemies.

The key recommendations to industry are adherence to the IRM strategy and related pest management practices as outlined in the *Brassica IPM Handbook*, and in particular the use of crop scouting to allow well-informed control decisions.

TECHNICAL SUMMARY

The Problem

Diamondback moth (DBM), *Plutella xylostella* (L.), has attained major pest status in *Brassica* vegetable crops around the world. Insecticide use for control of other pests has disrupted natural enemies and selected for insecticide resistance in DBM. In Australia, resistance to organophosphate and synthetic pyrethroid insecticides is widespread in DBM populations in vegetable crops. In extreme cases, damage from larval feeding and pupal contamination renders produce unmarketable and damaged crops have been ploughed in. Prior to the commencement of this project, the main causes of the pest management problems faced by Australian growers of *Brassica* vegetables were a limited understanding of pest biology, over-reliance on insecticides and poor spray timing.

The Project Science

Sampling

The efficiency and reliability of presence-absence sampling in the classification of DBM population levels was investigated. Research and validation of sampling methods was translated into a pilot training program for crop scouts in Victoria.

Dispersal

Short distance dispersal of male and female DBM in *Brassica* vegetable crops was studied by mark (fluorescent dye)-recapture (delta pheromone traps and sticky buckets) techniques.

Insecticide Performance

The relative efficacy of five new DBM insecticides was assessed in field experiments. The relative toxicity of weathered foliar residues of these insecticides to the cabbage white butterfly (*Pieris rapae*) parasitoid, *Cotesia glomerata*, the aphid parasitoid, *Diaeretiella rapae*, and the DBM parasitoids, *Diadegma semiclausum* and *Diadromus collaris*, was assessed by 24 exposures to excised leaf portions in ventilated arenas.

The individual effects of milk powder and dimethoate on the efficacy of *Bacillus thuringiensis* for DBM control were field assessed.

Insecticide Resistance Management

By the mid-1990s there was wide-scale organophosphate and synthetic pyrethroid resistance in many DBM populations in Australian *Brassica* vegetables. A "two-window" rotation strategy was developed in conjunction with AVCARE to prolong the effective lives of the four new insecticide groups registered during the life of this project. A national resistance monitoring program was established in 1999 to test field populations of DBM from each State with a variety of new and long-established insecticides in a leaf-dip bioassay.

Oviposition studies

Egg recruitment and egg placement by DBM and cabbage white butterfly and the effect of surfactants on DBM oviposition has been investigated.

DBM Management in Seedling Nurseries

Current pest management practices and the potential for the alternative use of *Trichogramma* egg parasitoids have been investigated.

Major research findings and industry outcomes

Sampling

- A time-saving "presence-absence" sampling technique for DBM larvae has been developed, validated and promoted to growers and pest scouts.

Dispersal

- DBM moths do not fly far within actively growing host crops. The average moth dispersal range is estimated at 12-60 m and over 95% of moths are expected to remain within 200m of the release point.
- Tentative conclusions drawn from the dispersal studies include:
- For management strategies which rely on the isolation of the source and target populations, such as resistance management by insecticide rotation, these populations should be separated by at least 2.0 km.
- For strategies which rely on minimal mixing of source and target populations, such as crop-break and mating disruption, the control (target) area should be at least 600 m away from non-control (source) areas.
- Refuge populations set up for dilution of resistance levels should be placed within 50-60 m of the target population.
- For pathogen auto-dissemination using traps, the trap interval should be less than 60 m and for maximal effect should be less than 20 m.

Insecticide Performance

- The five new insecticides, Regent[®] (fipronil), Secure[®] (chlorfenapyr), Success[™] (spinosad), Proclaim[®] (emamectin benzoate) and Avatar[®] (indoxacarb) were equally effective against DBM.
- These new insecticides differ markedly in their toxicity to parasitoid wasps.
- Neither the addition of milk powder nor dimethoate to *Bacillus thuringiensis* affected the spray treatment efficacy against DBM larvae.
- These findings have been made available to relevant chemical companies, growers and crop scouts to assist with *Brassica* pest management, and are being used to formulate pest management recommendations and refine the "two-window" insecticide resistance management (IRM) strategy.

Insecticide Resistance Management

- The "two-window" IRM strategy has been progressively revised since its introduction in November 1997. The chosen calendar periods provide similar market-share for the insecticides in each window, and take account of the dynamics of the pest complex in each State. The strategy has been actively promoted, assisted by the distribution of glossy colour flyers to all growers (updated December 1999). Adherence to this strategy is likely to increase the number of effective applications of these new insecticides at least 2 to 2.5 times.
- Baseline toxicity data for all of the new insecticides registered or soon to be registered for DBM have now been obtained for one population of DBM from each state in Australia.
- The resistance screening service has documented resistance levels to synthetic pyrethroid and organophosphate insecticides for different States. This information assists in property and regional level pest management
- It has been experimentally demonstrated that piperonyl butoxide synergism is insufficient to 'rejuvenate' SPs for the control of Queensland DBM populations.

Oviposition studies

- Seedlings treated with Pulse[®] had a significantly higher number of eggs than all other surfactant treatments.
- The main egg-laying sites of DBM and cabbage white butterfly on newly transplanted cabbage plants (*Brassica oleracea* cv. Green Coronet) were identified.

DBM Management in Seedling Nurseries

- Most seedling growers identify DBM as the key pest of *Brassica* seedlings. Intensive DBM spray programs in nurseries have important implications for the IRM "two-window" strategy. Promotion of the IRM strategy in seedling nurseries is of major importance.

Recommendations

The key recommendations to industry are adherence to the IRM strategy and related pest management practices as outlined in the *Brassica* IPM Handbook, and in particular the use of crop scouting to allow well-informed control decisions.

Contribution to new technology

The "presence-absence" scouting plans, the "two-window" IRM strategy, the toxicity rating of the 5 new insecticides, the baseline DBM susceptibility data for these new insecticides and the quantification of DBM local movement patterns are significant contributions to the development of new DBM management technologies.

Future work

Management of DBM is still chemically intensive in Australian vegetable crops. The first steps have been taken in making growers aware of the pest's biology and the potential for improving its management and reducing spraying through crop scouting. Growers have been able to realize short-term benefits by improving spray application and substituting the new insecticides and *Bacillus thuringiensis* for the old insecticides (which were compromised by high levels of resistance), and the long-term benefit of an extended lifespan for the new insecticides by adhering to the "two-window" IRM strategy.

The next step is to enhance the biological components of the IPM program and to provide more IPM tools. A second phase of the national DBM project will endeavour to measure and enhance the impact of beneficial insects in commercial vegetable crops. Insecticide resistance management will be improved through continuation of the national resistance monitoring program and continued investigation of movement of DBM between vegetable crops and other host plants. Innovative control tactics such as use of adulticides, speedling dissemination of biocontrol agents and selection of less susceptible cultivars will be investigated as potential IPM tools.

INTRODUCTION

Historical background to project

Diamondback moth (DBM), *Plutella xylostella* (L.), has attained major pest status in *Brassica* vegetable crops around the world. Use of synthetic insecticides for control of other pests has disrupted natural enemies and selected for insecticide resistance in DBM. DBM control problems in Australia first occurred in the Lockyer Valley, Queensland in the early 1980s. Resistance to synthetic pyrethroids has since been detected in DBM populations in all states. Damage is caused by larvae tunnelling into the heads of cabbage and Brussels sprouts and contamination of produce due to presence of pupae inside broccoli florets. In extreme cases, produce has been unmarketable and damaged crops have been ploughed in. Limited understanding of pest biology, reliance on insecticides and poor spray timing were the main causes of problems faced by growers of *Brassica* vegetables in Australia, prior to commencement of the project.

Why it was undertaken

Diamondback moth is a continuing problem affecting *Brassica* vegetables in Australia, an industry which is worth over \$150 million per year. In the summer/autumn of 1993/94, diamondback moth numbers in Victoria were high and growers experienced insecticide control failures. Supermarkets rejected produce due to feeding damage and the presence of larvae and pupae in cabbage, broccoli and cauliflower. Growers responded by using repeated insecticide applications and found themselves on a "chemical treadmill" in an attempt to control the pest. These problems resulted in researchers and industry groups developing a national HRDC-funded project to examine the development of an Integrated Pest Management (IPM) strategy for diamondback moth.

Significance for industry

The project promotes Integrated Pest Management as a method for dealing with diamondback moth and other pests in *Brassica* crops as a solution to the industry's problem of dependence on insecticides. The strategic use of insecticides with timing of applications based on information gained through crop monitoring has been addressed and will help to reduce insecticide use without jeopardizing quality of produce. Other aspects of strategic chemical use such as setting up spray rigs to achieve good coverage, using label rates and avoiding tank mixes of multiple insecticides, have also been promoted. Reducing pest pressure through non-chemical management practices is also recommended and includes using clean seedlings, ploughing in crop residues, growing vigorous plants to resist pests and diseases and using crop breaks to reduce DBM numbers and levels of insecticide resistance. Use of these tactics will help the *Brassica* vegetable industry overcome its problem with control of diamondback moth, a pest that has become resistant to synthetic pyrethroid insecticides.

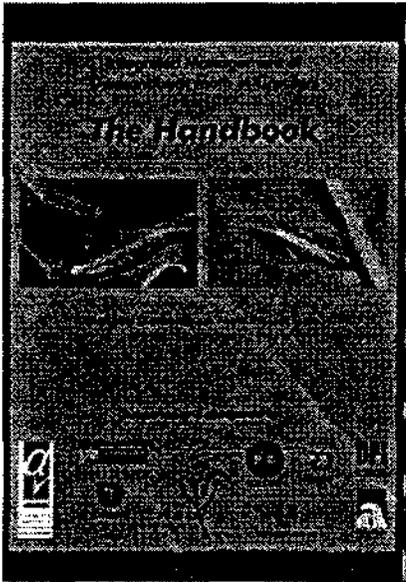
Aims

The broad objectives of the project were to address the short-term need of crucifer vegetable growers to improve their control of diamondback moth (DBM) with currently-available insecticides, to limit the further development of insecticidal resistance by DBM and other crucifer pests, in particular to new insecticides, and to address the longer-term need to develop cost-effective alternative methods of DBM control.

TECHNOLOGY TRANSFER

Communication outputs

The major communication outputs of the project included *The Handbook* which was sent to all *Brassica* growers and updated several times during the project, spray application roadshows held in each state, construction of DBM IPM web sites (Agriculture Victoria and SARDI) (<http://www.nre.vic.gov.au/agvic/ihd/projects/dbm.htm>, http://www.sardi.sa.gov.au/crops/entomolo/dbmipm/aus_dbm_ipm.html), field days and grower meetings held in each State and newsletters, media articles and radio interviews.



Activities undertaken to ensure adoption of the R&D throughout the life of the project:

VICTORIA

Nancy Endersby & Peter Ridland, Agriculture Victoria

- **Workshops and field days for growers:**
Spray Application Roadshows (Werribee Sth 31/3/98, Cranbourne 2/4/98), QA Workshop Vegetable Growers for Costas 24/6/98, Rhône-Poulenc spray application technology evening, Werribee South 16/11/98, E.E. Muir & Sons spray application technology evening, Cranbourne 17/11/98, National DBM Project display at Werribee Vegetable Expo 6/5/99, *Brassica* pest identification workshop for new broccoli growers at Winchelsea for Riverside vegetables (19/1/00)

- **Meetings and presentations for vegetable growers**
Presentation of DBM IRM strategy to vegetable growers at

E.E. Muir & Sons' Phosdrin® meeting, Bear Inn, Cranbourne (22/10/98), Launch of DBM Insecticide Resistance Management Strategy in conjunction with Cyanamid's launch of Secure™ (10/11/98), Werribee Vegetable Expo Seminar: National DBM Project: your vegetable levy in action! (04/05/99), Nancy Endersby was invited by Rachel Lancaster of Agriculture Western Australia to give a presentation about the project and crop monitoring at a field day which was well attended by cauliflower growers from Manjimup and Albany. Nancy also spoke about insecticide resistance at the launch of the WA version of the 99/00 DBM Insecticide Resistance Management strategy by Françoise Berlandier at the Canningvale markets in Perth on 8th October 1999.

- **Presentations to students and apprentices involved with the vegetable industry:** Bendigo Institute of TAFE Advanced Certificate of Horticulture & nursery apprentices (23/10/97), Peninsula TAFE nursery trainee group (17/06/98), Swinburne University 1st year Diploma of Horticulture students (12/11/98), Glenormiston College Vegetable Apprentices (1st year students) (14/05/99)
- **Workshops with vegetable industry bodies and related industries:**
Crop Scouting Training days for E.E. Muir & Sons (1/12/98, 26/11/99) plus ongoing training in the field, IPM session for AgrEvo as part of CHS workshop (18/11/97), IPM workshop for Dow AgroSciences, Crop Health Services (12-13/10/98), Crop Scouting Training day for Costa's (02/03/99), Forage *Brassica* workshop at Warrnambool (resellers, farmers, DNRE) (19/04/99).

NEW SOUTH WALES

Leigh James, NSW Agriculture

- Coordinated the preparation, publication and national distribution of the 1998-99 (the first year featured the new chemistry products Secure[®] & Regent[®] in 2 windows), 99-00 (Secure[®] or Success[®] & Regent[®]) & 2000 (Secure[®] or Success[®] & Regent[®] or Proclaim[®] in 2 windows) DBM IRM strategy flyers.
- Coordinated the preparation, publication and national distribution of the DBM IPM extension folder cover and initial contents in 1998. Chapters included; *Integrated Pest Management – What Does it Really Mean?*, *Crop Monitoring – the Key to Informed Decision Making*, *Insecticide Resistance Management – Getting the Best From Your Sprays While Getting the Better of DBM*, *The Role of Bacillus thuringiensis in Managing DBM*, and *How Fast Does DBM Develop?*
- Coordinated the preparation, publication and national distribution of the new DBM IPM extension folder contents in 2000. New chapters included; *Ensuring Good Spray Coverage*, *Brassica Information on the Internet – Pests, Diseases, & Agronomy*, and *Sources of Information About Brassica Crops, Pests, Diseases, Disorders & Agronomy*.
- Author of DBM IPM folder chapters on Insecticide Resistance Management (1998) & Good Spray Coverage (2000). Coauthor and editor of most chapters.
- Presented the unrefereed paper, *National Diamondback Moth Project – Advancing the Integrated Management of DBM in Crucifer Vegetables* at the 1997 NSW Vegetables Conference in September at Bathurst and an updated version at the 1999 Sydney Basin Field Grown Vegetables Conference in July at Richmond.
- Presented the 1999-00 DBM IRM strategy and key DBM management points at the Annual Australian Chinese Growers Association Field Day held in October 1999 at Leppington.
- Prepared the refereed paper *Review of the National Diamondback Moth Project – Advancing the Integrated Management of DBM in Crucifer Vegetables* for the proceedings of the 2000 Sydney Basin Field Grown Vegetables Conference held in July at Richmond and an updated version for the 2000 NSW Vegetables Conference at Cowra.
- The current DBM IPM extension folder chapters & IRM strategy were also included in the proceedings of the **Sydney Basin Field Grown Vegetables Conference** in 1999 & 2000.
- The current DBM IPM extension folder & IRM strategy were distributed at the 1999 New South Wales Vegetables Conference held in September at Bathurst.
- Conducted the NSW launch of the DBM IPM extension folder and the 1998-99 (first year) DBM IRM strategy in conjunction with the State launch of Secure[®] at the University of Western Sydney-Hawkesbury, Richmond in November 1998. The IPM extension folder & IRM strategy was distributed to Sydney basin Ag chemical resellers and hort farm advisers at the UWS-H launch and also by subsequent personal delivery.
- The IPM extension folder & IRM strategy was also direct mailed to Ag chemical resellers and hort farm advisers in Central West NSW in December 1998-January 1999.
- Held a meeting at Bathurst to launch the DBM IPM extension folder and 1998-99 DBM IRM strategy to *Brassica* growers in the Central West of NSW in October 1998. Coordinated the development of a Central West DBM IRM for 1998-99.

- Held a meeting to update Central West *Brassica* growers about new DBM IPM extension folder chapters and the 1999-00 DBM IRM strategy at Bathurst in November 1999 in conjunction with a session on Success[®].
- Conducted 2 spray application demonstrations at night lead by Peter Hughes QDPI at Castlereagh and Freemans Reach in winter 1998.
- As an accredited Chemcert instructor, I held 3 subsequent spray application demonstrations in the Hawkesbury Valley using fluorescent dye & a black light during 1998-99.
- Conducted a Field Day in January 1999 at Castlereagh to assess PSO & Bt and spray application technology trials for DBM control in collaboration with the University of Western Sydney-Hawkesbury.
- In collaboration with Workcover NSW, conducted urine, blood & apparel testing of 25 *Brassica* vegetable growers pre & post mevinphos use in March 1999. Analysis was performed by UC, Riverside. Results may be used to help substantiate to the NRA why there should be continued access & use of mevinphos by Australian *Brassica* vegetable growers.
- Promotion of the 2000 DBM IRM strategy in March at Sydney Markets in conjunction with Proclaim[®] launch.
- Formed a Hawkesbury Valley *Brassica* grower cluster group in 1998. This group of about 25 core growers met informally as often as monthly to discuss best practice & developments in *Brassica* production technology, particularly the National Diamondback Moth & Clubroot Projects.
- A significant number of growers have purchased hand-lenses/magnifying glasses during the past few years and practise crop monitoring. Compared to the low level of expertise prior to 1996-97, many are now competent in identification of insect pests & beneficials. Most can recognise DBM eggs, larvae, pupae & moths.
- The plan in NSW to encourage the adoption of the IPM/IRM strategy is considered as being successful due the extensive promotion of the concepts and practices at a number of extension activities such as spray application demonstrations, industry conferences and the *Brassica* cluster group etc. The project and IPM/IRM strategy also received excellent support and promotion by Ag chemical reseller and chemical company representatives during their day-to-day and group activities. On-going questioning of growers and industry representatives at extension activities throughout the duration of the project verify that the level of awareness and knowledge about the principles and practices of the new IPM/IRM strategy rose from a low level at the start of the project in 1997 to a competent level in 2000. Grower surveys and testimonials indicate that DBM control difficulties in the Sydney basin are significantly less now than they were in 1996-97.

WESTERN AUSTRALIA

Françoise Berlandier and Stewart Learmonth, Agriculture Western Australia

- Presentation to growers (FB), Manjimup cauliflower group, Manjimup (30 July 1997)
- DBM field day, Carabooda (Northern Metro Growers) (FB) (Sep 1997)
- Presentation about DBM and Window IRM strategy, Manjimup (SL) (1997)
- Regent® launch, gave talk about DBM and IRM strategy, Perth (FB) (1997)
- Grower spray road show with Peter Hughes (QDPI), Perth (FB) (12 Oct 1998)
- Grower spray road show with Peter Hughes (QDPI), Manjimup (SL) (13 Oct 1998)
- Gave talk to Manjimup cauliflower group, Manjimup (FB) (31 Aug 1999)
- Update on IRM and DBM management, Manjimup (SL) (1999)
- Grower meeting at Canningvale, Perth (FB) (Oct 1999)
- Gave talk to Horticulture TAFE students (FB) (Feb 2000)
- Article in *WA Grower* magazine (FB) (Feb 2000)
- Gave talk at Proclaim® launch to Northern Metro growers (FB) (April 2000)
- Gave talk at Proclaim® launch to Southern Metro growers (FB) (April 2000)
- Gave talk at Proclaim® launch to Southern Metro growers (SL) (April 2000)

FB = F. Berlandier, SL = Stewart Learmonth

TASMANIA

Lionel Hill, Julia French, Felicity Wardlaw, DPIWE Tasmania

- 140 *Plutella* Handbooks with the first batch of chapters were distributed via two processing company mail systems and supplemented by some group meetings as detailed in Extension Outputs. We are still checking the distribution system to ensure that all levy payers receive outputs. The unavailability of grower lists continues to confound extension efforts.
- Five field-evenings were conducted and well attended. They demonstrated deposition of sprays using a fluorescent dye.
- Dye was supplied to field officers from the major *Brassica* seed-grower to run several evenings for their growers.
- One field day exhibit of a *Brassica*-pest poster and display of live beneficials was held on the north-west coast.
- Two information sessions were held with private consultants and processing company field officers to exchange information.
- Two information sessions for growers or consultants were held with Nancy Endersby, Knoxfield IHD, as guest speaker.
- Three information sessions about novel insecticides, hosted by the leading retailer/advisory consultant, were attended and the opportunity used to exchange information on grower practices and adoption of novel insecticides.
- Several communications with and two visits to the sole and dominant seedling nursery were undertaken. One visit included Nancy Endersby. We also examined two samples of speedlings to provide the consulting agronomist with feedback on the success of his control strategy. This outdoor nursery supplying 95% of the Tasmanian *Brassica* industry is a unique feature of the state's industry structure.
- Five or so radio interviews were broadcast on ABC Rural Radio to present IPM information and to introduce the new DPIWE IPM-agronomists to the industry.
- Five articles were published in the state agricultural journal, published by DPIWE that goes to all farmers.
- Several articles were published in *Tasmanian Country*, *Advocate* and *Examiner* newspapers to promote *Brassica* IPM and to introduce the new DPIWE IPM-agronomists to the industry.
- Several faxes to leading private-sector consultants were circulated with project reports and reminders about IPM methods and forecasts of pest abundance.

QUEENSLAND

Bronwyn Walsh and John Duff

- One presentation explaining resistance strategy and significance of pests and beneficial identification and control strategies to reseller focus group.
- Two presentations at product launches explaining the resistance strategy.
- Three revision courses on *Brassica* pest and beneficial identification with *Brassica* industry
- Newspaper article for local paper on general project activities. See attached.
- Ten presentations on project activities or up-dated resistance strategy at *Brassica* industry meetings.
- Project's activities presented to QDPI and interstate colleagues at Qld Leafy and Heading Vegetable Workshop
- Two meetings presenting HRDC project activities to ACIAR team
- Meeting to organise the Fourth International DBM Workshop which is to be held in Melbourne, November 2001

SOUTH AUSTRALIA

Greg Baker, Jianhua Mo, Michael Keller

1997

An evening grower meeting was held on 9 December 1997 at the Virginia Horticultural Centre to introduce the HRDC DBM Project team and the Project objectives, to discuss insecticidal resistance management (IRM) principles and to present the newly-formulated DBM insecticide rotation "two-window" strategy. A total of 14 growers, resellers and crop monitors were in attendance. Greg Baker provided an overview of the Project, Dr Rick Roush discussed IRM and the "two-window" strategy, Dr Mike Keller presented a photo-illustrated talk about the beneficial insects of *Brassica* vegetables and the impact on an important DBM parasitoid of the 4 new insecticides being introduced into this market, and Dr Peter Cameron from the New Zealand Crop Research Institute discussed the New Zealand experience with crop monitoring and presence-absence sampling for *Brassica* pests.

1998

Spray application roadshow: Invitations were mailed out in the first week of April to 38 *Brassica* growers seeking their attendance at an early-evening spray application roadshow on 20 April 1998 at a prominent grower's property at Virginia. Invitations were also extended to crop monitors and technical personnel from the major chemical companies and reseller agencies that service this industry.

The presentation format was the same as described for the Victorian workshops. Thirty four growers and 11 others were in attendance. The participants keenly appreciated both the presentation on spray application principles and the field demonstration using UV fluorescent dye.

SA Vege R&D Forum: Greg Baker participated in the South Australian Vegetable Industry R & D Forum held at Virginia on the 10th July, 1998. Greg provided an update on HRDC-funded DBM and WFT R&D and technology transfer (TT) activities, and led a *Brassica* grower group through a priority setting session for future *Brassica* R&D and TT.

Grower meeting: On 9 December 1998 an evening meeting was held for *Brassica* growers at the Virginia Horticulture Centre in conjunction with Cyanamid. An update on DBM integrated pest and insecticide resistance management, on the place of the newly-launched Secure[®] in the DBM 2-window insecticide resistance management (IRM) strategy and on the 1997-98 findings and 1998-99 research plans for the National DBM project was presented.

1999

SA Vege R&D Forum: At the R & D Forum and Priority-setting meeting for SA vegetable growers, held on 3 August 1999 at the Virginia Horticulture Centre by Craig Feutrill (SA Vegetable IDO), Greg Baker and Jianhua Mo respectively addressed these meetings about the objectives and outcomes of the National DBM project. The *Brassica* growers in attendance were unanimous that DBM be listed as the primary R&D issue.

Greg Baker gave a presentation on DBM pest management and the National DBM project at the **Central West Vegetables Conference** at Bathurst on 22 September 99.

National and state publicity for the National DBM project and the 2-window IRM strategy was gained from articles in the **October 1998** issue of the **Good Fruit and Vegetable** magazine and the **January 1999** issue of **The Grower** respectively.

A **Pest Management Update** newsletter was faxed out to all *Brassica* growers on Craig Feutrill's SA *Brassica* grower contact list in November 1999.

2000

A **Pest Management Update** newsletter was faxed out to all *Brassica* growers on Craig Feutrill's SA *Brassica* grower contact list in February 2000.

Greg Baker gave a presentation on DBM pest management and the key findings of the 1997-2000 National DBM project at the **Sydney Basin Vegetables Conference** at Richmond on 15 July 2000.

An article in the **May 2000** issue of **The Grower** publicized the visit of the New Zealand *Brassica* IPM entomologist Graham Walker, and the respective NZ and Australian experience with *Brassica* crop scouting.

FUTURE TECHNOLOGY TRANSFER ACTIVITIES

The technology transfer begun in this project will be continued and developed in a new national project 'Implementing the Pest Management of Diamondback Moth', funded by HRDC to run from 1st July 2000 to 30th June 2003. Field days will be held in each state each year, training of crop scouts will continue and workshops will be conducted in conjunction with the HRDC project 'IPM for Brassicas'.

An IPM Adoption Coordinator will formulate, refine and help implement the communication strategy of the project, disseminate research results and recommendations to the farming community and its advisers, seek feedback from the relevant stakeholders and facilitate communication among the researchers, extension officers, IDO's, growers, crop scouts and chemical companies and resellers.

RESEARCH REPORTS

Evaluation of sequential binomial sampling plans for decision-making in the management of the diamondback moth (*Plutella xylostella*) (Plutellidae: Lepidoptera)

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Introduction

Diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is a key pest of the important vegetable group that includes cabbage, broccoli, cauliflower, collards, rapeseed, mustard, and Chinese cabbage. Pressure from the emergence of insecticide resistance has forced the vegetable industry to implement some form of integrated pest management (IPM) strategy or insecticide resistance management (IRM) (Heisswolf et al, 1997). However, adoption of these strategies by growers has been slow. In Australia, most growers still spray their crops largely on a calendar basis. To persuade more growers to adopt monitoring-based spray programs, easy-to-use and time-efficient sampling plans are needed, as well as extension effort to convey the benefits of IPM and IRM.

One sampling technique that is easy-to-use and has the potential to be time-efficient is binomial sampling. Binomial sampling provides an attractive alternative to enumerative sampling as the abundance of the target organism in a sample unit is recorded in only one of two categories. In its simplest form, only presence-absence data are collected. The advantage of binomial sampling becomes more apparent as the degree of population aggregation increases, the density of the population increases, and the pests become smaller in relation to the dimensions of the sampling unit (Jones, 1994). Although DBM does not form clusters, its earlier instars are quite small (< 5mm) and easily overlooked on their leafy host plants. The larvae also tend to wriggle away and drop down when disturbed. As a result, accurate recording of the number of larvae on a plant can be very difficult under field conditions. Finally, binomial information in itself (i.e. without converting to density) has significant practical value. For most growers, the percentage of infested plants is perhaps all that is needed to make a spray/no-spray decision.

This paper investigates the efficiency and reliability of presence-absence sampling in the classification of DBM population levels under Wald's sequential probability ratio test (SPRT) using action thresholds commonly used by *Brassica* vegetable growers in Australia. There have been no published reports of binomial sampling for DBM. A sequential sampling plan based on enumerative data was developed for DBM monitoring in Malaysia (Hing and Sivapragasam, 1996). Application of this sampling plan elsewhere is limited because of its use of relatively high action thresholds (7-14 larvae/plant) and involvement of a distribution-specific parameter (k of the negative-normal distribution).

Methods

1. Data description

Sampling data from four host crops, Brussels sprouts, cabbage, cauliflower and broccoli, collected in three states, South Australia (SA), Victoria (Vic), and Queensland (Qld), were used in this study. Sample sizes ranged from 35 to 300 plants. Data sets with a sample size of less than 100 plants were used for setting up the sampling plans and the rest for validating the sampling plans.

2. Sampling Plans

Under SPRT, a population under a binomial distribution is classified as below or above a prescribed action threshold (AT) according to the position of the sample point (n , T_n) relative to the lower and upper stop lines determined below (Fowler and Lynch, 1987):

$$T_{lower} = \frac{\ln \frac{\beta}{1-\alpha}}{\ln \frac{p1(1-p0)}{p0(1-p1)}} + \frac{\ln \frac{1-p0}{1-p1}}{\ln \frac{p1(1-p0)}{p0(1-p1)}} n \quad (1)$$

$$T_{upper} = \frac{\ln \frac{1-\beta}{\alpha}}{\ln \frac{p1(1-p0)}{p0(1-p1)}} + \frac{\ln \frac{1-p0}{1-p1}}{\ln \frac{p1(1-p0)}{p0(1-p1)}} n$$

where n is the sample size, T_n the accumulated number of infested plants sampled, α the error rate for recommending control when in fact the infested proportion is below the AT, β the error rate for recommending no control when in fact the infested proportion is above the AT, and p_0 and p_1 the nominal proportions below and above the AT respectively. If $T_n < T_{lower}$, the population level is considered below the AT, and vice versa. If $T_{lower} \leq T_n \leq T_{upper}$, the population level relative to the AT can not be classified and more plants need to be sampled.

In this study, α was set to 0.1 and β to 0.05. The lower β value was chosen to guard against the error of recommending no-control decision when control is needed. Based on personal survey of local *Brassica* growers, four ATs each were investigated for the classification of proportions of infested plants (0.15, 0.25, 0.35, and 0.45) and larval density (0.2, 0.4, 0.6, and 0.8 larvae/plant). For the classification of proportions of infested plants, p_0 and p_1 were set to 0.05 below and above the AT, respectively. For the classification of larval density, p_0 and p_1 were set to 0.1 larvae/plant below and above the AT, respectively.

3. Conversion between proportions of infested plants and densities

Classification of mean density with presence-absence sampling requires the conversion of density-based ATs into proportion-based ATs. This was done with the inverse of Gerrard and Chiang's empirical equation (1970):

$$\ln(-\ln[1-p]) = \gamma \tilde{A} + \delta \tilde{A} \ln(m) \quad (2)$$

where p is the proportion of plants infested with larvae, m is the larval density, γ and δ are parameters to be estimated. This equation was used in favour of distribution-based equations because of its independence of underlying distributions.

4. Evaluation

Performance of the sampling plans was evaluated with the operational characteristics (OC) and the average sample number (ASN) curves. The OC curve is a plot of the probability of "no intervention" (or no spray) versus the true population level (larval density or proportions of plants with larvae in this study). For each sampling plan, ranges of population levels for which $OC \leq 0.05$ or $OC \geq 0.95$ (OC5-95) was determined. The ASN curve is a plot of average sample number over the population level. As growers do not normally sample more than 50 plants in their monitoring of DBM populations, ranges of population levels for which $ASN \leq 50$ plants (ASN50) was determined for each sampling plan. Both the OC5-95 range and the ASN50 range consist of two separate sub-ranges, one each on either side of the AT. Calculations of the OC and ASN functions were performed with the algorithms of Nyrop and Binns (1992).

5. Validation

Validation of the sampling plans was performed by simulated re-sampling of 20 independent data sets. The sample sizes of these data sets ranged from 100 plants to 600 plants. The proportion of infested plants was 0.02-0.56 and the larval density was 0.02-1.46 larvae/plant. Individual plants

within a data set were randomly selected with replacement. The initial sample size was set to 10 plants and the increment to 1 plant. Sampling was terminated when a decision could be made with regard to the population level relative to the AT. For each AT, 1000 simulations were run, at the end of which the percentages of simulation runs which correctly classified the population levels relative to the ATs (Correct%) and the average sample size (ASN_{sim}) were calculated.

Results

1. Classification of proportions of infested plants

Sampling plans for the four proportional ATs are given in Table 1. The OC curves under these sampling plans were parallel curves centred around their respective ATs (Figure 1). The OC5-95 ranges were found 0.07 proportion units below the ATs and 0.05-0.06 proportion units above the ATs. These OC5-95 ranges represented 87-88% of all possible population levels (0 - 1).

Table 1. Sequential stop lines at 4 proportion-based action thresholds and 4 density-based action thresholds.

Action Threshold	Upper stop line (T_{upper})	Lower stop line (T_{lower})
15% plants infested (0.15)	$2.7762 + 0.1452 n$	$-3.5643 + 0.1452 n$
25% plants infested (0.25)	$4.1768 + 0.2477 n$	$-5.3625 + 0.2477 n$
35% plants infested (0.35)	$5.0953 + 0.3489 n$	$-6.5418 + 0.3489 n$
45% plants infested (0.45)	$5.5524 + 0.4497 n$	$-7.1285 + 0.4497 n$
0.2 larvae/plant	$2.0580 + 0.1441 n$	$-2.6422 + 0.1441 n$
0.4 larvae/plant	$4.0978 + 0.2709 n$	$-5.2610 + 0.2709 n$
0.6 larvae/plant	$5.8037 + 0.3716 n$	$-7.4512 + 0.3716 n$
0.8 larvae/plant	$7.2786 + 0.4556 n$	$-9.3448 + 0.4556 n$

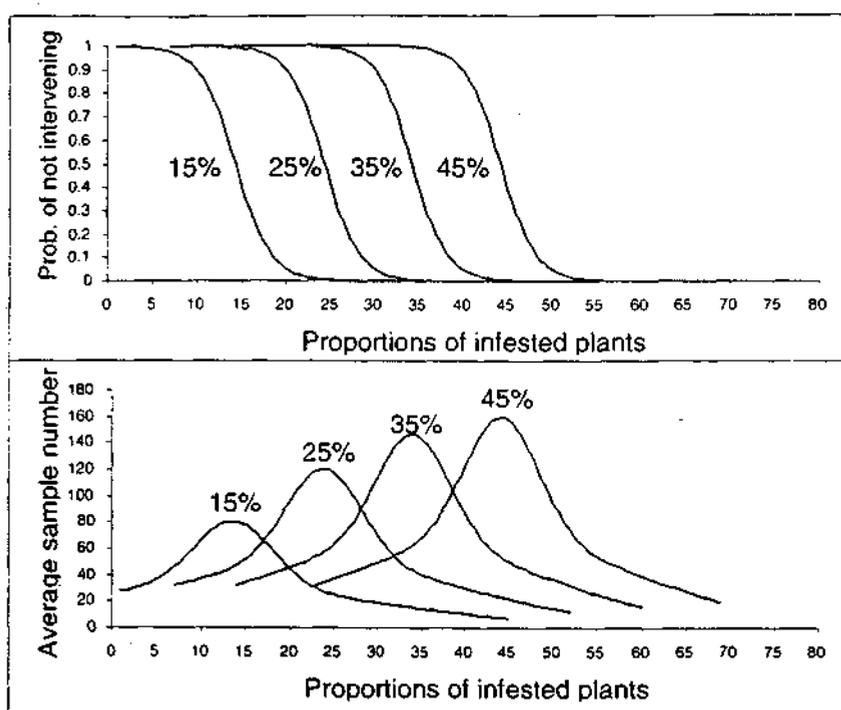


Figure 1. Operating characteristic (OC, =probability of not intervening) and average sample number (ASN) functions for the classification of proportions of plants infested with DBM larvae at 4 action thresholds (15%, 25%, 35%, and 45% infested plants) using sequential presence-absence sampling.

As the AT increased from 0.15 to 0.45, peak ASN values increased from 81 plants to 160 plants (Figure 1). The ASN50 ranges were found 0.08 - 0.15 proportion units below the ATs and 0.05 - 0.12 proportion units above the ATs, with larger separation distances associated with the higher ATs (Table 2). Overall, these ASN50 ranges represented 73-87% of all possible population levels, with higher representation shown by sampling plans for the lower ATs (Table 2).

Results of the re-sampling analyses of the sampling plans for the classifications of proportions of infested plants were shown in Table 3. Under the sampling plan for AT=0.15, the percentage of correct decisions was 100% for all data sets in which the proportions of infested plants differed from the AT by at least 0.05. Under the other three sampling plans, the minimal rates of correct decisions were slightly lower (95-99%) for data sets over the same relative range of population levels. The average numbers of plants sampled to reach these decisions were 17, 36, 30, and 35 under the sampling plans for AT= 0.15, 0.25, 0.35, and 0.45, respectively. Over 70% of the data tested within these population ranges had an average sample size of less than 50 plants, irrespective of the ATs. As expected, the rates of correct decisions were much lower and the average sample numbers were much higher for data sets in which the proportions of infested plants lay within the ± 0.05 range of the ATs (Table 3).

Table 2. Ranges of population levels (prop. of infested plants or larval density) over which the expected correct classification rate was at least 95% (OC5-95) (corresponding to $OC \leq 0.95$ or $OC \leq 0.05$) and those over which the expected average sample size is ≤ 50 plants (ASN50). The matching maximal ASN value or maximal error rate for each range was given for cross references. Numbers in brackets are percentages of the widths of the specified ranges over the width of the entire population level range (0-1).

	Action threshold	OC5-95 range	ASN50 range
		Maximal ASN	Maximal error rate
Proportion of infested plants (p)	0.15	$p < 0.08$ or $p > 0.20$ (88%) 52	$p < 0.07$ or $p > 0.20$ (87%) 0.05
	0.25	$p < 0.18$ or $p > 0.31$ (87%) 73	$p < 0.14$ or $p > 0.33$ (81%) 0.01
	0.35	$p < 0.28$ or $p > 0.41$ (87%) 88	$p < 0.21$ or $p > 0.46$ (75%) 0.00
	0.45	$p < 0.38$ or $p > 0.51$ (87%) 94	$p < 0.30$ or $p > 0.57$ (73%) 0.00
Number of larvae /plant (m)	0.2	$m < 0.05$ or $m > 0.31$ 28	Any m values 1
	0.4	$m < 0.18$ or $m > 0.58$ 50	$m < 0.20$ or $m > 0.58$ 0.07
	0.6	$m < 0.31$ or $m > 0.87$ 70	$m < 0.28$ or $m > 1.00$ 0.01
	0.8	$m < 0.42$ or $m > 1.16$ 85	$m < 0.33$ or $m > 1.40$ 0.01

2. p-m relationships

The 108 data sets used in the construction of p-m relationship can be grouped into 5 groups according to crop variety and origin of state: cabbage, cauliflower and broccoli in Victoria, cabbage in Queensland and Brussels sprouts in South Australia. A common $\ln[-\ln(1-p)] - \ln(m)$ relationship appears to be shared by the 5 groups of data sets (Figure 2). Comparisons of regression lines constructed from individual data groups did not reveal significant differences among the slopes ($F = 0.9129$, D.F. = 4, 98, $P > 0.05$) or the intercepts ($F = 2.2437$, D.F. = 4, 102, $P > 0.05$). Hence a common regression line was fitted to represent the relationship between $\ln(-\ln(1-p))$ and $\ln(m)$ in all the data sets. The resulting regression line was highly significant ($F = 3104.6903$, D.F. = 1, 106, $P < 0.001$), explaining 97% of total variation in the dependent variable (Figure 2).

Table 3. Percentages of simulation runs that correctly classified the proportion of infested plants at each of the four proportional action thresholds (0.15, 0.25, 0.35 and 0.45) (Correct%) and the corresponding average sample sizes (ASN_{sim}). One thousand simulation runs were performed for each data set. N = number of plants in the data set, p = proportion of plants infested with larvae.

Data	N	p	Correct%				ASN _{sim}			
			0.15	0.25	0.35	0.45	0.15	0.25	0.35	0.45
S-cabb	600	0.17	83.3	98.4	100.0	100.0	71	70	39	26
PCB98	420	0.55	100.0	100.0	100.0	100.0	11	15	28	58
PCB99	360	0.63	100.0	100.0	100.0	100.0	10	13	20	34
Bshrt11	100	0.73	100.0	100.0	100.0	100.0	10	11	14	21
Bshrt12	100	0.71	100.0	100.0	100.0	100.0	10	11	15	22
Bshrt29	100	0.2	100.0	100.0	100.0	100.0	29	24	20	17
CabIHD1	100	0.34	100.0	99.5	56.2	99.5	18	49	163	65
CabIHD2	100	0.63	100.0	100.0	100.0	100.0	10	12	20	33
Bshrt2-68	100	0.26	100.0	70.7	98.6	100.0	27	122	73	38
Bshrt5-32	100	0.16	73.7	99.0	100.0	100.0	82	63	35	25
Bshrt3-10	100	0.12	79.3	100.0	100.0	100.0	87	43	30	22
Bshrt26-50	100	0.12	75.9	100.0	100.0	100.0	84	43	29	22
Bshrt37-63	100	0.17	82.5	98.7	100.0	100.0	78	68	37	26
Bshrt61-69	100	0.13	67.3	99.8	100.0	100.0	92	47	31	23
Bshrt44-48	100	0.71	100.0	100.0	100.0	100.0	10	11	15	23
Bshrt18-40	100	0.38	100.0	100.0	88.1	95.8	15	35	121	98
Bshrt13-56	100	0.35	100.0	99.4	56.1	99.0	16	43	158	75
Bshrt19-21	100	0.4	100.0	100.0	100.0	100.0	34	27	22	18
Bshrt27-34	100	0.17	80.7	98.6	100.0	100.0	75	68	38	26
Bshrt46-57	100	0.19	92.0	94.8	100.0	100.0	59	91	43	28

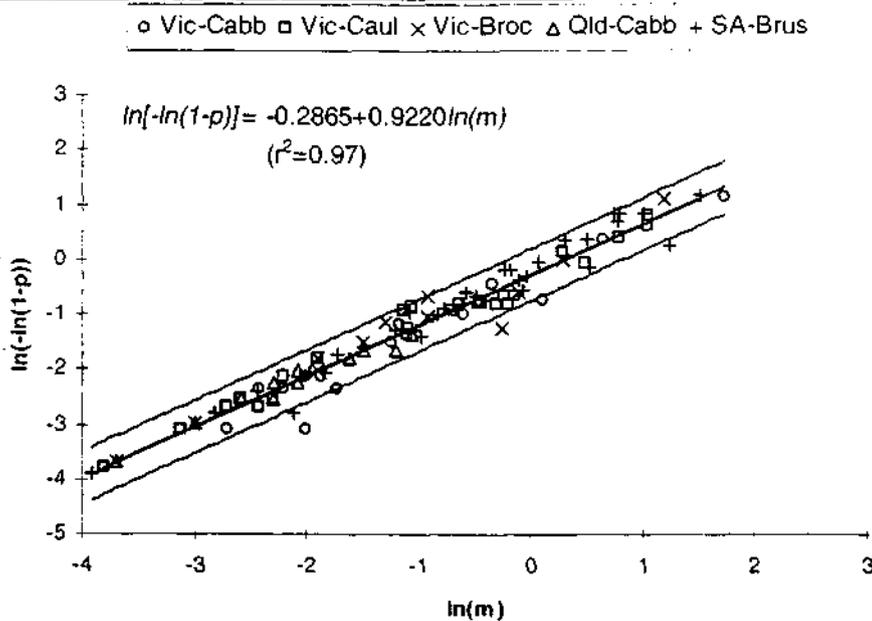


Figure 2. Plot of $\ln[-\ln(1-p)]$ on $\ln(m)$ from 5 groups of data sets and the common regression line, where m is the larval density and p the proportion of plants with larvae present. The two parallel lines on either side of the common regression line shows the 95% confidence interval of the regression.

3. Classification of larval density

Sampling plans for the four density-based ATs are given in Table 1. The OC curves for these sampling plans (Figure 3) are not as steep as those for the classification of the proportions of infested plants (Figure 2). As a result, the OC5-95 ranges were located further away from the ATs (Table 2). Specifically, to have a ≥ 0.95 probability of making a no-intervention decision, the larval density had

to be lower than the AT by at least 0.15 larvae/plant at AT=0.2 larvae/plant to at least 0.38 larvae/plant at AT= 0.8 larvae/plant. Conversely, to have a ≥ 0.95 probability of making an intervention decision, the larval density had to be higher than the AT by at least 0.11 larvae/plant at AT= 0.2 larvae/plant to at least 0.36 larvae/plant at AT= of 0.8 larvae/plant.

The peak ASN values increase from 41 plants at AT= 0.2 larvae/plant to 160 plants at AT= 0.8 larvae/plant (Figure 3). The ASN50 range at AT= 0.2 larvae/plant covered the entire range of possible population levels. For the other three ATs, the ASN50 ranges were found 0.2 - 0.47 larvae/plant below the AT and 0.18 - 0.6 larvae/plant above the AT (Table 2). The higher the AT, the further away the ASN50 range was from the AT.

Results of the re-sampling analyses showed that, under all 4 sampling plans, the percentage of correct decisions was over 95% for all data sets in which the larval density differed from the ATs by at least 0.08 (AT = 0.2 larvae/plant) - 0.16 larvae/plant (AT = 0.6 larvae/plant) (Table 4). At AT = 0.8 larvae/plant, the percentages of correct classifications were consistently high (>99%). The average sample sizes taken to reach these decisions were 18 plants at AT = 0.2 larvae/plant, 35 plants at AT = 0.4 larvae/plant, 31 plants at AT = 0.6 larvae/plant, and 45 plants at AT = 0.8 larvae/plant (Table 4). Simulations for data sets with larval density close to the AT yielded less accurate results and used larger sample sizes.

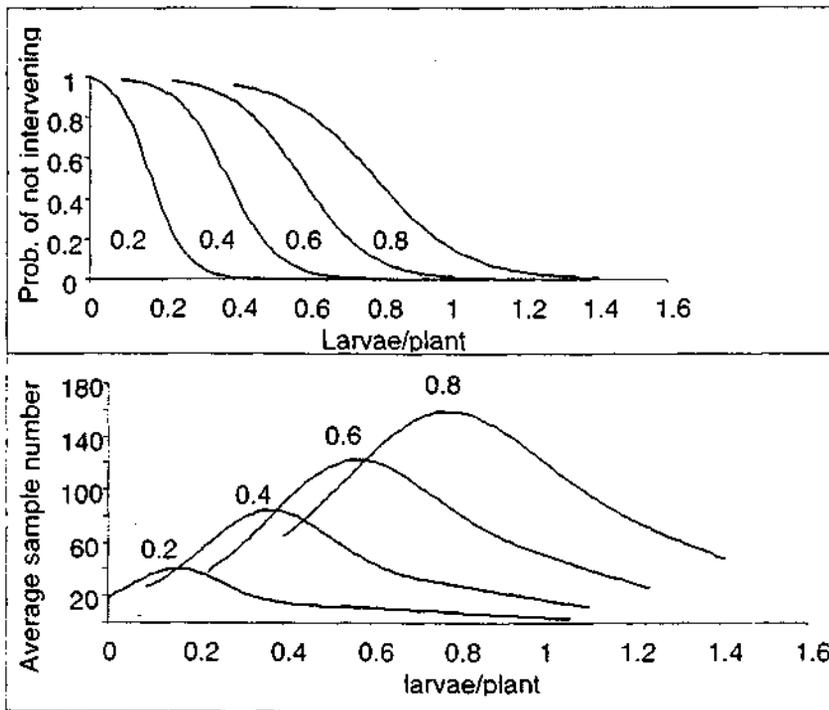


Figure 3. Operating characteristic (OC = probability of not intervening) and average sample number (ASN) functions for the classification of DBM larval density at 4 action thresholds (0.2, 0.4, 0.6, and 0.8 larvae/plant) using sequential presence-absence sampling.

Table 4. Percentages of simulation runs that correctly classified the larval density at each of the four proportional action thresholds (0.2, 0.4, 0.6 and 0.8 larvae/plant)(Correct%) and the corresponding average sample sizes (ASN_{sim}). One thousand simulations were run for each data set. N = number of plants in the data set. m = number of larvae per plant in the data set.

Data	N	m	Correct%				ASN _{sim}			
			0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
S-cabb	600	0.26	80.6	99.1	100.0	100.0	45	55	39	34
PCB98	420	1.18	100.0	100.0	100.0	99.9	10	16	34	79
PCB99	360	0.92	100.0	100.0	100.0	100.0	10	13	24	44
Bshrt11	100	1.49	100.0	100.0	100.0	100.0	10	11	17	27
Bshrt12	100	1.31	100.0	100.0	100.0	100.0	10	11	18	29
Bshrt29	100	0.02	100.0	100.0	100.0	100.0	22	22	22	22
CabiHD1	100	0.53	99.8	98.2	82.0	100.0	15	58	166	82
CabiHD2	100	1.28	100.0	100.0	100.0	100.0	10	13	24	44
Bshrt2-68	100	0.28	99.0	98.0	99.7	100.0	22	65	54	48
Bshrt5-32	100	0.18	32.5	99.6	100.0	100.0	48	49	36	32
Bshrt3-10	100	0.12	69.4	100.0	100.0	100.0	52	35	31	28
Bshrt26-50	100	0.12	70.2	100.0	100.0	100.0	52	36	30	28
Bshrt37-63	100	0.2	75.0	99.5	100.0	100.0	46	53	38	33
Bshrt61-69	100	0.2	61.8	100.0	100.0	100.0	52	38	32	29
Bshrt44-48	100	1.46	100.0	100.0	100.0	100.0	10	11	18	30
Bshrt18-40	100	0.52	100.0	99.8	32.0	99.3	13	39	197	123
Bshrt13-56	100	0.44	100.0	86.0	74.0	99.9	14	54	183	92
Bshrt19-21	100	0.04	99.7	100.0	100.0	100.0	26	24	23	23
Bshrt27-34	100	0.22	76.0	99.6	100.0	100.0	47	52	38	34
Bshrt46-57	100	0.24	87.0	97.8	100.0	100.0	37	63	42	36

Discussion

Two sets of sequential binomial sampling plans were developed, one targeting the proportions of plants infested with DBM larvae and the other larval density, with the objective of providing simple and efficient monitoring methods for DBM populations. The results showed that all four proportion-based sampling plans performed well in classifying the proportions of infested plants relative to the action thresholds. The expected rate of correct classification was $\geq 95\%$ for most possible population levels (87-88%). This was confirmed in the simulated re-sampling analyses of 20 independent data sets, which showed a 100% correct classification rate for all data sets in which the proportion of infested plants was not in the immediate vicinity of the action threshold (separated by >0.05 proportion units). Although the expected sample size to achieve the $\geq 95\%$ accuracy was up to 94 plants, a sample size of 50 plants was sufficient when the true population level differed from the action thresholds by a minimum of 0.07-0.15 proportion units. In fact, simulated re-sampling of actual data showed average sample sizes of <40 plants in reaching $\geq 95\%$ accuracy.

Classification of larval densities relative to action thresholds using sequential binomial sampling plans involves the additional step of changing the density-based action thresholds into proportion-based action thresholds. This inevitably introduces some errors to the sampling plans due to the uncertainty of any proportion-density models (Binns and Bostanian, 1990, 1992). As a result, the expected performance of the four density-based sampling plans was not as satisfactory as the four proportion-based sampling plans, as seen in the comparison of the steepness of the OC and ASN curves between the sets of sampling plans (Figure 2, 3). However, satisfactory performance ($\geq 95\%$ accuracy at ≤ 50 plants sample size) can be expected from the four density-based sampling plans if the true population density is not too close to the action threshold (Table 2). This was confirmed in the re-sampling analyses of 20 independent data sets, which yielded correct decision rates of $> 95\%$ at average samples sizes of ≤ 45 plants for all data sets in which the population density differed from the action thresholds by a minimum of 0.08 (AT = 0.2 larvae/plant) to 0.16 larvae/plant (AT = 0.6 larvae/plant).

Presence-absence data upon which these sampling plans were based are a special form of binomial data in which the cut-off point is 1. Many studies have shown that the precision of sequential binomial sampling plans for classifications of population densities can be increased by using higher cut-off points (Binns, 1990; Nyrop and Binns, 1992; Boeve and Weiss, 1997; Trumper and Gyenge, 1998). Other cut-off points were not investigated in this study as the action thresholds practiced by most *Brassica* vegetable growers in Australia are mostly below 1 larvae/plant.

As in any sequential sampling plan, when the true population level was close to the action threshold the probability of making correct decisions were relatively low (< 0.95) and the average sample sizes were relatively high (up to 160 plants). To avoid excessive sample sizes with no promise of significant improvement on sampling precision, it is suggested that the maximum sample size be limited to 50 plants when applying the sampling plans. If no decision is reached by that sample size, growers are advised to make their own decisions according to other relevant information such as historical pest level data, crop development stage and pheromone trapping data. Termination of a sequential sampling plan in this way introduces errors (Fowler and Lynch, 1987). However, the likelihood of taking such an action under the any of the sampling plans presented here is not high according to the results of this study.

Selection between the two sets of sampling plans depends on grower's primary concern about DBM infestation and crop development stage. If the primary concern is the proportion of plants infested with DBM larvae, or the crop is in a development stage sensitive to DBM damage and one larva is sufficient to cause significant damage to the host plant, then the use of one of the proportion-based sampling plans can be considered. If the primary concern is the abundance of DBM larvae in the crop, then density-based sampling plans would be the better choices.

The sampling plans for proportions of infested plants can also be used in multi-pests scenarios. In taking this approach, the multiple pests will be treated as a single hypothetical pest and a plant infested with any member pest will be counted as a infested plant. However, the action threshold needs to be adjusted to reflect the multi-pests situations. Assuming p_a as the adjusted action threshold and p_i as the action threshold for pest i , then $p_a = 1 - \prod (1 - p_i)$. In a 2-pest situation with action threshold of 15% for both species, the adjusted threshold will be ca. 28%. It needs to be pointed out that only pests which can be controlled with similar management actions should be lumped together.

Acknowledgement

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CROP SCOUT TRAINING IN VICTORIA

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Introduction

Regular crop monitoring underpins Integrated Pest Management programs. Before commencement of the national diamondback moth (DBM) project, crop monitoring in *Brassica* vegetable crops in southern Australia was a rare occurrence. Vegetable growers need to employ scouts or be trained in crop scouting to have an impact on the management of DBM. Development of a pilot training system for crop scouts has been a fundamental part of the project.

A group of crop scouts was trained in late spring in each year of the project. In most cases the scouts were tertiary students of agriculture or horticulture who worked as crop scouts throughout their summer holiday. Some continued part-time throughout autumn. Some new scouts were trained each year and several scouts participated in the program in more than one year. An agricultural reseller employed most of the scouts. Some training sessions for reseller staff and other companies were also run.

Method

Sample size and sampling method was developed at the Vegetable Research Station, Frankston, Victoria, prior to commencement of the current project. Details of development of the method are given in Workshop report 1 (Appendix 2). The sampling method was trialled in commercial crops in the first season of the project and modifications have been incorporated as experience was gained in commercial crops. Scouts were trained to use the following scouting method:

Scouting Protocol

- Minimum of one planting scouted once per week
- Where possible follow one crop through from transplant to harvest, but check additional younger plantings as time permits
- Sample unit: whole plant - both sides of all outer leaves, head wrapper leaves and as much of the head as can be observed without destruction.
- Look at 40 plants in a single age planting
- Walk the crop in a V-shape starting from a different point each week
- Sample 4 plants at random at 5 evenly spaced locations for each leg of the V
- For the first 6 weeks after transplanting count all pest life stages on the whole plant
- From 7 weeks after transplanting to harvest sample for presence/absence of larvae. Start in the centre of the plant and work outwards until a larva is found. Record anything of interest observed.
- Record pest and beneficial insects on crop scouting record form
- Conservative threshold of 15% plants infested with larvae
- Set up and maintain two pheromone traps in a planting. Traps should be checked at least weekly.

A sample score sheet and grower reports can found in Workshop Report 2 (Appendix 3).

All scouts had a one-day training session in the laboratory as an introduction to the theory of monitoring, history of pest problems in *Brassica* crops and an introduction to identification of pests and beneficial insects. A wide range of material including photographs, slides and live specimens was used to familiarise the scouts with insects they would encounter in *Brassica* crops.

Topics addressed in the laboratory training day included:

Diamondback moth

- History of the diamondback moth problem
- Insecticide resistance in DBM
- How insecticide resistance develops
- Integrated Pest Management – key component is crop scouting

AIRAC Insecticide Resistance Management Strategy for DBM

Benefits of crop scouting

- Detecting the build-up of pests well before economic damage can occur
- Ensuring correct decisions on whether control measures are necessary
- Optimising the timing of spraying or other control measures
- Selecting the most appropriate control measure
- Finding out how successful the control measure has been
- Identifying problem varieties and areas within crops

Pest identification and life cycles (photographs and practical exercises with live specimens)

- Distinguishing the 4 instars of DBM
- How to distinguish DBM from other larvae
- Cabbage white butterfly, cabbage centre grub, *Helicoverpa*, Aphids, Others

Identification of beneficial arthropods and life cycles (photographs and practical exercises with live specimens)

- *Diadegma semiclausum*, *Diadromus collaris*, *Apanteles ippeus*
- Cabbage white butterfly parasitoids
- Aphid parasitoid
- Predators: Coccinellids (ladybirds), Lacewings, Syrphids (hoverflies), Spiders, Others

Scouting Protocol

Equipment required for crop scouting

Safety

- Checking with the grower when last spray applications were made
- Re-entry periods of insecticides
- Protective clothing

Examples from commercial crops: spray applications vs pest numbers

Practical training in the field

Crop scouts were accompanied in the field by the trainers on several occasions and encouraged to ask questions and compare results. Scouts collected any unidentified insects between sessions for identification by the trainers. The scouts modified the example score sheets and report forms to suit the crops they were working in. They generated reports for each grower after each monitoring session. Generally one planting was followed through from transplanting to harvest. Six weeks after the crops were transplanted, the scouts would change from full insect counts on 40 plants to presence/absence of larvae on 40 plants.

Results

1997/ 98 season

Crop monitoring was conducted by the project team at four commercial properties in Werribee South, Dandenong and Narre Warren from December 1997 to June 1998. Crop types scouted were cauliflower, plain cabbage and savoy cabbage. A full report of the season was made in Workshop Report 1 (Appendix 2). 45 plants were sampled from throughout one age planting at weekly intervals from transplant to harvest with the exception of the Savoy cabbage which was sampled for 6 weeks only. After each sampling occasion the grower was informed of the pest levels present in his crop. This was followed up by a fax report of a summary of the data. For this season's trials the grower decided what insecticides he would use and when he would apply them. All growers in the study group kept spray records.

1998/99 and 1999/00 seasons

The project team trained a total of seven crop scouts employed by a Victorian chemical reseller. The scouts were organised to scout for eight (1998/99) and 17 (1999/2000) Werribee and Cranbourne Brassica-growing properties. The scouts operated in Cranbourne/ Mornington Peninsula and Werribee South districts each week. In South Australia, two scouts were trained to scout on three properties. Experience gained each season is being used to refine the crop scouting system and the method of scout training so, that in future, scouting can be more effectively promoted and taught to growers. Since commencement of the project, a private consultant has moved into the area of crop scouting in Werribee and Cranbourne, further adding to the implementation of crop scouting in Victoria.

Discussion

Communication

Several communication factors were identified which are considered as important components of a successful crop scouting program. It is important that strong communication links are established and maintained between trainers and scouts and scouts or advisers and growers. A meeting of interested growers before the commencement of a crop scouting program to explain the methods, benefits and limitations of scouting is of use. Detailed crop scouting data should be converted into a report that can be easily understood by the grower. Some assistance with interpretation of the results and their implications is also important. An end of season summary is a valuable opportunity to ask for grower feedback about which parts of the scouting service they value and which are of less use. The results can be put in context within a district.

Grower assessment of the program

Growers from Werribee South had an end of season feedback session on the scouting program at the end of the 1998/99 season. At this meeting, all of the growers who had participated in the program said that they had found the monitoring results to be of value. Those who had the reports explained to them early in the season or who had experienced crop scouting in the 1997/98 trials by the project team had a better understanding of the results than those who only received them by fax. Some growers were prepared to spray less when pest pressure was low. One grower who had experienced crop scouting in the 1997/98 trials had trained his brother to scout for larvae and found his results similar to those of the scouts. The growers were keen to continue participating in the program and requested for the scouting to be extended to lettuce crops, as *Helicoverpa* had been a particular problem during the season.

Benefits derived

At certain times of the year, crop scouting provides the opportunity for growers to apply insecticides less frequently compared with a regular program. At times of peak pest pressure this benefit may not arise, but additional benefits of crop scouting realised during the program included identification of pest problems in the nursery (late stage DBM larvae were observed on seedlings one week after transplant on several occasions), noting influx or lack of other pests such as aphids and monitoring activity of beneficial insects.

Spray records

Ideally growers and scouts/advisers would be in regular communication about actions taken and growers would supply accurate spray records from week to week. Keeping track of the spray records is essential for helping with future spray recommendations, adhering to insecticide resistance management guidelines, checking for spray failures with particular insecticide groups and checking for safe re-entry periods for crop scouts. A limitation of this program was that growers would supply spray records at the end of the season, but were reluctant to give reports on a weekly basis.

Commercial crop scouting program

In the long term, broad scale implementation of crop scouting is dependent on its adoption by commercial enterprises. Many chemical resellers are looking to offer their clients a wider range of services such as consultancy and a crop scouting service fits well into this model. Some private

consultants are starting to offer crop scouting in vegetable crops in southern Australia. Packing sheds, grower cooperatives and buyers for supermarkets who work with groups of growers have an interest in employing crop scouts. Individual growers could also employ a scout or have existing staff or family members trained as crop scouts. The seasonality of work can cause some problems with new personnel having to be trained each season. Ideally an organisation could have one permanent scout who employs and trains others as required for the peak season of insect pest pressure. In situations where crop scouts report to other advisers/consultants who, in turn, liaise with the growers and make spray recommendations, the adviser must be confident with the scouting method and interpretation of results, to avoid over conservative spray application recommendations.

Future crop scout training

Training of crop scouts will continue to be a fundamental part of the proposed second-phase of the national DBM project. Results from each season were used to refine the crop scouting system and method of scout training to be used for the eventual benefit of all growers. A simple method of crop scouting based on recording the presence or absence of DBM larvae will be promoted to growers and others involved with the *Brassica* vegetable industry at workshops throughout Australia (see report, p.15 by J. Mo, G. Baker & M. Keller). Initially spray decisions can be based on the conservative threshold of 15% of plants infested with larvae. As crop scouts gain more experience they may observe and record other life stages and may feel confident in using a less conservative threshold, to further reduce the number of spray applications they make, without jeopardizing quality.

DIAMONDBACK MOTH FIELD SCOUTING

LIONEL HILL, JULIA FRENCH AND FELICITY WARDLAW

Introduction

The DPIWE IPM team conducted crop monitoring in two fresh market broccoli crops, one in spring and the second in summer. This report concerns mainly the second crop which was monitored for a six-week period. The spring crop received negligible pest pressure and no insecticide applications. The primary purpose was training the team to become familiar with crop pest identification within a recommended scouting method.

Method

The second scouting effort was conducted on a commercial broccoli crop in Gawler located in the north-west of Tasmania. The field, at an approximate elevation of 150-200 m on an east-north-east slope, was under sequential planting. Only the first two plantings were scouted. Plants were randomly selected while walking a figure-8 through the crop. Forty plants were monitored at each visit. Records were made on the presence of eggs, larvae and mines of diamondback moth (DBM) and cabbage white butterfly (CWB). Two sticky traps containing *P. xylostella* pheromone were located at either end of the field to monitor the abundance and activity of male *Plutella* moths. The pheromone lures were not replaced over the monitoring period and the traps were moved once during the first harvest period. Aphid infestation, parasitism and other necessary notes were also collected during the scouting process. The data were recorded on sheets provided by N. Endersby of Agriculture Victoria Knoxfield. Information regarding spray application dates, types has not yet been provided.

Results

Table 2 gives the total number of DBM adults and larvae along with CWB eggs that was observed in the monitored broccoli crop at each visit. The crop was sprayed with Success[®], at least, but we were unable to get insecticide application dates from the grower.

Note that the peak in DBM adults over the first three weeks didn't result in a peak of larvae activity in later weeks. DBM eggs were not counted due to inexperience in egg identification and later due to large plant size. Many larvae were observed to be dying from insecticide application or disease. They were distinguished by taking on a brown, soft appearance. This was not observed until the third and fourth week of monitoring.

Table 2: Monitoring results for Gawler broccoli crop

Date	Trapped DBM moths	DBM Larvae	CWB Eggs
24/01/00	102	11	5
31/01/00	191	10	18
04/02/00	180	10	40
10/02/00	51	0	59
17/02/00	39	12	11
24/02/00	*	6	3
01/03/00	29	3	7
14/03/00	*	0	2

Conclusion

The monitoring training exercise, combined with concurrent laboratory and field-cage rearing, has made the IPM team confident in *Brassica* pest identification and scouting. The scouting method used was effective as it provided a detailed overview of the pest activity in the field. Closer to harvest, the pest activity became difficult to monitor due to the size of the plant.

Local Dispersal of the Diamondback Moth, *Plutella xylostella* (Lepidoptera: Plutellidae)

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Introduction

Information on the dispersal of pest insects is needed in the designing and implementation of effective IRM/IPM strategies. One commonly practised IRM strategy is the rotation of insecticides, or the restriction of the use of insecticides with similar modes of action to some predefined periods. Ideally the same rotation plan should be uniformly implemented across an entire region. Where uniform implementation is not feasible, areas under different rotation plans should be separated by large enough distances to minimise gene flow among populations in these areas. Another recognised IRM strategy is the provision of refuges of insecticide-susceptible populations. For this strategy to be effective, the refuges should be set up within certain distances of the target populations to ensure significant exchanges of individuals between susceptible and resistant populations. Similarly, dispersal information is needed to determine the minimal separation distances between control and non-control areas in IPM strategies such as crop-break, mating disruption and sterile insect release and to determine the maximal trap intervals in IPM strategies such as trap-and-kill and auto-dissemination of insect pathogens.

Diamondback moth (DBM), *Plutella xylostella* (Lepidoptera: Plutellidae), is the most important pest of *Brassica* vegetables in many parts of the world. Although the insect is considered able to migrate over long distances (Mackenzie, 1958; Lorimer, 1981; Chu, 1986), very little is known about the dispersal pattern of the insect. The only published dispersal study suggests a mean flight distance of 286-615 m (Shirai and Nakamura, 1994). No estimates were given on the likelihood of the moths dispersing to a given distance. Further, as the study was based on pheromone trap catches, the estimates applied only to male DBM moths. As part of national project on the integrated management of DBM, a dispersal study was conducted in South Australia between October 1997 and May 2000, focusing on the non-migratory dispersal of the insect. The results of the study and the practical implications of the results are reported and discussed here.

Materials and Methods

1. Test Insects

Moths used in this study were from laboratory colonies reared with potted canola, cabbage, and Chinese cabbage. The rearing condition was 25 – 28 °C and 12L:12D photo-period. In each spring a new colony was started with wild DBM larvae/adults collected from *Brassica* weeds/canola crops. The colony was reinvigorated every 2-3 months by introducing wild individuals.

2. Marking and Release

Fluorescent powder (Magruder Color Co., Elizabeth, NJ) was chosen as the marking agent. Marking was done in transparent plastic containers (26 x 19 x 6 cm). Moths were introduced into the marking container through a mesh sleeve opening to a circular hole cut in the centre of the cover. About 500 moths were placed in each container. The marking containers were transported to the experiment sites in an Esky (40 L) with ice packs inside. Just before the release, 0.05–1.00 g of the fluorescent powder was placed into each container and shaken for a few seconds. The moths were then released by opening the caps of the marking containers.

To determine the effect of marking on the mortality of marked moths, healthy pupae from the culture were sorted into males and females and placed in individual glass tubes. Emergence of the pupae was checked daily. Moths emerging on the same day from each sex were randomly divided into two groups of equal numbers. Moths from one group in each sex were marked with the fluorescent powder

according to the method described above and transferred into clean glass tubes. The test moths were checked daily for live-death status until the last moth had died. The test condition was the same as in rearing. Significant differences in the average life span between marked and unmarked individuals were checked with two-sample t-tests.

The effect of marking on the response of marked males to the pheromone sources was studied in a wind tunnel (temperature: 20 °C; wind speed: 0.1 m/s; light period: 12L:12D). A pheromone trap (25 cm x 35 cm) baited with the 3-component DBM sex pheromone (R. Vickers, CSIRO Long Pocket Laboratories, Brisbane, Australia) was placed in the centre of the upwind end (10-cm away) at a height of 30 cm. Equal numbers of marked and un-marked virgin males were released in the downwind end of the wind tunnel and allowed to respond to the pheromone source for 24h. The number of moths caught in each category (marked or un-marked) was recorded at the end of the test and the differences were analysed with chi-square tests.

To determine the effect of irrigation and rain on the persistence of the marking on the moth bodies, marked moths were placed in a cylindrical bag made of coarse mesh and showered with a constant flow of water from a sprinkler for either 0.5 hrs or 1.0 hrs. The diameter of the bag was made about the same as that of the sprinkler to ensure full coverage of the bag with the shower. After the draining of excess water, the moths were checked for fluorescent marking with a UV spotlight (TrAc Pack Pro, Labino AB, Sweden).

3. Experiment Sites and Host crops

All mark-recapture experiments were conducted in a commercial broccoli and cauliflower farm in the northern Adelaide plains (34°43'S, 138°33'E). The crops were planted continuously throughout the year, resulting in a mixture of different ages of the crops at any time. Each planting was done in adjacent rectangular blocks (10 m wide, 110 – 230 m long) separated by 5-m wide tractor paths. The distance between adjacent plants within a block was about 0.5 m. The crops were regularly irrigated with overhead sprinklers. All experiments were conducted when the crops were about 6-10 weeks old.

4. Traps

Recaptures of the released moths were made with delta pheromone traps (Figure 1, A), yellow sticky bucket (YSB)(Figure 1, B) and light traps (Figure 1, C). The pheromone traps were made with 2-L blank milk cartons. The side length of the triangular opening of the trap was 25 cm and the length of the trap 35 cm. A card board piece (25 x 35 cm) coated with Tanglefoot® was inserted on the base of the pheromone trap. A rubber tube impregnated with the 2-component sex pheromone of the DBM (Long Pocket Laboratories of the CSIRO Division of Entomology) was placed in the centre of the sticky base.

The YSB consisted of an inverted bucket (base diameter: 25 cm, opening diameter: 35 cm, height: 35 cm) and a 5 cm wide ring made from particle board. The outer surface of the bucket and the upper surface of the ring were coated with Tanglefoot®. A square hole was cut in the centre of the bucket base to allow a wooden stake to poke through. The height of the trap was controlled with a bull clip placed on the wooden stake. The ring of the YSB was designed to increase the trapping efficiency as observations showed that a considerable number of moths that bumped into the bucket wall did not get stuck but fell to the ground. Pheromone traps were placed at a height of ca. 50 cm and YSB ca. 30 cm (from the ring to the ground).

The light trap was made with metal sheets. The opening (47 x 30 cm) faced the ground and was made larger than the top (32 x 15 cm). A rigid plastic board slightly smaller than the opening of the light trap sits on the inside rim of the opening. The upper side of the plastic board was coated with Tanglefoot®. Two rectangular slits (21 x 2.5 cm) were cut out from the two edges of the plastic board to serve both as moth entry and light exit. A black light (20 w) charged by a car battery was placed on the ceiling of the trap.

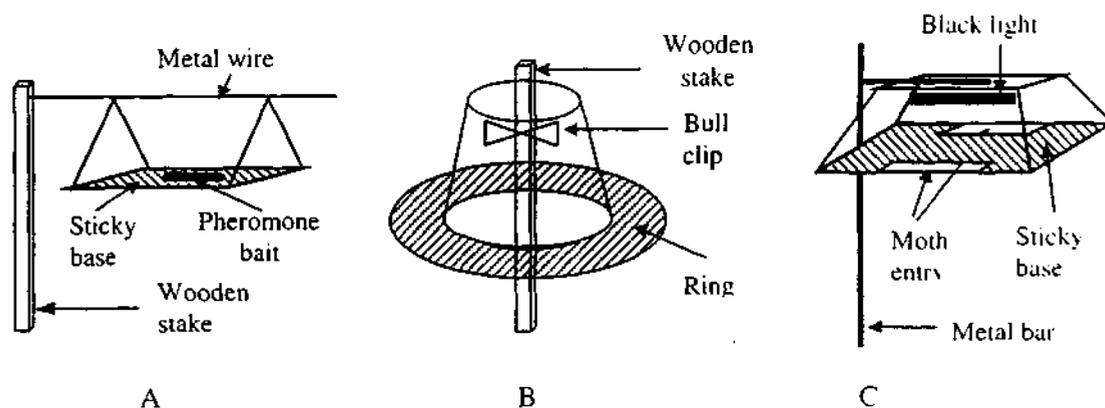


Figure 1. Illustrations of the delta pheromone trap (A), yellow sticky bucket (B) and light trap (C), and the ways they were set up in the field (not drawn to scale).

5. Experimental Designs

A. Discrete Plot Design

The first two experiments were designed as discrete plots. In the first experiment, 4 plots (40 x 40 m) were set up in two neighbouring cauliflower blocks (Figure 2, A). The closest distances between neighbouring plots ranged from 50 m to 150 m. Within each plot, 25 pheromone traps were placed in a 5 by 5 pattern (trap interval: 10 m). Newly emerged males were marked with red and green fluorescent powder and released in the centres of 2 of the plots respectively (Figure 2, A). Eight days later all traps were retrieved and checked under UV light for marked moths. In the second discrete experiment, 4 plots (20 x 20 m) of Brussels sprouts were set up in an open field (Figure 2, B). Nine pheromone traps and 9 sticky cardboard rectangles (32 x 38 cm) were placed in each plot in a 3 x 3 pattern. The cardboard rectangles were fixed to the wooden stake supporting the pheromone traps. A light trap was also placed in the centre of each plot. Moths were marked with red fluorescent powder and released in the centre of one of the central plot. Eight days later the traps were retrieved and checked under UV light for marked moths.

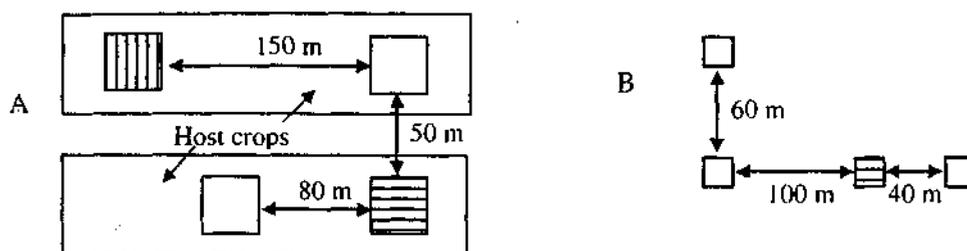


Figure 2. Layouts of the plots in the two discrete plot experiments. Each square represents a plot. The patterned squares show the release plots, with different pattern indicating the use of different colours of the fluorescent powder. Plots in the first experiment were laid out within host field (A), whereas plots in the second experiments in open fields.

B. Grid Design

Traps were laid out in a grid pattern across a continuous patch of a *Brassica* field at an inter-trap distance of 10 m. The dimensions of grids in terms of the number of rows of traps and the number of traps per row varied from 5 x 21 to 7 x 21, depending on the dimensions of the crop fields available for experiments. Marked moths were released in the centre of the grids. To minimise possible artefacts arising from moths bumping into the traps immediately following the releases, the centre traps were not placed until 1 h after the releases. The total number of moths released in each experiment varied from 1000 to 3000. Seven grid-based experiments were conducted, 3 with pheromone traps and 3 with YSB. In most experiments, more than one releases were made. With multiple releases, separations of recaptures from different releases were made possible by the use of different colours of the fluorescent powder. Recapture data from different releases were treated as

different data sets. In experiments using pheromone traps, the sticky bases of the pheromone traps were replaced every 1-2 days. All sticky bases and the traps were checked under UV light for marked moths at the end of each experiment. In experiments using YSB, the buckets were checked daily at the site with a portable UV light. Duration of the experiments ranged 5-9 days.

6. Meteorological Data

Temperature, relative humidity, wind direction and wind speed were recorded hourly during the experiments with a data logger (STARLOG, Model 6004, UNIDATA, Western Australia) with a wind speed and direction sensor (Model 6504-FS, UNIDATA, Western Australia). The data logger and the temperature and relative humidity probes were placed inside a Stevenson's Screen placed at the experimental sites.

7. Data Analyses

Recaptures from individual traps in an experiment were according to the distances of the traps to the release point and the average number of recaptures per trap (y) was calculated for each distance (x). The relationship between Y and X was modelled with Hawkes' (1972) empirical dispersal equation:

$$y = \exp(a - b\sqrt{x}) \tag{1}$$

Parameters a and b were estimated with non-linear regression. Equation (1) gives the density of moths at a given point. Since dispersal occurs in all directions, the density of moths at a given distance should be the point density multiplied by $2\pi x$, ie. $2\pi xy$. The number of moths remaining within a distance of x_c is estimated by:

$$\int_0^{x_c} 2\pi xy \tag{2}$$

The distance within which the probability of moths remains is p , x_p is therefore given by the following equation:

$$\int_0^{x_p} 2\pi xy = p \int_0^{\infty} 2\pi xy \tag{3}$$

For each experiment, x_p was estimated for $p = 0.95, 0.99, \text{ and } 0.999$. These were the estimated distances from the release point within which 95%, 99%, and 99.9% of the moths would remain. The estimates were obtained with numerical integrations. The average dispersal distances were estimated as $20/b^2$ (Hawkes, 1972), where b is the parameter in equation (1).

To characterise the variability in dispersal range and dispersal direction of individuals of a population, the standard ellipse (Batschelet, 1981) was constructed for each experiment and, where data permit, for recapture data from each day of each experiment. The standard ellipse describes the centre of recaptures as well as the standard deviations of recaptures along two cardinal directions, e.g. x-axis and y-axis in a xy-coordinate system. A standard ellipse is given by the following equation:

$$A(x - \bar{x})^2 + 2B(x - \bar{x})(y - \bar{y}) + C(y - \bar{y})^2 = D \tag{4}$$

Where \bar{x} and \bar{y} are the average recapture distances along the x-axis and y-axis respectively, and $A, B, C,$ and D are parameters of the standard ellipse. Let x_i and y_i be the distances from the release point of the i^{th} recaptured moth along x-axis and y-axis directions respectively, n be the total number of recaptured moths, s_x and s_y be the standard deviations of recaptures along the two directions respectively, and $\text{cov}(x,y)$ be the covariance of recaptures along the two directions, parameters $A, B, C,$ and D are estimated as follows:

$$A = s_y^2, B = \text{cov}(x, y), C = s_x^2, D = s_x^2 s_y^2 - \text{cov}^2(x, y), \text{ where} \quad (5)$$

$$s_x^2 = \frac{1}{n-1} \sum (x_i - \bar{x})^2$$

$$s_y^2 = \frac{1}{n-1} \sum (y_i - \bar{y})^2$$

$$\text{cov}(x, y) = \frac{1}{n-1} \sum (x_i - \bar{x})(y_i - \bar{y})$$

Significant departures of the centres of the recaptured moths from the release point were tested with Hotelling's one-sample test (see Batschelet, 1981) and differences between the centres of two recapture data sets (e.g. males vs females) by Hotelling's two-sample test (see Batschelet, 1981).

To analyse the effect of wind on the direction of moth movement, the rectangular trapping grid was divided into two equal sections. The dividing line was perpendicular to the longer side of the grid and run through the release point. Moths caught by traps positioned on the two sections (excluding traps on the dividing line) were summed separately and the differences tested for significance with chi-square test. The mean directions of winds of all speeds and for wind with speed ≥ 5 km/h over the trapping period under investigation were calculated using the algorithms of Batschelet (1981). Considering the frequent changes of wind directions, the trapping period used for analysing the wind effect was restricted to one day. To determine the directions of moth movement with trapping data, it is necessary that all moths caught by the traps can be traced to the same spatial point prior to the start of the trapping period. For this reason, only recaptures from the 1st days following releases and those from the 1st days when significant recaptures from the release points were detected were used.

Results

1. Marking on moth longevity and response to pheromones

No significant differences were detected in the longevity between marked and un-marked moths at $\alpha=0.05$ (Student-t tests), irrespective of the sexes (Figure 3).

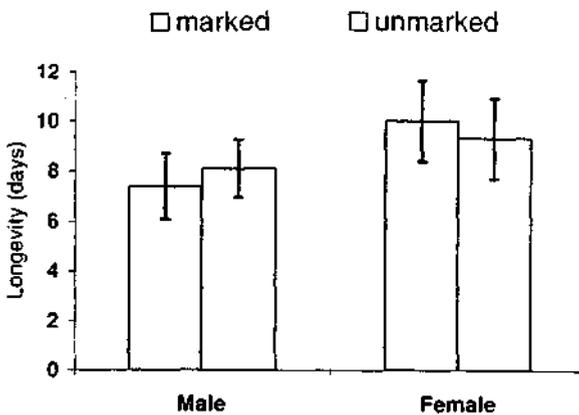


Figure 3. Comparisons of longevity between moths marked with fluorescent powder and un-marked moths. The number of moths tested in each category and each sex was 10. The bars show the 95% confidence intervals.

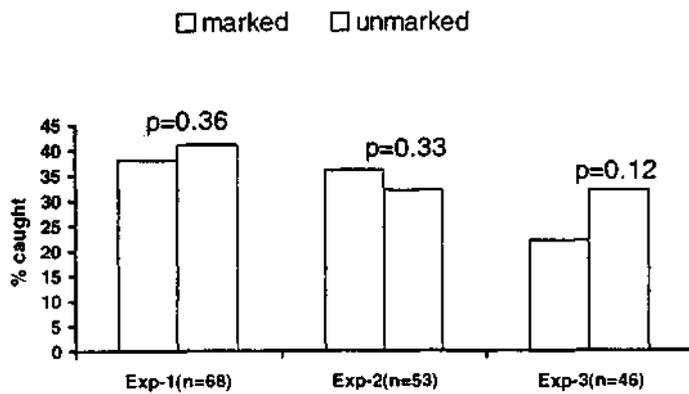


Figure 4. Percentages of marked and unmarked moths caught by a delta pheromone trap inside a wind tunnel. The p-values were obtained with Chi-square tests.

Wind tunnel experiments revealed no significant differences in the percentages of moths caught by the pheromone trap between marked and unmarked males ($P > 0.05$, Chi-square tests) (Figure 4).

2. Discrete-Plot Experiments

Results from the two discrete-plot experiments were shown in Table 1-2. The majority of the released moths (79% - 100%) were captured in the release plots. Recapture rates in the non-release plots ranged 0 - 16%. Less than 10% were caught in plots spaced over 100 m away from the release plot. In one release none of the marked moths were captured in the adjacent plots, although the closed distance of one of them to the release plot (edge to edge) was only 50 m away (Figure 2). The second experiment used 3 different types of traps. The light traps caught the highest number of moths, followed by sticky board and pheromone traps.

Table 1. Results from discrete-plot mark-recapture experiment I. The distances were measured from the centre of the release plot to the centres of the target plots.

Release-1			Release-2		
Plot	Distance (m)	%Recap.	Plot	Distance (m)	%Recap.
A	release plot	88%	A	190	0%
B	190	6%	B	90	0%
C	210	5%	C	release plot	100%
D	114	1%	D	120	0%
total recaptures = 75			total recaptures = 16		

Table 2. Results from discrete-plot mark-recapture experiment II. The distances were measured from the centre of the release plot to the centres of the target plots.

Plot	Distance (m)	Trap			Total
		pheromone	Light	Sticky board	
A	release plot	84%	72%	84%	79%
B	60	12%	20%	13%	16%
C	120	5%	8%	3%	5%
D	144	0%	0%	0%	0%
Total recaptured		43	79	61	183

3. Dispersal Ranges

Data from the grid-based experiments were used to estimate the dispersal ranges and analyse the dispersal patterns. In estimating the dispersal ranges, only those data sets that had non-zero recaptures at more than five different distances were used. This selection criterion was applied to allow meaningful fitting of data to the dispersal model (Equation 1). A total of 12 data sets met this criterion, 6 from pheromone trap based experiments and 6 from YSB based experiments. All data sets were satisfactorily fitted with the dispersal model, as indicated by the high r^2 values (Tables 3-5). The recaptures-distance relationships in all but one data set were characterised by a rapid decline of the number of recaptures as the traps moved away from the released point (Figure 5, A). The decline was more gentle in one data set (Figure 5, B) due to the much lower overall recapture rate.

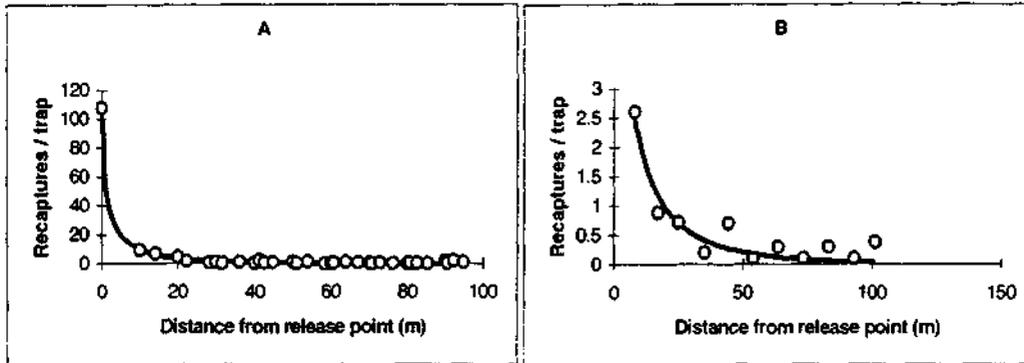


Figure 5. Fitted relationships between number of recaptures and distance as shown by 2 of the 12 data sets. A. Typical fitting result shown by most data sets; B. Fitting result from one particular data set.

The estimated dispersal ranges based on the relationships were given in Tables 1-3. Regardless of trap types and sexes, the data suggested very limited dispersal ranges of the moths. The estimated average dispersal distance is less than 60m and over 95% of the moths would stay within 178 m of the release point. The maximal estimated distances within which 99% and 99.9% of the released moths are likely to remain were 299 m and 506 m respectively. Higher estimates of dispersal ranges were obtained from data from pheromone traps (Table 3) than from YSBs (Tables 4-5), probably because of the different trapping capacities of the two types of traps. The area of the trapping surface of the YSB was over 10 times as large as the pheromone trap. The lower trapping capacity of the pheromone traps may have limited their recaptures close to the release point. Female dispersal ranges (Table 4) were slightly higher than male dispersal ranges (Table 5) in 4 of the 6 data sets collected from YSBs. In the other 2 data sets, the dispersal ranges of the two sexes were similar.

Table 3. Fitted parameters of the dispersal model $y = \exp(a - b \sqrt{x})$ and the dispersal ranges estimated from the fitted models. The dispersal ranges estimated were average dispersal distances, and the distances from the release points within which 95%, 99%, and 99.9% of the released individuals would remain. Male recapture data from grid-based experiments using pheromone traps.

Data	a	b	r^2	Avg. Dist.	95% Dist.	99% Dist.	99.9% Dist.
P1-A	4.6821	0.7547	0.9983	35	106	177	300
P1-B	3.6636	0.7905	0.9978	32	96	162	273
P2	2.5550	0.5805	0.8963	59	178	299	506
P3	3.5836	0.9511	0.9994	22	67	112	189
P4-A	4.9053	0.9856	0.9995	21	62	104	176
P4-B	4.8829	0.9617	0.9997	22	65	109	184

Table 4. Fitted parameters of the dispersal model $y = \exp(a - b \sqrt{x})$ and the dispersal ranges estimated from the fitted models. The dispersal ranges estimated were average dispersal distances, and the distances from the release points within which 95%, 99%, and 99.9% of the released individuals would remain. Male recapture data from grid-based experiments using yellow sticky buckets.

Data	a	b	r ²	Avg. Dist.	95% Dist.	99% Dist.	99.9% Dist.
Y1-A	5.9839	1.1685	0.9999	15	44	74	125
Y1-B	5.1375	1.1637	0.9997	15	44	75	126
Y2-A	4.2627	1.0670	0.9990	18	53	89	150
Y2-B	4.7707	1.1037	0.9997	16	49	83	140
Y2-C	5.3706	1.2060	0.9998	14	41	69	117
Y3	5.8290	1.0572	0.9998	18	54	90	164

Table 5. Fitted parameters of the dispersal model $y = \exp(a - b \sqrt{x})$ and the dispersal ranges estimated from the fitted models. The dispersal ranges estimated were average dispersal distances, and the distances from the release points within which 95%, 99%, and 99.9% of the released individuals would remain. Female recapture data from grid-based experiments using yellow sticky buckets.

Data	a	b	r ²	Avg. Dist.	95% Dist.	99% Dist.	99.9% Dist.
Y1-A	5.3376	0.9169	0.9996	24	72	120	203
Y1-B	4.8903	0.9988	0.9998	20	60	101	171
Y2-A	4.0775	1.0435	0.9995	18	55	93	157
Y2-B	4.6348	0.9980	0.9997	20	60	101	172
Y2-C	5.2311	1.2284	0.9999	13	40	67	113
Y3	5.1761	1.0621	0.9997	18	53	89	151

Data from the YSBs provided direct comparisons of the dispersal ranges of the males and the females. The estimated dispersal ranges were similar in males and females in 3 data sets and slightly higher in females in the other data sets (Tables 2-3). Comparisons of the mean recapture distances revealed no significant differences between males and females in 4 data sets ($p > 0.05$, t-test). In the remaining 2 data sets, the mean recapture distance was significantly higher in females in one data set and significantly higher in males in the other data set ($p = 0.01$, t-test) (Figure 6).

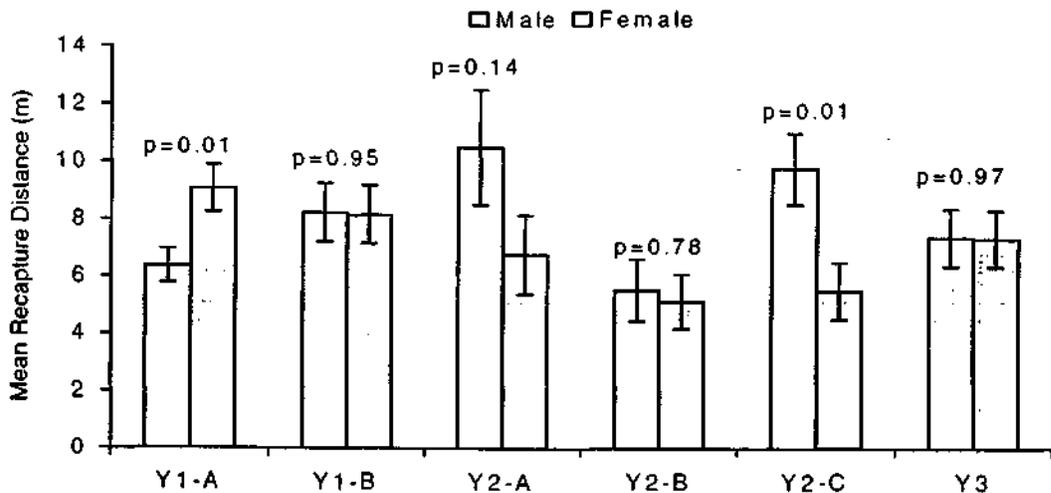


Figure 6. Comparisons of the mean recapture distances in experiments using the yellow sticky buckets. The error bars show the standard deviations. The p-values were obtained from t-tests.

4. Dispersal Patterns

The standard ellipses for the grid-based data sets were shown in Figures 7-9. It can be seen that, by the end of the experimental duration (5-9 days), the recapture centres were still within close distances to the release points (< 10 m) in all data sets. Significant departures of the centres from the release points were only detected in 2 of the 6 data sets from pheromone traps (Figure 7), in 1 of the 6 data

sets from male recapture data from YSBs (Figure 8), and in 1 of the 6 data sets from female recapture data from YSBs (Figure 9) ($p < 0.05$, Hotelling's one sample tests). However, the variation ranges of the distances of individual recaptures differed considerably from data sets to data sets, as seen in the sizes of the standard ellipses. This was particularly evident along the direction of the y-axis, or the longer side of the rectangular trapping grids, ranging from about 50 m to less than 20 m. The differences did not appear to be due to trap types or sexes if the moths.

Comparison of the recapture centres between males and females revealed no significant differences ($p > 0.05$, Hotelling's two sample test) in 5 of the 6 data sets from the YSBs. In the only data set where significant difference was detected the centres of the recapture males and females were separated by < 5 m.

The relatively stationary property of the recapture centres was more clearly seen in the standard ellipses for daily recaptures. Figure 10 shows the standard ellipses for daily recaptures from day 1 to day 5 in males and from day 1 to day 4 in females in a grid-based mark-recapture experiment using the YSBs. It can be seen that, for both sexes, the centres of the daily ellipses stayed around the release point. However, the sizes of the ellipses increased gradually with the progressing of days. Standard ellipses were not constructed daily for the other data sets due to insufficient daily recaptures. It was decided that daily recaptures had to be greater than 5 for a minimum of 3 consecutive days for a meaningful analysis of daily dispersal patterns. This condition was not met in the other data sets mainly because the recaptures were concentrated in non-consecutive days.

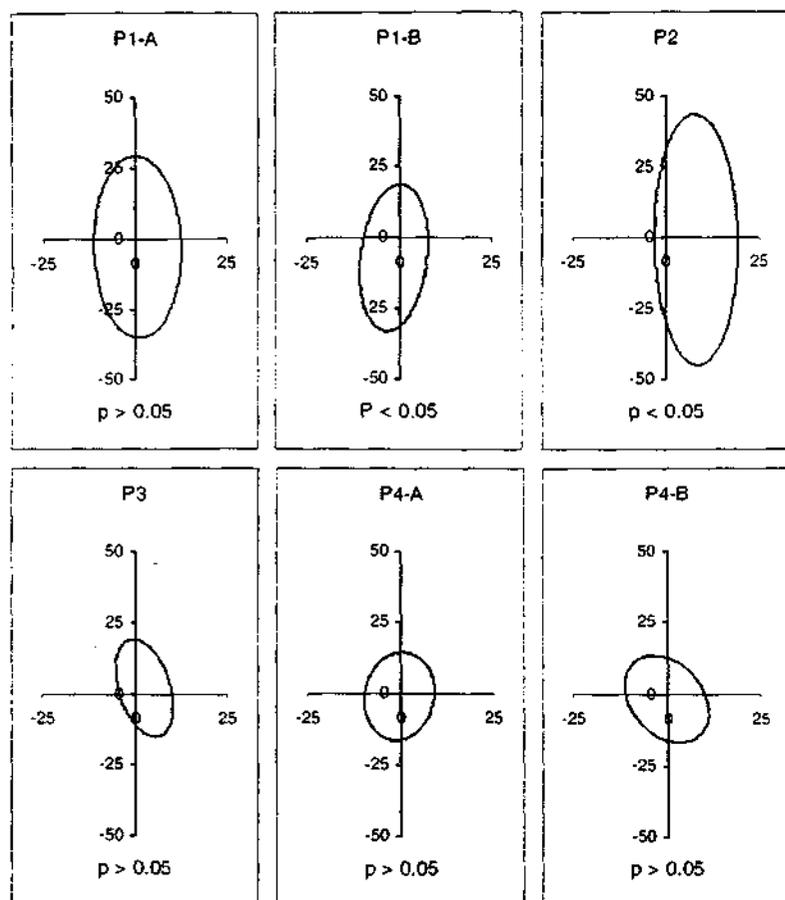


Figure 7. Standard ellipses of males from pheromone traps. The p-values show results of one-sample Hotelling test testing departures of the recapture centres from the release points.

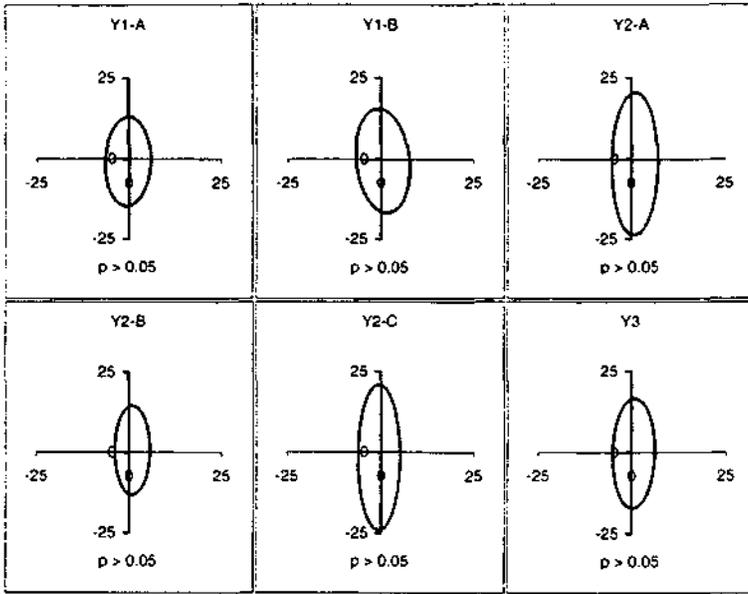


Figure 8. Standard ellipses of males from yellow sticky buckets. The p-values show results of one-sample Hotelling test testing departures of the recapture centres from the release points.

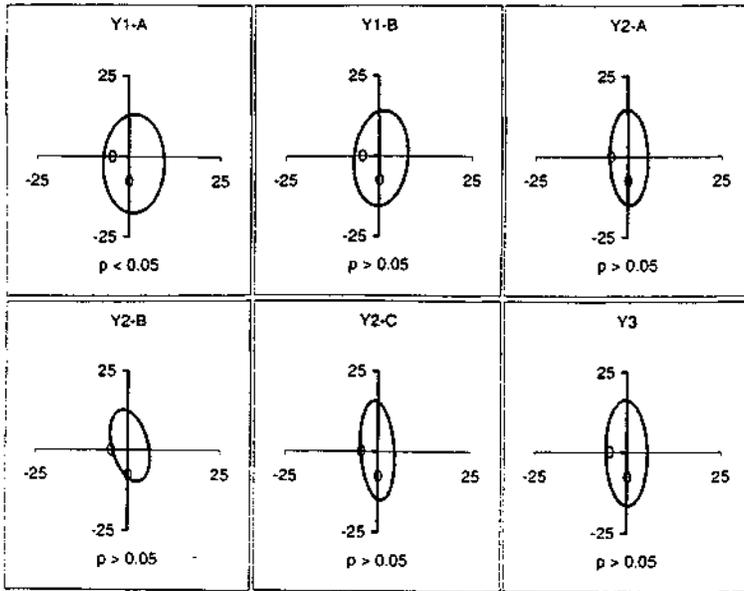


Figure 9. Standard ellipses of males from yellow sticky buckets. The p-values show results of one-sample Hotelling test testing departures of the recapture centres from the release points.

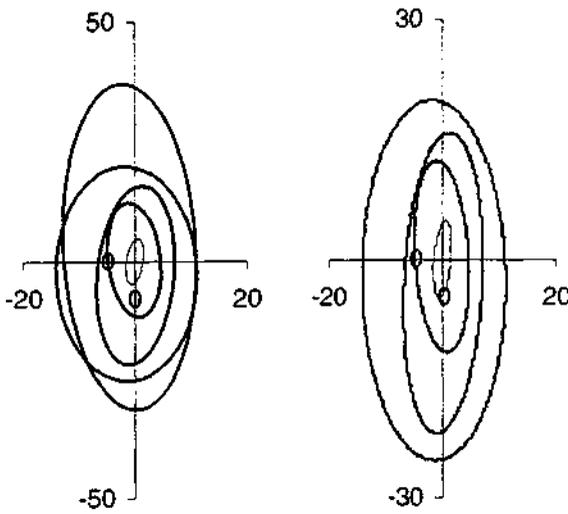


Figure 10. Standard ellipses of daily recaptures of males (left, day 1-5) and females (right, day 1-4). Data from a grid-based mark-recapture experiment using yellow sticky buckets. The sequence of the ellipses from the inner most to the outer most represented recaptures from the 1st day to the last day.

5. Effects of temperature and wind

The grid-based dispersal experiments were conducted in an average daily temperature range of 13-28°C. Over this temperature range there was no significant correlation between average daily temperature and average recapture distance in pheromone trapping data ($p=0.6078$), YSB trapping data ($p=0.1916$), or combined data ($p=0.8057$)(Pearson's correlation test) (Figure 11).

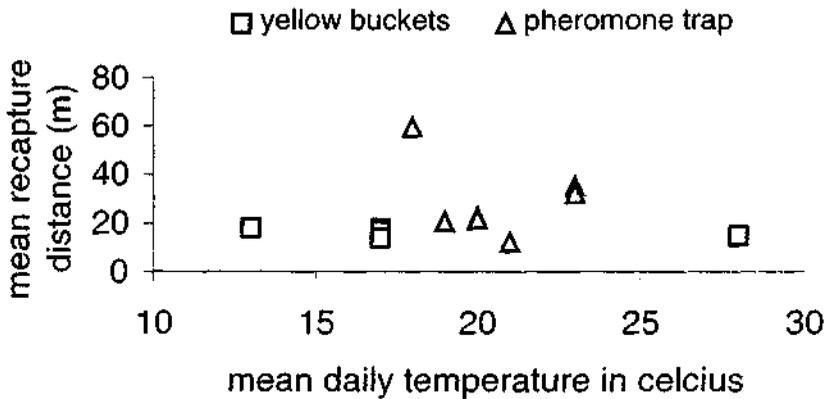


Figure 11. Relationships between mean recapture distances and mean daily temperatures in pheromone trapping data and YSB trapping data.

Six daily recapture data sets met the conditions for analyses of the effects of wind on directions of moth movements. Significant differences in the total numbers of recaptures between the two sides of the rectangular trapping grid were detected in 3 data sets ($p < 0.01$, chi-square test) (Figure 12). Of the 3 data sets, the recapture direction (lower recapture side to higher recapture side) and the mean wind direction appeared negatively associated in one data set, unrelated in another data set, and positively associated in the 3rd data set, when the mean wind direction was calculated for wind of all speeds. When the mean wind direction was calculated for wind with speed ≥ 5 km/h, the association appeared negative in one data set and weakly negative in the other 2 data sets.

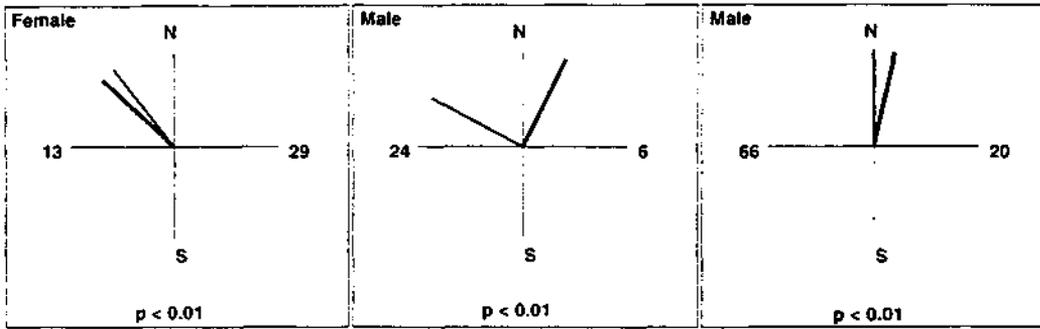


Figure 12. Total numbers of recaptures on the two sides of the rectangular trapping grid and corresponding mean wind directions (thin line: for wind of all speed; bold line: for wind with speed ≥ 5 km/h). p-values show chi-square tests results of the total numbers of recaptures

Discussion

This paper reports for the first time estimates of the dispersal ranges of males and females of DBM moths based on quantitative relationships between distance and moth density. Within active host fields, both sexes of the adults did not appear to disperse far, with an estimated average dispersal distance of less than 60 m. In most data sets the estimates were as low as less than 30 m. Less than 5% are expected to disperse 200 m or more and less than 1% are expected to disperse 300 m or more. The limited dispersal ranges can be explained by the abundance of host plants. When the nearest hosts are only centimetres there is no need for the females to fly great distances for in search of oviposition sites. Males disperse in search of females and their optimal strategy would be to go to the closest females or the closest pheromone sources. Observations at night vision goggles showed that most DBM moths flew close to the ground and below the plant canopy, which also suggests very limited dispersal ranges. Other indirect evidences supporting the finding of limited local movement of DBM are observations of patchy distributions of insecticide resistance levels among local DBM populations. Tabashnik et al. (1987) found local DBM populations in Hawaii exhibiting significant differences in insecticide resistance levels although the populations were separated by as little as 5 km. Shirai and Nakamura (1994) reported much higher average dispersal distances of DBM (286 – 615 m). However, their estimates were based on a few individuals caught in the non-release fields. The majority of the moths (80 – 94%) which were caught in the release fields were not included in their calculations.

The dispersal of the insect within healthy host fields appeared non-directional. This was seen in the largely stationary positions of the recapture centres around the release points over the experimental periods. Movements away from the release points by individuals can be explained by some form of random diffusion processes. Wind speed during the experiments ranged of 0.5 – 2.3 m/s. In this speed range wind did not seem to significantly influence the directions of dispersal.

There was no compelling evidence suggesting different dispersal patterns of the two sexes of DBM adults. Both the mean recapture distances and the locations of the centres of recaptured moths were mostly similar. The slightly higher estimated dispersal ranges of females in some experiments may have been due to random errors of the recapture data. As in most mark-recapture experiments, the majority of recaptures in this study were made by traps close to the release points with only a small number of moths caught in the edge traps. In fitting the dispersal equation, however, these few outliers tend to have great influences on the estimation of the parameters of the model.

Results from this study can be used in the designing and/or implementation of a number of IPM/IRM strategies against DBM. The success of resistance dilution with the provision of susceptible refuge populations relies on frequent gene flows between the target populations and the refuge populations. Hence the refuge populations should not be placed too far away from the target populations. Using the average dispersal distances as a guideline, the suggested maximal separation is 60 m. The latter was about the highest average dispersal distance obtained from this study (after rounding to the nearest tens). This distance may also be considered as the maximal trap interval for the alternative control

strategy of pathogen auto-dissemination. However, for maximal effect, trap interval may have to be < 20 m, the distance around which the average dispersal distances from most experiments were centred.

Some strategies require that target populations be isolated from non-target populations, such as mating disruption, rotations of insecticides, and crop-break. These strategies should ideally be implemented uniformly across the whole crop production area so that non-target populations from host crops become a non issue in this area. However, when uniform implementation is not possible because of some practical difficulties (e.g. disagreements between farmers), the target populations should be separated from the non-target populations by some minimal distances. Results from this showed that 99% of the moths would not disperse in excess of ca. 300 m (the highest estimated dispersal distance from the release point within which 99% of the released population would remain). Multiply by a safety factor of 2 this gives a minimal separation distance of 600 m between target and non-target populations.

Local dispersal within healthy host crops is only one aspect of the dispersal process. The ranges and patterns of dispersal from harvested crops are likely to be quite different from those of healthy host crops due to the need to find suitable hosts. As *Brassica* growers normally plant crops sequentially during the growing season, it is likely that crops of all ages will be present at any one time. Hence dispersal from harvested crops should be considered as common events. Apart from local dispersal, the insect is also known to engage in long distance migrations (Mackenzie, 1958; Lorimer, 1981; Chu, 1986). In the southern states of Australia, there is an annual influx of DBM from mid spring to early summer. The origin of these moths is likely to be *Brassica* weeds and canola crops. Unlike local dispersal, migrations of moths are normally wind-assisted and can cover hundreds of kilometres. To better understand the dispersal process and use the information to fine tune relevant management strategies, it is important that dispersal from harvested crops, weeds and canola crops are studied.

Acknowledgements

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REDUCED SUSCEPTIBILITY TO PERMETHRIN IN DIAMONDBACK MOTH POPULATIONS FROM VEGETABLE AND NON-VEGETABLE HOSTS IN SOUTHERN AUSTRALIA

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Abstract

Diamondback moth (DBM), *Plutella xylostella* (L.), has attained major pest status in *Brassica* vegetable crops around the world. In many cases, use of synthetic pyrethroid insecticides for control of other pests, such as *Pieris rapae*, has disrupted natural enemies and selected for insecticide resistance in DBM, changing the pest status of the moth from minor to major. We estimated levels of resistance to the synthetic pyrethroid, permethrin, using a leaf dip bioassay, for 28 DBM populations collected from brassicaceous weeds, canola, forage turnips and seed turnips and for five DBM populations from *Brassica* vegetables. Populations were collected in Victoria, Tasmania, southern New South Wales, ACT, South Australia and Western Australia between September 1999 and January 2000. Nineteen of 28 populations from non-vegetable hosts were significantly more tolerant than a susceptible laboratory population (resistance ratios ranged from 2.1 to 6.9). All five populations from vegetable hosts were significantly tolerant (resistance ratios from 3.6 to 13.0). These results are early indications that populations of DBM with reduced susceptibility to permethrin may be found in areas remote from intensive vegetable growing districts. *Brassica* vegetables account for only a small proportion of the host plants available for DBM in southern Australia. Large areas of non-vegetable hosts have, in the past, received few applications of insecticides. Reports that growers of forage brassicas and canola are finding it necessary to apply synthetic pyrethroids to their crops with increasing frequency (1-4 applications per crop) suggest that resistant DBM populations are being generated. Alternatively, DBM populations may be moving from the more intensively sprayed vegetable crops onto non-vegetable hosts. Further studies on the insecticide resistance status of DBM populations from a range of host plants in different locations may provide some evidence of isolation or mixing of populations which could have important consequences for insecticide resistance management.

Introduction

Diamondback moth (DBM), *Plutella xylostella*, has damaged *Brassica* vegetable crops throughout the world and is renowned for developing resistance to insecticides (Talekar and Shelton 1993). In Australia, resistance to synthetic pyrethroid insecticides has been identified in DBM populations from vegetable growing areas in all states (Wilcox (1986), Altmann (1988), Hargreaves (1996), Endersby and Ridland (1997), Baker and Kovaliski (1999)).

Canola, brassicaceous weeds and forage brassicas are all hosts for DBM. *Brassica* vegetables account for a very small proportion of the host plants available for DBM in southern Australia. 12,226 hectares were planted to *Brassica* vegetables in 1999 (ABS 2000), whereas the area planted to canola in Australia increased by 79% from 697,000 hectares in 1997-98 to an estimated 1.2 million hectares in 1998-99 (ABS 2000). The biggest increase was in Western Australia, which saw plantings increase by 116% to 536,000 hectares (ABS 2000). There are also vast areas of brassicaceous weeds, particularly in Western Australia where wild radish, *Raphanus raphanistrum*, has developed resistance to acetolactate synthase (ALS)-inhibiting herbicides (Rieger *et al.* 1999). In southern Victoria, dairy farmers often grow large areas of forage brassicas such as turnips in late spring to early summer.

In contrast to the intensively sprayed vegetable crops, non-vegetable host plants have received few, if any, insecticide applications until recent times. If we assume there is no regular long-range movement of DBM from vegetable production areas to remote areas of canola and weeds, we would expect DBM found on such non-vegetable host plants to be susceptible to synthetic pyrethroids. The current

study, however, documents low levels of resistance to permethrin in DBM populations from canola, forage brassicas and brassicaceous weeds in southern Australia.

Materials and Methods

DBM eggs, larvae and pupae were collected from 33 different locations in southern Australia from September 1999 to January 2000. Populations were reared on cabbage seedling leaves (*Brassica oleracea* var. *capitata* cv. Green Coronet) in the laboratory at 25 °C (16h:8h, L:D) for one to three generations. A susceptible laboratory population of diamondback moth was used as a reference in each assay. The susceptible population has been maintained at IHD Knoxfield since it was obtained from the University of Adelaide, Department of Crop Protection Waite Campus, SA, in 1994. For each DBM population we estimated levels of resistance to permethrin. In all, we tested 28 DBM populations from non-vegetable host plants and five populations from *Brassica* vegetables.

A leaf dip bioassay after Tabashnik and Cushing (1987) was adopted for testing susceptibility to permethrin. Cabbage leaf discs of 4.5 cm diameter were dipped for 5 s in distilled water solutions of formulated insecticide (Ambush® Emulsifiable Concentrate Insecticide - Crop Care Australasia Pty Ltd) and hung vertically to dry in a fume hood for 2 h. Control discs were dipped in distilled water. No wetting agents were used. Discs were placed into Gelman® 50 mm diameter x 9 mm plastic Petri dishes. Ten larvae were placed on each disc and four replicates of each concentration were set up. Mortality was assessed after 48 h at 28°C. Larvae were considered dead if they did not move when touched with a paintbrush.

Analysis

Concentration-mortality data for each population were analysed using the probit analysis program, POLO-PC (Russell *et al.* 1977) (LeOra Software). We used the program to estimate the lethal concentration expected to cause 50% mortality (LC₅₀) of each insecticide for each diamondback moth population and the 95% confidence intervals for these concentrations. The slope (+ standard error) of the probit line was also estimated.

The program also performed χ^2 tests for goodness-of-fit of the data to the probit model. If the model fits, the calculated value of χ^2 is less than the χ^2 table value for the appropriate degrees of freedom. If the model does not fit (i.e. the χ^2 value exceeds the table value), the LC₅₀ value for the particular population may not be reliably estimated and is adjusted with the heterogeneity factor (χ^2/df). The index of significance for potency estimation (g) was used to calculate 95% confidence intervals for potency (relative potency is equivalent to tolerance ratio) (Robertson and Preisler 1992, p.29).

Parallelism of the probit regression lines implies a constant relative potency at all levels of response (Finney 1971). POLO-PC was used to test equality and parallelism of the slopes of the probit lines for the field population and the laboratory susceptible population. If the slopes are parallel, then overlap of the 95% confidence intervals for the two populations indicates that no significant difference exists between the LC₅₀ values.

Results

The lowest resistance ratio estimated was for a population from weeds remote from vegetable production areas and the two highest resistance ratios were from DBM collected in commercial vegetable crops (Table 1). All five populations from vegetable hosts were significantly resistant (resistance ratios from 3.6 to 13.0). However, we observed that 19 out of 28 populations from non-vegetable hosts showed a low level of resistance (resistance ratios ranged from 2.1 to 6.9) (Appendix A).

Table 1. Classification of permethrin resistance ratio categories of diamondback moth populations from vegetable and non-vegetable host plants in southern Australia, 1999-2000

Host plant	Number of populations in resistance ratio category			
	A	B	C	D
Weeds (<i>Brassicaceae</i>)	2	4	10	0
Canola (<i>Brassica</i> spp.)	0	3	6	0
<i>Brassica</i> vegetables	0	0	3	2
Forage turnips (<i>Brassica rapa</i>)	0	0	2	0
Seed turnips (<i>Brassica rapa</i>)	0	0	1	0

A = significantly lower than standard laboratory population (Waite) – susceptible
B = no significant difference from Waite population – susceptible
C = significantly higher than Waite population – low level of resistance
D = significantly higher than Waite population – level approaching control failure

The resistance ratios of the DBM populations from vegetable crops at Bairnsdale and Nairne (Figure 1) are approaching 20 which is the level at which growers were experiencing control failures in 1995.

Since the first round of tests in 1995, a decrease in resistance levels of DBM from vegetable brassicas in Werribee is indicated. This may reflect the reduction in use of synthetic pyrethroid insecticides that occurred after the control failures and/or movement of susceptible moths into the area.

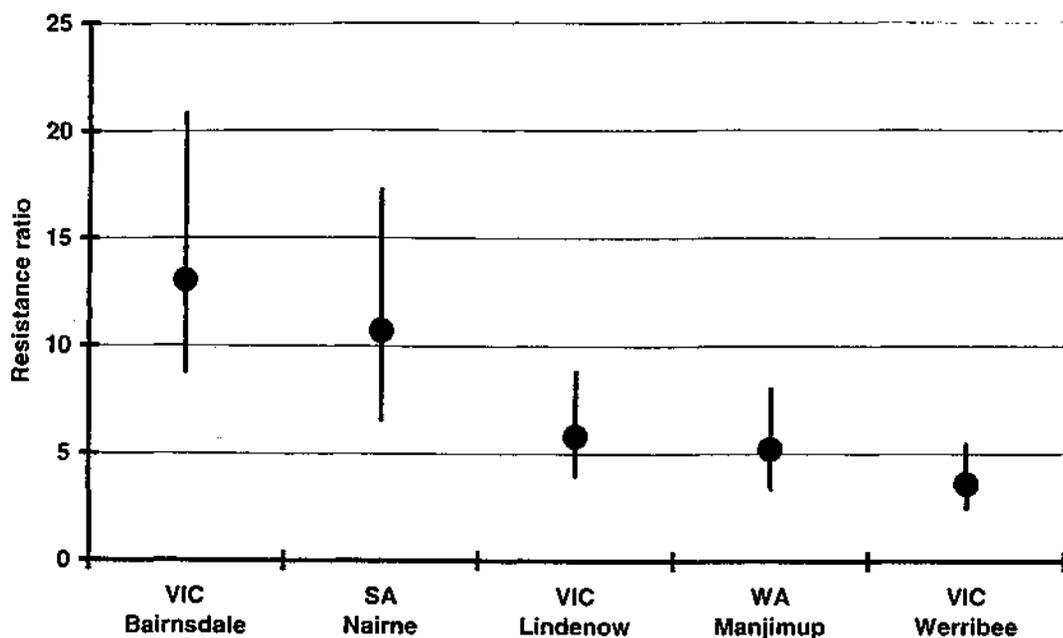


Figure 1. Permethrin resistance ratios and 95% confidence intervals of diamondback moth populations collected from vegetable crops in southern Australia, 1999-2000.

The two highest resistance ratios to permethrin estimated in populations from canola are from Western Australia (Figure 2). Three other populations from canola were susceptible to permethrin (Balliang and Balliang East from Victoria and Yeelanna from South Australia).

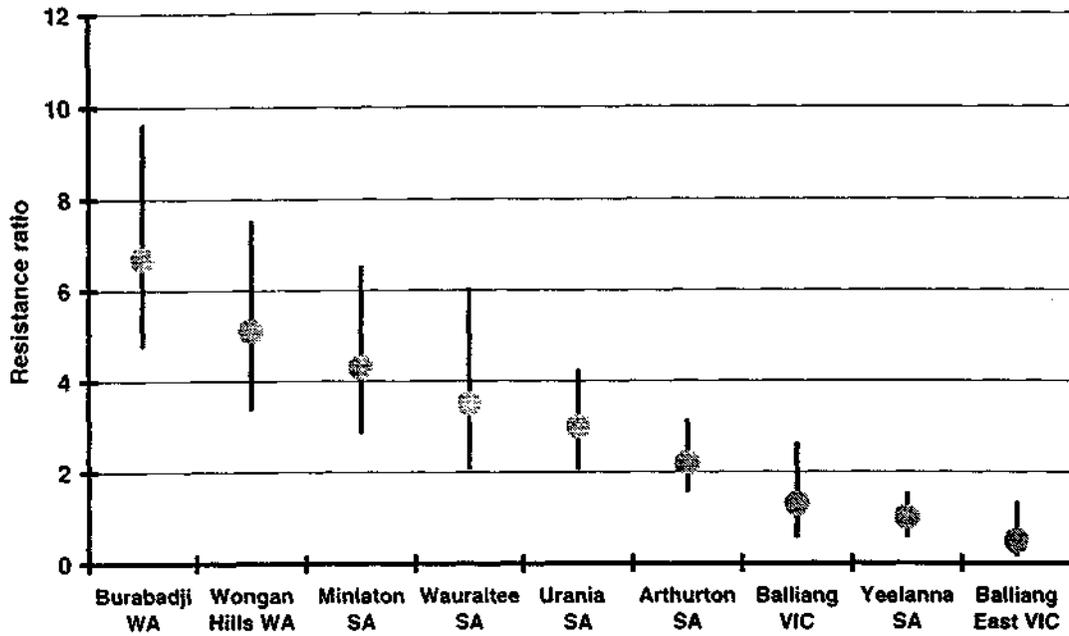


Figure 2. Permethrin resistance ratios and 95% confidence intervals of diamondback moth populations collected from canola crops in southern Australia, 1999-2000.

Three populations from weeds were collected close to vegetable production areas: Deadman's Gully WA, Werribee VIC and Cranbourne VIC (Figure 3) and are likely to have a history of exposure to insecticides. Some extremely susceptible populations were collected in Victoria away from production areas (Thomastown, Clunes and Loch), but there were many other DBM populations showing low levels of resistance which were collected from weeds in areas remote from vegetable growing regions.

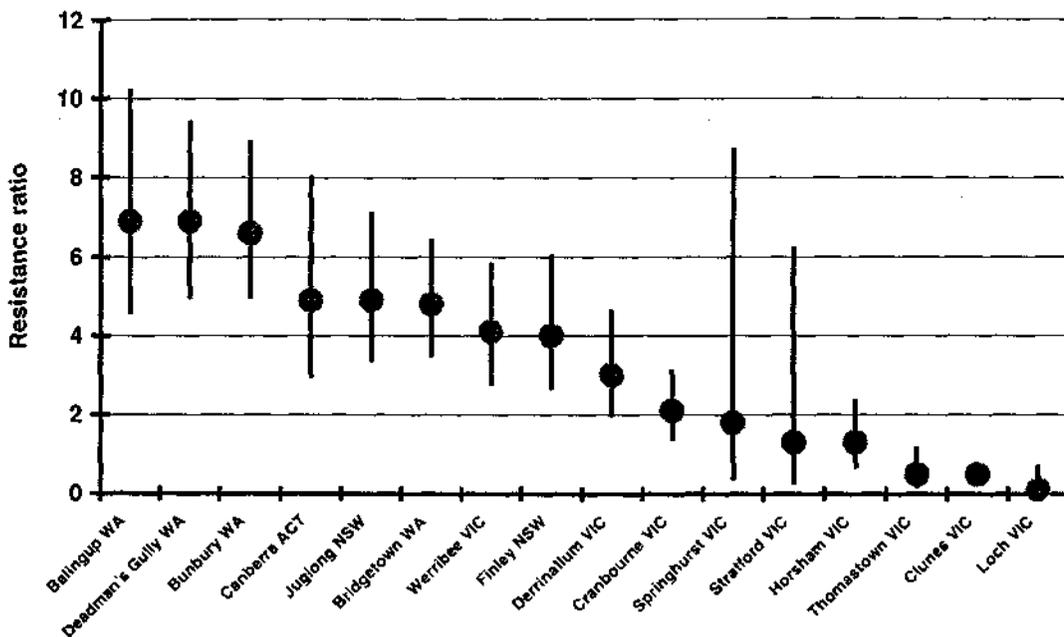


Figure 3. Permethrin resistance ratios and 95% confidence intervals of diamondback moth populations collected from weeds in southern Australia, 1999-2000.

Populations from forage and seed turnips in Victoria and Tasmania also showed low levels of resistance to permethrin (Figure 4). Appendix B shows LC_{50} and LC_{95} values of populations tested.

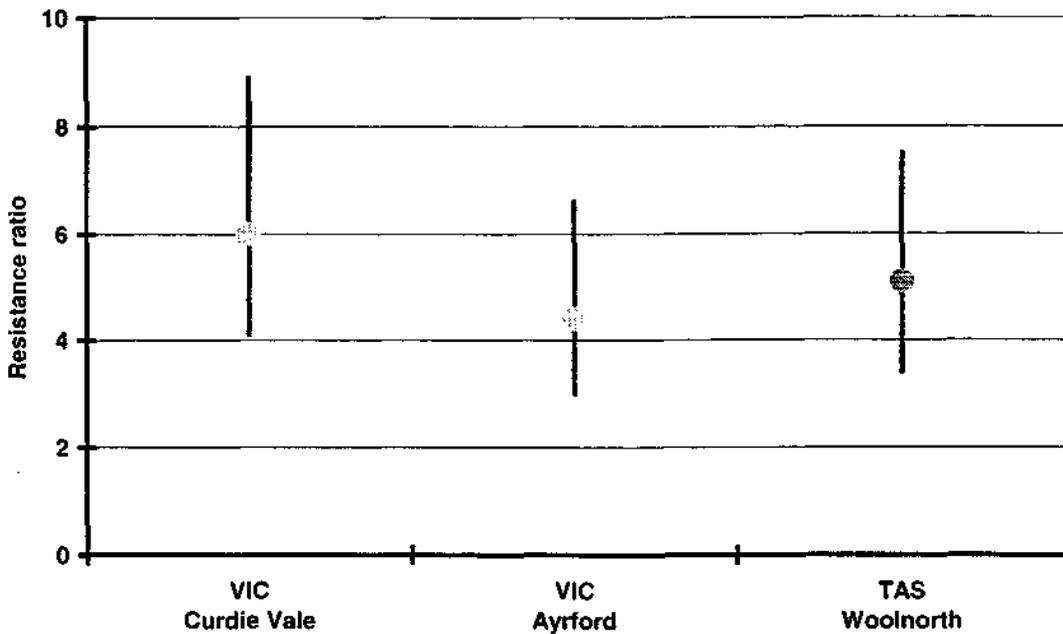


Figure 4. Permethrin resistance ratios and 95% confidence intervals of diamondback moth populations collected from seed and forage turnips in southern Australia, 1999-2000.

Discussion

Insecticides are being applied to canola and forage brassicas with increasing frequency. Some canola growers in northern Western Australia have started to apply synthetic pyrethroids for control of DBM, particularly in response to very high pest pressure in spring 1999 and winter 2000. Some growers are also using synthetic pyrethroids early in the crop for RLEM control, a practice which could inadvertently be selecting for resistance in DBM. Many forage *Brassica* growers in Victoria also applied synthetic pyrethroids to their crops in spring 1999, with a frequency of one to four applications per crop, which suggests that resistant DBM populations are being generated.

Many factors may be causing an increase in numbers of DBM in non-vegetable hosts and selection for synthetic pyrethroid resistance. The great increase in area of host plants such as canola must be generating higher numbers of moths. Favourable weather conditions such as a dry winter in 1999 could explain the massive numbers of DBM in spring canola and forage brassicas. Spraying for other pests may be inducing insecticide resistance in DBM as well as destroying natural enemies which leads again to increased numbers of DBM. We observed very high levels of biological control by the ichneumonid parasitoid, *Diadegma semiclausum*, in some unsprayed forage crops around Warrnambool in December 1999, but in sprayed crops within the same district, use of synthetic pyrethroids had started to disrupt this level of biological control. Unfortunately, the growers and their advisers believe that their only control option is to use synthetic pyrethroid insecticides. *Bacillus thuringiensis* would be the ideal biological insecticide for use in this situation, but is considered too expensive. A continued increase in use of synthetic insecticides in non-vegetable will continue to exacerbate problems with DBM. Enhanced biological control and other non-insecticide control methods will be the only way to reduce DBM to minor pest status.

There is little published information about long range movement of DBM in southern Australia between different types of host plant, but resistance levels in remote weed crops suggest that moths are moving from vegetable and canola growing regions. Information about movement patterns is important for design of rational insecticide resistance management strategies for vegetable and non-vegetable crops. The current study should be expanded to look at the resistance status of more

populations on a range of host plants, but in order to gain a better understanding of long range moth movement, genetic studies such as use of microsatellite DNA markers will be required.

Acknowledgements

We thank Agriculture Western Australia, SARDI and others for organizing collection of DBM populations from canola in WA and SA.

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APPENDIX A

Collection details, resistance ratios and generation tested for resistance to permethrin for diamondback moth populations from southern Australian 1999-2000. Resistance ratios assume parallel slopes for each test. If parallel slopes could not be fitted for a particular assay, then ratio was calculated at LC₅₀. A resistance ratio of 1 indicates that a field population is equivalent in susceptibility to the susceptible laboratory population (Waite).

DBM population	Date	Resistance	95% c. i.		Gen
	Collected	Ratio	lower	Upper	
Loch VIC weeds	7/9/99	0.1*	0.02	0.7	F1
Clunes VIC weeds	6/10/99	0.5	0.3	0.7	F1
Balliang East VIC canola	12/10/99	0.5*	0.2	1.3	F1
Brock St, Thomastown VIC weeds	19/10/99	0.5*	0.2	1.2	F4
Yeelanna SA canola	7/10/99	1.0	0.6	1.5	F1
Stratford VIC weeds	12/11/99	1.3*	0.3	6.2	F2
Kirks Bridge Rd VIC canola	27/9/99	1.3*	0.6	2.6	F1
Horsham VIC weeds	3/11/99	1.3*	0.7	2.3	F3
Springhurst VIC weeds	24/10/99	1.8*	0.4	8.7	F1
Cranbourne weeds VIC	28/10/99	2.1*	1.4	3.1	F2
Arthurton SA canola	7/10/99	2.2	1.6	3.1	F1
Derrinallum VIC weeds	8/12/99	3.0*	2.0	4.6	F1
Urania SA canola	7/10/99	3.0	2.1	4.2	F1
Wauraltee SA canola	7/10/99	3.5	2.1	6.0	F1
Werribee cabbage VIC	15/9/99	3.6	2.5	5.4	F1
Finley NSW weeds	27/10/99	4.0*	2.7	6.0	F1
Werribee weeds in crop VIC	16/11/99	4.1*	2.8	5.8	F2
Minlaton SA canola	7/10/99	4.3	2.9	6.5	F1
Ayrford VIC forage turnips	8/12/99	4.4	3.0	6.6	F2
Bridgetown WA weeds	7/10/99	4.8*	3.5	6.4	F1
Canberra ACT weeds	25/10/99	4.9*	3.0	8.0	F1
Jugiong NSW weeds	26/10/99	4.9*	3.4	7.1	F1
Wongan Hills WA canola	7/10/99	5.1*	3.4	7.5	F1
Woolnorth TAS seed turnips	5/01/00	5.1*	3.4	7.5	F1
Manjimup WA cauliflower	7/10/99	5.2*	3.4	8.0	F1
Lindenow old cabbage VIC	8/9/99	5.8	4.0	8.8	F1
Curdie Vale VIC forage turnips	8/12/99	6.0*	4.1	8.9	F1
Bunbury WA weeds	7/10/99	6.6	5.0	8.9	F1
Burabadji WA canola	7/10/99	6.7	4.8	9.6	F1
Balingup WA weeds	7/10/99	6.9*	4.6	10.2	F1
Deadman's Gully WA weeds	7/10/99	6.9*	5.0	9.4	F1
Nairne SA Brussels sprouts	15/11/99	10.7*	6.6	17.2	F1
Bairnsdale new seedlings VIC	7/9/99	13.0	8.8	20.8	F1

*calculated at LC₅₀

APPENDIX B
LC₅₀ and LC₉₅ for permethrin tested on diamondback moth populations from southern Australia compared with the standard laboratory population (Waite), 1999-2000.

Date tested	Population	Host	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀	95% confidence intervals	LC ₉₅	95% confidence intervals
6/10/99	Waite	Lab	279	40	2.35 ± 0.34	0.84	0.08	21.9	26	8.4	5.7 - 11.1	42.2	31.1 - 67.4
6/10/99	Werrbee	Cabbage	281	40	1.68 ± 0.20	1.49	0.09	38.8	26	25.5	17.3 - 34.6	244.3	148.1 - 580.2
12/10/99	Waite	Lab	280	40	2.16 ± 0.38	0.75	0.12	19.4	26	10.5	5.7 - 15.2	60.8	42.9 - 108.3
12/10/99	Lindenow	Cabbage	279	41	1.57 ± 0.18	1.08	0.06	28.0	26	52.5	39.9 - 68.5	590.4	348.7 - 1364.8
12/10/99	Barnsdale	Cabbage	282	40	1.58 ± 0.19	0.93	0.06	24.3	26	125.9	97.7 - 172.7	1378.2	755.0 - 3570.6
18/10/99	Waite	Lab	280	40	2.38 ± 0.26	1.35	0.07	35.0	26	11.6	8.7 - 14.8	57.0	40.7 - 95.8
18/10/99	Loch	Weed	280	40	1.21 ± 0.36	1.20	0.46	31.3	26	1.5	0.004 - 4.9	33.2	17.7 - 108.5
1/11/99	Waite	Lab	279	40	2.23 ± 0.28	1.01	0.07	27.2	26	12.5	8.9 - 16.2	68.4	49.5 - 111.9
1/11/99	Arthurton	Canola	279	40	1.90 ± 0.22	1.05	0.06	26.3	26	26.1	19.7 - 32.9	191.6	131.3 - 341.4
1/11/99	Urania	Canola	282	40	1.84 ± 0.20	1.19	0.06	30.9	26	34.7	26.3 - 44.3	271.5	178.4 - 520.8
3/11/99	Waite	Lab	280	40	1.82 ± 0.24	0.94	0.06	24.4	26	6.2	4.1 - 8.3	49.7	34.8 - 84.2
3/11/99	Minlaton	Canola	280	40	1.84 ± 0.21	1.53	0.08	39.8	26	26.7	18.6 - 35.5	208.4	132.8 - 442.3
3/11/99	Kirks Bridge Rd	Canola	280	40	1.19 ± 0.21	0.82	0.12	48.3	26	7.8	3.2 - 12.8	189.9	111.6 - 509.2
17/11/99	Waite	Lab	280	40	1.82 ± 0.14	1.66	0.10	43.2	26	8.8	5.3 - 12.6	70.9	45.1 - 150.9
17/11/99	Wauraltee	Canola	280	40	1.44 ± 0.19	1.93	0.14	50.1	26	27.1	14.9 - 41.1	376.2	191.7 - 1484.6
17/11/99	Yeelanna	Canola	280	40	1.53 ± 0.27	1.09	0.14	28.3	26	7.2	2.9 - 11.4	85.8	55.6 - 194.4
23/11/99	Waite	Lab	280	40	2.26 ± 0.31	0.96	0.07	25.1	26	7.7	5.4 - 10.0	41.1	30.1 - 65.8
23/11/99	Wongan Hills	Canola	280	40	1.58 ± 0.19	1.58	0.09	41.0	26	39.1	27.2 - 53.7	433.1	241.9 - 1214.7
23/11/99	Burabadi	Canola	280	40	1.99 ± 0.26	1.24	0.09	32.1	26	49.2	33.0 - 67.1	328.8	212.5 - 682.8
29/11/99	Waite	Lab	280	40	2.26 ± 0.28	1.49	0.10	34.0	26	21.0	14.3 - 28.0	112.4	76.2 - 216.9
29/11/99	Manjimup	Cauliflower	280	40	1.25 ± 0.19	1.31	0.12	38.8	26	108.5	72.7 - 177.7	2245.3	880.3 - 14538.9
29/11/99	Clunes	Weeds	280	40	2.36 ± 0.41	3.10	0.39	80.7	26	9.7	2.3 - 15.8	48.4	29.1 - 234.5
1/12/99	Waite	Lab	280	40	2.52 ± 0.27	1.21	0.06	31.4	26	13.4	10.5 - 16.6	60.0	43.8 - 96.5
1/12/99	Balling Linn	Canola	280	40	0.92 ± 0.19	1.93	0.35	50.3	26	7.3	0.4 - 17.3	438.5	157.7 - 15038.9
8/12/99	Waite	Lab	280	39	2.37 ± 0.25	1.05	0.05	27.4	26	16.8	13.4 - 20.6	83.3	60.9 - 131.1
8/12/99	Bunbury	Weeds	280	40	1.99 ± 0.22	0.60	0.05	15.7	26	111.4	90.6 - 141.2	746.2	482.6 - 1435.3
13/12/99	Waite	Lab	280	40	3.46 ± 0.48	1.16	0.09	30.1	26	8.1	6.1 - 10.0	24.2	18.8 - 36.3
13/12/99	Balingup	Weeds	280	40	1.12 ± 0.16	1.71	0.16	44.5	26	55.8	34.2 - 89.8	1710.4	605.3 - 17517.9

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for permethrin tested on diamondback moth populations from southern Australia compared with the standard laboratory population (Waite), 1999-2000.

Date tested	Population	Host	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀	95% confidence intervals	LC ₉₅	95% confidence intervals
15/12/99	Waite	Lab	280	40	3.42 ± 0.43	0.56	0.06	14.5	26	12.1	10.0 - 14.2	36.6	29.2 - 51.3
15/12/99	Deadman's Gully	Weeds	280	40	1.49 ± 0.18	0.71	0.06	18.5	26	82.9	64.4 - 110.1	1061.7	590.3 - 2679.7
15/12/99	Bridgetown	Weeds	280	40	1.58 ± 0.18	1.49	0.09	38.7	26	57.5	42.0 - 79.4	632.7	343.2 - 1831.3
5/1/00	Waite	Lab	279	40	3.51 ± 1.03	0.73	0.33	19.1	26	11.6	5.3 - 15.1	34.2	26.3 - 76.2
5/1/00	Nairne	Sprouts	280	40	1.30 ± 0.17	1.45	0.11	37.8	26	124.3	82.1 - 177.6	2267.9	1092.2 - 9035.5
11/1/00	Waite	Lab	280	40	3.43 ± 0.51	1.65	0.15	43.0	26	19.8	14.0 - 25.1	59.6	43.7 - 109.0
11/1/00	Stratford	Weeds	280	40	1.21 ± 0.17	1.13	0.10	29.5	26	25.3	15.5 - 35.9	584.8	297.3 - 2010.2
11/1/00	Springhurst	Weeds	280	40	1.23 ± 0.17	1.69	0.13	44.0	26	36.0	22.1 - 53.2	685.2	317.2 - 3231.3
13/1/00	Waite	Lab	240	40	3.19 ± 0.38	1.81	0.11	39.8	22	9.3	6.8 - 11.9	30.4	22.0 - 52.6
13/1/00	Canberra	Weeds	280	40	0.79 ± 0.16	1.75	0.29	45.6	26	45.2	19.7 - 87.2	5400.4	1001.7 - 1324537.9
13/1/00	Finley	Weeds	280	41	1.07 ± 0.17	1.57	0.16	40.8	26	37.0	20.9 - 57.5	1278.8	475.7 - 11665.0
13/1/00	Jugiong	Weeds	280	40	1.18 ± 0.17	1.14	0.10	29.6	26	45.2	30.7 - 63.9	1120.0	515.3 - 4661.7
17/1/00	Waite	Lab	280	40	3.59 ± 0.47	0.53	0.07	13.8	26	5.9	4.8 - 7.1	16.9	13.3 - 24.2
17/1/00	Derrinallum	Weeds	280	40	1.46 ± 0.20	1.27	0.11	33.0	26	17.8	10.2 - 25.7	238.0	140.0 - 615.5
25/1/00	Waite	Lab	280	40	2.87 ± 0.36	0.86	0.06	22.3	26	6.5	5.1 - 8.0	24.5	18.8 - 36.0
25/1/00	Curdie Vale	Turnip	280	40	1.17 ± 0.17	1.37	0.12	35.6	26	39.3	25.1 - 57.5	991.6	432.4 - 5105.5
16/2/00	Waite	Lab	280	40	2.56 ± 0.28	4.14	0.20	107.7	26	11.8	6.7 - 17.8	52.3	31.6 - 157.6
16/2/00	Ayrford	Turnip	280	40	2.23 ± 0.27	0.79	0.06	20.7	26	50.4	38.9 - 62.9	274.9	197.6 - 450.3
16/2/00	Werribee	Weeds	280	40	1.25 ± 0.17	1.01	0.08	26.2	26	48.1	34.6 - 65.6	996.2	497.9 - 3279.8
28/2/00	Waite	Lab	280	40	3.37 ± 0.41	0.46	0.06	12.0	26	8.6	7.0 - 10.2	26.5	21.0 - 37.3
28/2/00	Woolnorth	Turnip	280	40	1.25 ± 0.18	1.17	0.10	30.3	26	43.6	28.1 - 63.1	895.0	429.7 - 3474.8
15/3/00	Waite	Lab	280	40	2.47 ± 0.27	3.28	0.17	85.3	26	9.8	5.8 - 14.3	45.5	28.3 - 118.0
15/3/00	Cranbourne	Weeds	280	40	1.63 ± 0.21	1.64	0.11	42.7	26	20.3	11.9 - 29.3	207.0	123.1 - 531.4
25/5/00	Waite	Lab	280	40	2.46 ± 0.28	1.94	0.11	28.7	26	8.47	5.6 - 11.5	39.5	27.0 - 75.6
25/5/00	Thomastown	Weeds	280	40	1.44 ± 0.30	1.10	0.20	50.4	26	4.08	0.9 - 7.9	56.6	36.5 - 131.5
25/5/00	Horsham	Weeds	280	40	1.17 ± 0.19	1.02	0.12	26.4	26	11.02	5.0 - 17.3	278.0	153.4 - 852.0

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

National Diamondback Moth Insecticide Resistance Monitoring PROPOSAL SUMMARY

This document outlines a proposal to establish a national system for monitoring changes in susceptibility to novel insecticides registered (or soon to be registered) for control of diamondback moth (DBM), *Plutella xylostella*, in Australia.

A range of field-collected populations of DBM from around Australia will be screened twice a year for changes in susceptibility to fipronil, spinosad, emamectin benzoate, chlorfenapyr and indoxacarb. In addition, a synthetic pyrethroid, an organophosphate and a formulation of *Bacillus thuringiensis* var *kurstaki* will be tested.

Results will be supplied to AIRAC on a 3-monthly basis. Extra testing will be conducted in event of control problems. Each year, the results from the previous year will be discussed and the testing plan for the next 12 months will be detailed in consultation with AIRAC representatives and growers.

In order to implement the testing in this financial year, we propose that the resistance monitoring system will consist of two phases:

Phase 1 (July 1999 - June 2000)

Addition to the existing HRDC Project VG97014 "Advancing the integrated management of diamondback moth in crucifer vegetables"

Background

The major pest of vegetable brassicas in Australia is diamondback moth (DBM). Prophylactic use of insecticides over many years has led to the development of insecticide resistance, and hence control failures and economic crop losses. Resistance to synthetic pyrethroid insecticides has been identified in growing areas in all states and resistance to organophosphate insecticides has been identified in some states.

In 1997, an HRDC project VG97014 "Advancing the integrated management of diamondback moth in crucifer vegetables" was established with additional funding from major agrochemical companies. Also in 1997, AIRAC, in consultation with researchers, devised a two-window insecticide resistance management strategy for diamondback moth. By late 1998, chlorfenapyr and fipronil had both been registered and so the two-window strategy was launched to growers nationally. The strategy is reviewed regularly and is to be updated as new products become registered.

A national resistance monitoring program would involve testing field populations from each major *Brassica* producing state using diagnostic doses for each of the new products. Where significant changes in response are observed in any field population, more detailed testing would be conducted to determine resistance status of the population. These data will provide valuable insights on the progress of the resistance management strategy to all facets of the industry.

Brief literature review

French-Constant and Roush (1990) reviewed the techniques of resistance detection including both pesticide and biochemical assays. This comprehensive review outlines the strengths and weaknesses of various resistance detection strategies.

Brent (1986) listed seven possible aims of resistance monitoring:

1. document resistance or confirm whether control failure was caused by resistance
2. measure and identify resistant genotypes accurately (necessary to meet remaining aims)
3. provide early warning of impending resistance problems
4. determine changes in distribution or severity of resistance

5. make recommendations about pesticides least affected by resistance
6. measure biological characteristics of genotypes under field conditions
7. test effectiveness of resistance management tactics

Roush and Miller (1986) demonstrated that to detect resistant individuals at a frequency of 1% requires a sample of 1500 individuals (with an imperfect diagnostic dose such as we have with *Plutella*) whereas only 100 individuals would be required to detect resistance frequencies of 10%. Realistically, the approach outlined below will primarily address only the first aim unless very large (and expensive) samples (>1500 larvae per site) are used.

Current situation

Currently, most resistance testing in Australia is conducted by Nancy Endersby at the Institute for Horticultural Development, Knoxfield. Testing for resistance to *Bacillus thuringiensis* is being done by Mahmood Ahmad at the Waite Institute as part of his PhD program. Limited testing with synthetic pyrethroids and organophosphates is being conducted by Agriculture Western Australia as part of the national project. With only existing resources, substantial expansion of resistance testing would be impossible.

Intended approach

Substantial changes in susceptibility to synthetic chemicals and *Bacillus thuringiensis*, in commercial *Brassica* crops in Australia will be identified through leaf dip bioassays. The researchers at IHD have developed a standard protocol, using a standard susceptible strain and the Tabashnik & Cushing (1987) leaf dip method, for testing. Discriminating doses for most of the commonly used insecticides in the industry have been determined. This will allow the testing of DBM populations from around Australia to determine their susceptibility to particular insecticides.

Phase 1 - (July 1999 - June 2000) - Addition to the HRDC project VG97014

“Advancing the integrated management of diamondback moth in crucifer vegetables”

- screening of a range of field populations to establish or confirm appropriate diagnostic doses for indoxacarb and chlorfenapyr
- test a minimum of 4 populations of DBM from Queensland and 2 populations from New South Wales, Victoria, South Australia and Western Australia with a diagnostic dose for 8 compounds (compared to the susceptible Waite population each time, 10 replicates, 10 third instar larvae per replicate). Field populations will be collected (minimum of 200 life stages) at the end of each window.

Test chemicals will be: fipronil, chlorfenapyr, spinosad, emamectin benzoate, indoxacarb, a synthetic pyrethroid, *Bacillus thuringiensis* and an organophosphate: methamidophos.

- more detailed bioassays will be undertaken in particular cases as required
- results to be forwarded every 3 months to AIRAC and to project researchers
- results from the previous year will be discussed and the testing plan for the next 12 months will be detailed in consultation with AIRAC representatives and growers.

Phase 2

Fully incorporate the agreed resistance testing strategy into the proposed Phase II HRDC project for diamondback moth (July 2000 - June 2003) which will be submitted as a preliminary proposal to HRDC later this year.

Investigators and Proposed location

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National DBM Insecticide Resistance Testing program FIRST ROUND OF DBM BIOASSAY RESULTS to 31st July 2000

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Introduction

The major pest of *Brassica* vegetables in Australia is diamondback moth (DBM), *Plutella xylostella* (L.). This pest has developed insecticide resistance due to prophylactic use of insecticides over many years. Insecticide resistance has caused control failures and economic loss in vegetable crops. Resistance to synthetic pyrethroid insecticides has been identified in DBM populations from vegetable growing areas in all states and resistance to organophosphate insecticides has been identified in some states. Earliest resistance testing of DBM in Australia was conducted by Hargreaves (1996), followed by Baker and Kovaliski (1999) and Endersby and Ridland (1997).

In 1997, a project funded by the Horticultural Research and Development Corporation "Advancing the integrated management of DBM in crucifer vegetables" was established with additional funding from major agrochemical companies. Also in 1997, AIRAC, in consultation with researchers, devised a two-window insecticide resistance management strategy for DBM. By late 1998, chlorfenapyr and fipronil had both been registered for control of DBM and so the two-window strategy was launched to growers around Australia. The strategy is reviewed regularly and is updated as new products become registered. Four products are currently partitioned into the two-window strategy. In southern Australia, Secure[®] (chlorfenapyr) and Success[®] (spinosad) may be used from 1st September to 31st January, whereas Regent[®] and Proclaim[®] may be used from 1st February to 31st August.

The national resistance monitoring program was established in 1999. The program involves testing of field populations of DBM from each major *Brassica* producing state with a variety of new and long-established insecticides. The data collected will provide valuable insights to all facets of the industry on the progress of the resistance management strategy. This is the first report of the program and gives details of results to July 31st 2000.

Methods

Larvae of diamondback moth were collected from *Brassica* crops in New South Wales, South Australia, Tasmania, Western Australia and Victoria (Table 1) and were reared on cabbage seedling leaves (*Brassica oleracea* var. *capitata* cv. Green Coronet) in the laboratory at 25 °C (16h:8h, L:D) for one to three generations. A susceptible laboratory population of diamondback moth, maintained at IHD Knoxfield since it was obtained from the University of Adelaide, Department of Crop Protection Waite Campus, SA, in 1994, was used as a reference.

Table 1. Origin and generation of Australian diamondback moth populations tested for susceptibility to insecticides, 1999/2000

Population	Origin	Generation tested
Waite	Laboratory population	*
Manjimup WA	Cauliflower crop	F1 – F3
Nairne SA	Brussels sprouts crop	F1 – F3
Werribee South VIC	Broccoli crop	F1 – F2
Woolnorth TAS	Forage <i>Brassica</i> crop	F1 – F2
Castlereagh NSW	Savoy cabbage crop	F1 – F2

A leaf dip bioassay after Tabashnik and Cushing (1987) was adopted for testing susceptibility to each insecticide. Variations in method for some insecticides were determined by company preferences or were those used in previous monitoring programs for the particular insecticide. For example, fipronil was tested worldwide at 22°C and indoxacarb was tested at 25°C. The remaining insecticides were all

tested at 28°C (Table 2). Cabbage leaf discs of 4.5 cm diameter were dipped for 5 s in distilled water solutions of formulated insecticide and hung vertically to dry in a fume hood for 2 h. Control discs were dipped in distilled water. No wetting agents were used except for Bond Spraymate™ with emamectin benzoate and X-77® with indoxacarb. Discs were placed into Gelman® 50 mm diameter x 9 mm plastic Petri dishes. For fipronil, five third instar diamondback moth larvae were placed on each disc and eight replicates of each concentration were set up. For each of the other insecticides, ten larvae were placed on each disc and four replicates of each concentration were set up. Mortality was assessed at different times for different insecticides (Table 2). Larvae were considered dead if they did not move when touched with a paintbrush.

Table 2. Insecticides tested, assessment times and temperatures used in bioassays of diamondback moth, *Plutella xylostella* from Australia, 1999/2000

Insecticide	Product name	Assessment times	Temperature
alpha-cypermethrin	Fastac®	48 h	28°C
<i>Bacillus thuringiensis</i>	Delfin WG®	72 h, 96 h	28°C
chlorfenapyr	Secure®	48 h, 72 h	28°C
emamectin benzoate	Proclaim®	48 h, 72 h	28°C
fipronil	Regent®	48 h, 72 h	22°C
indoxacarb	Avatar®	48 h, 72 h	25°C
methamidophos	Nitofol®	48 h	28°C
novaluron	Rim On®	48 h, 72 h	28°C
permethrin	Ambush®	48 h	28°C
spinosad	Success®	72 h	28°C

Analysis

Concentration-mortality data for each population were analysed using the probit analysis program, POLO-PC (Russell *et al.* 1977) (LeOra Software). We used the program to estimate the lethal concentration expected to cause 50% mortality (LC₅₀) of each insecticide for each diamondback moth population and the 95% confidence intervals for these concentrations. The slope (+ standard error) of the probit line was also estimated.

The program also performed χ^2 tests for goodness-of-fit of the data to the probit model. If the model fits, the calculated value of χ^2 is less than the χ^2 table value for the appropriate degrees of freedom. If the model does not fit (i.e. the χ^2 value exceeds the table value), the LC₅₀ value for the particular population may not be reliably estimated and is adjusted with the heterogeneity factor (χ^2/df). The index of significance for potency estimation (g) was used to calculate 95% confidence intervals for potency (relative potency is equivalent to tolerance ratio) (Robertson and Preisler 1992, p.29).

Parallelism of the probit regression lines implies a constant relative potency at all levels of response (Finney 1971). Equality and parallelism of the slopes of the probit lines for the field population and the laboratory susceptible population were also tested for by POLO-PC. If the slopes are parallel, then overlap of the 95% confidence intervals for the two populations indicates that no significant difference exists between the LC₅₀ values.

Results

A summary of the results comparing the levels of tolerance to the test insecticides for the five populations tested so far for round 1 (1999/2000) is presented in Table 3. The summary is based on comprehensive listings of tolerance ratios for the ten insecticides tested on diamondback moth populations from WA, SA, VIC, TAS and NSW compared with the standard laboratory population (Waite) 1999/2000, provided in Appendix A. A tolerance ratio of 1 indicates that a field population is equivalent in susceptibility to the Waite population.

Similarly, the values of LC₅₀ and LC₉₅ and associated statistics from the probit analyses for the ten insecticides tested on diamondback moth populations from WA, SA, VIC, TAS and NSW compared with the standard laboratory population (Waite) 1999/2000 are listed in Appendix B.

Baseline susceptibility data (unpublished) for chlorfenapyr were obtained for nine Australian DBM populations in 1998/99 and results are presented in Appendix C.

Table 3. Comparison of levels of tolerance to ten insecticides tested on DBM populations from five states in round 1 (1999/2000)

Insecticide		WA	SA	VIC	TAS	NSW
alpha-cypermethrin	48 h	C	C	C	C	C
<i>Bacillus thuringiensis</i>	96 h	A	A	A	A	Not yet tested
chlorfenapyr	48 h	A	B	B	B	Not yet tested
emamectin benzoate	72 h	C	B	C	B	A
fipronil	72 h	A	B	A	A	Not yet tested
indoxacarb	72 h	A	A	A	Not yet tested	Not yet tested
methamidophos	48 h	B	A	B	A	B
novaluron	72 h	A	A	A	Not yet tested	Not yet tested
permethrin	48 h	C	D	E	E	E
spinosad	72 h	A	A	A	A	Not yet tested

SCALE

- A – No tolerance:** A tolerance ratio of 1 indicates that a field population is not significantly different in susceptibility to the laboratory population (Waite).
- B – Very low tolerance:** Tolerance ratios significantly higher than 1, but upper 95% confidence interval not greater than 3.5
- C – Low tolerance:** Tolerance ratios with 95% confidence intervals between 2 and 13.1
- D – Moderate tolerance:** Upper 95% confidence intervals approaching 20 - reduced efficacy of this insecticide could be observed against this population in the field.
- E – High tolerance:** Upper 95% confidence intervals of 20 or above. This insecticide could fail to provide adequate control of this population in the field.

Conclusions

ALPHA-CYPERMETHRIN

Low tolerance to alpha-cypermethrin was observed in all populations tested. Tolerance ratios ranged from 3.6 to 8.9 times the standard laboratory population (Waite) (Appendix A).

BACILLUS THURINGIENSIS

No tolerance was shown towards *Bacillus thuringiensis* in the populations tested.

CHLORFENAPYR

Out of nine populations tested in 1998/99 (Appendix C), only one population (Castlereagh, NSW) showed tolerance to chlorfenapyr and this was at a very low level. In the current round of tests, the WA population showed no tolerance to chlorfenapyr. Very low levels of tolerance to chlorfenapyr were observed in the SA, VIC and TAS populations tested. Tolerance ratios ranged from 1.46 to 1.85 times the standard laboratory population (Waite) (Appendix A).

EMAMECTIN BENZOATE

Baseline susceptibility data for emamectin benzoate were generated for Australian DBM populations in 1997 (Endersby and Ridland, 1998a) and a 21-fold difference between the lowest and highest LC₅₀

values at 96 h were observed these tests. Lasota *et al.* (1996) suggested that some variability in tolerance to avermectins between DBM populations could be due to differences in translaminar uptake of the compounds between different leaf discs.

In the current round of bioassays, the NSW population showed no tolerance to emamectin benzoate. The NSW population tested in 1997 (Endersby and Ridland, 1998a) showed a low level of tolerance [72 h ratio of 2.38 (1.33 – 4.63)]. Both the WA and VIC population showed low tolerance to the insecticide in the current round of tests. The WA tolerance ratio in 1997 (72 h) was 6.05 (3.09 – 12.94) compared with the 1999/00 ratio of 3.43 (2.31 – 5.35). The VIC tolerance ratio in 1997 (72 h) was 1.62 (0.90 – 2.92) compared with 2.74 (1.96 – 3.85) in the current round of tests. SA and TAS populations showed a very low level of tolerance to this compound. SA had one susceptible and one tolerant population in 1997 (#1 1.59 [0.86 – 2.97], #2 13.27 [5.20 – 69.37]). The TAS 1997 72 h ratio was 1.57 (0.82 – 3.13) compared with 1.54 (1.17 – 2.03) in 1999/00.

FIPRONIL

WA, VIC and TAS populations showed no tolerance to this insecticide. The SA population showed very low tolerance to fipronil. The SA 72 h tolerance ratio of 1.88 (1.37 – 2.58) fits within the 95% confidence intervals of SA populations tested in 1996/97 [2.83 (1.85 – 4.39), 1.40 (0.89 – 2.11)], (Endersby and Ridland, 1998b) and in 1998/99 [1.4 (1.0 – 2.0)] (Endersby *et al.* 2000).

INDOXACARB

No tolerance was shown towards indoxacarb in the populations tested.

METHAMIDOPHOS

SA and TAS populations showed no tolerance to methamidophos. NSW, WA and VIC populations showed very low levels of tolerance to this organophosphate. Tolerance ratios ranged from 1.53 to 2.43 times the standard laboratory population (Waite) (Appendix A).

NOVALURON

No tolerance was shown towards novaluron in the populations tested.

PERMETHRIN

Highest levels of tolerance to permethrin were found in the NSW population. At this observed level of tolerance of permethrin, field control failures are often observed. At the upper 95% confidence intervals of the SA and VIC ratios, control failures could also be possible. The WA population showed a lower level of tolerance to permethrin than that of SA and VIC.

SPINOSAD

Baseline susceptibility data collected in 1997 (Endersby and Ridland 1998c) showed low levels of tolerance in a population from Tasmania and one from Western Australia. No tolerance was detected towards spinosad in any of the populations tested in the current study.

Plans for testing in the next six months

1. Short-term: complete testing of TAS and NSW populations
2. Full testing of Queensland population to complete round 1
3. Commencing round 2: collecting and testing new populations from each state
4. Synthetic pyrethroid testing of DBM populations currently causing problems in canola

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APPENDIX A

Tolerance ratio (assuming parallel slopes for each test) for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000. If parallel slopes could not be fitted for a particular assay, then tolerance ratio was calculated at LC₅₀.

A tolerance ratio of 1 indicates that a field population is equivalent in susceptibility to the Waite population.

ALPHA-CYPERMETHRIN

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen	
				Lower	Upper		
Nairne	SA	48	8.85	6.00	13.05	F2	Calculated at LC ₅₀
Manjimup	WA	48	6.08	4.50	8.45	F3	
Werribee South	VIC	48	4.16	2.87	6.23	F1	
Woolnorth	TAS	48	5.47	3.97	7.77	F1	
Castlereagh	NSW	48	3.56	2.60	4.94	F2	

BACILLUS THURINGIENSIS

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen
				Lower	Upper	
Manjimup	WA	72	0.52	0.29	0.92	F3
Nairne	SA	72	0.50	0.26	0.95	F3
Werribee South	VIC	72	1.00	0.51	1.96	F2
Woolnorth	TAS	72	0.98	0.46	2.07	F2
Manjimup	WA	96	0.63	0.27	1.36	F3
Nairne	SA	96	0.64	0.34	1.15	F3
Werribee South	VIC	96	1.11	0.51	2.47	F2
Woolnorth	TAS	96	0.47	0.14	1.30	F2

CHLORFENAPYR

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen	
				Lower	Upper		
Manjimup	WA	48	0.83	0.60	1.16	F2	Calculated at LC ₅₀
Nairne	SA	48	1.80	1.27	2.60	F2	
Werribee South	VIC	48	2.11	1.49	3.02	F1	
Woolnorth	TAS	48	1.59	1.20	2.11	F1	
Nairne	SA	72	1.46	1.01	2.12	F2	
Werribee South	VIC	72	1.85	1.23	2.89	F1	
Woolnorth	TAS	72	1.59	1.16	2.20	F1	

APPENDIX A (continued)

EMAMECTIN BENZOATE

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen
				Lower	Upper	
Manjimup	WA	48	3.01	1.92	4.94	F3
Nairne	SA	48	2.02	1.33	3.05	F3
Werribee South	VIC	48	3.51	2.15	6.16	F2
Woolnorth	TAS	48	1.39	0.85	2.30	F2
Castlereagh	NSW	48	1.48	1.06	2.08	F2
Manjimup	WA	72	3.43	2.31	5.35	F3
Nairne	SA	72	1.87	1.42	2.46	F3
Werribee South	VIC	72	2.74	1.96	3.85	F2
Woolnorth	TAS	72	1.54	1.17	2.03	F2
Castlereagh	NSW	72	1.45	0.88	2.44	F2

Calculated at LC₅₀

FIPRONIL

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen
				Lower	Upper	
Nairne	SA	48	1.87	1.33	2.67	F2
Manjimup	WA	48	0.96	0.67	1.34	F3
Werribee South	VIC	48	1.67	1.15	2.40	F1
Woolnorth	TAS	48	1.50	1.02	2.17	F1
Nairne	SA	72	1.88	1.37	2.58	F2
Manjimup	WA	72	1.17	0.91	1.50	F3
Werribee South	VIC	72	1.18	0.80	1.75	F1
Woolnorth	TAS	72	1.39	1.03	1.87	F1

Calculated at LC₅₀

INDOXACARB

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen
				Lower	Upper	
Manjimup	WA	48	1.43	0.76	2.74	F3
Nairne	SA	48	1.39	0.87	2.24	F3
Werribee South	VIC	48	0.56	0.33	0.91	F2
Manjimup	WA	72	1.02	0.56	1.85	F3
Nairne	SA	72	0.77	0.41	1.43	F3
Werribee South	VIC	72	0.60	0.36	1.00	F2

METHAMIDOPHOS

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen
				Lower	Upper	
Nairne	SA	48	1.12	0.91	1.39	F2
Manjimup	WA	48	1.53	1.16	2.05	F3
Werribee South	VIC	48	1.70	1.34	2.14	F1
Woolnorth	TAS	48	1.16	0.93	1.46	F1
Castlereagh	NSW	48	2.43	1.90	3.16	F2

Calculated at LC₅₀

APPENDIX A (continued)

NOVALURON

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen
				Lower	Upper	
Manjimup	WA	48	1.41	0.75	2.69	F3
Nairne	SA	48	0.93	0.51	1.72	F3
Werribee South	VIC	48	1.21	0.76	1.94	F2
Manjimup	WA	72	1.53	0.68	3.53	F3
Nairne	SA	72	0.25	0.12	0.49	F3
Werribee South	VIC	72	1.51	0.74	3.15	F2

PERMETHRIN

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen	
				Lower	Upper		
Nairne	SA	48	10.68	6.61	17.25	F1	Calculated at LC ₅₀
Manjimup	WA	48	5.18	3.35	8.00	F1	Calculated at LC ₅₀
Werribee South	VIC	48	14.39	9.03	25.21	F1	
Woolnorth	TAS	48	17.25	11.90	26.50	F2	
Castlereagh	NSW	48	21.61	14.21	32.88	F1	Calculated at LC ₅₀

SPINOSAD

DBM population	State	h	Tolerance Ratio	95% c. i.		Gen
				Lower	Upper	
Manjimup	WA	72	1.00	0.75	1.32	F1
Nairne	SA	72	1.28	0.63	2.87	F2
Werribee South	VIC	72	1.16	0.59	2.29	F1
Woolnorth	TAS	72	0.81	0.41	1.55	F1

APPENDIX B

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

ALPHA-CYPERMETHRIN

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ppm)	95% confidence intervals		LC ₉₅ (ppm)	95% confidence intervals	
08/03/00	Waite	48	280	40	3.35 ± 0.45	0.95	0.07	24.3	26	11.95	9.78	14.15	37.01	29.01	53.94
08/03/00	Nairne SA	48	280	40	1.33 ± 0.16	1.49	0.09	38.7	26	105.75	66.15	163.03	1827.62	895.59	6164.16
29/03/00	Waite	48	280	40	2.10 ± 0.28	1.10	0.08	28.6	26	9.17	6.34	11.96	55.59	38.89	99.72
29/03/00	Manjimup WA	48	280	40	2.57 ± 0.32	0.99	0.06	25.8	26	58.86	48.48	71.10	256.46	184.95	426.10
03/05/00	Waite	48	280	41	2.08 ± 0.28	0.94	0.07	24.5	26	16.01	11.29	20.90	98.98	69.84	168.64
03/05/00	Werribee South VIC	48	280	40	2.26 ± 0.26	2.29	0.13	59.6	26	67.72	47.69	95.77	361.82	214.44	1000.20
03/05/00	Woolnorth TAS	48	279	40	2.53 ± 0.33	1.32	0.10	34.4	26	89.26	70.18	115.61	398.28	259.86	851.06
19/07/00	Waite	48	280	41	2.20 ± 0.23	0.89	0.04	23.1	26	18.94	15.44	22.89	105.90	77.24	166.16
19/07/00	Castlereagh NSW	48	280	40	1.96 ± 0.23	1.32	0.08	34.2	26	66.76	50.28	88.34	462.57	285.84	1030.70

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

BACILLUS THURINGIENSIS

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (g of product/ 100 L)	95% confidence intervals		LC ₉₅ (g of product/ 100 L)	95% confidence intervals	
17/05/00	Waite	72	280	40	1.66 ± 0.19	1.48	0.08	38.5	26	0.83	0.49	1.21	8.13	5.16	16.67
17/05/00	Manjimup WA	72	280	40	1.44 ± 0.20	1.63	0.14	42.4	26	0.37	0.14	0.65	5.15	2.96	13.38
17/05/00	Nairne SA	72	282	40	1.45 ± 0.19	2.02	0.15	52.4	26	0.36	0.12	0.65	4.91	2.74	14.05
5/06/00	Waite	72	281	40	1.31 ± 0.14	2.47	0.11	64.1	26	0.25	0.13	0.43	4.49	2.08	18.05
5/06/00	Werribee South VIC	72	282	40	1.54 ± 0.17	1.56	0.08	40.6	26	0.27	0.16	0.41	3.11	1.74	7.84
5/06/00	Woolnorth TAS	72	279	40	1.33 ± 0.15	2.31	0.12	60.0	26	0.25	0.12	0.43	4.22	1.98	16.13
17/05/00	Waite	96	280	40	1.68 ± 0.26	1.32	0.13	34.2	26	0.29	0.12	0.49	2.79	1.71	6.22
17/05/00	Manjimup WA	96	280	40	1.23 ± 0.24	1.51	0.24	39.3	26	0.11	0.01	0.27	2.36	1.23	7.69
17/05/00	Nairne SA	96	282	40	1.59 ± 0.28	0.97	0.12	25.3	26	0.17	0.07	0.29	1.86	1.20	3.72
5/06/00	Waite	96	281	40	1.31 ± 0.20	2.09	0.20	54.4	26	0.07	0.02	0.14	1.29	0.59	6.65
5/06/00	Werribee South VIC	96	282	40	1.35 ± 0.20	1.45	0.14	37.8	26	0.08	0.03	0.14	1.35	0.70	4.55
5/06/00	Woolnorth TAS	96	280	40	0.94 ± 0.19	2.19	0.36	56.8	26	0.02	0.00	0.06	1.03	0.39	14.69

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

CHLORFENAPYR

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ppm)	95% confidence intervals	LC ₉₅ (ppm)	95% confidence intervals
01/02/00	Waite	48	280	40	2.70 ± 0.35	1.62	0.11	42.2	26	32.16	21.50 42.69	131.15	93.10 235.51
01/02/00	Manjimup WA	48	280	40	2.47 ± 0.33	0.89	0.07	23.1	26	25.85	18.61 33.01	120.06	89.67 186.02
23/02/00	Waite	48	280	40	2.55 ± 0.33	1.17	0.08	30.4	26	17.67	12.53 22.85	78.18	57.03 127.80
23/02/00	Nairne SA	48	280	40	2.02 ± 0.23	1.34	0.08	35.0	26	28.20	19.63 37.35	184.41	125.37 338.98
02/05/00	Waite	48	280	40	2.57 ± 0.27	1.25	0.06	32.4	26	43.69	34.30 54.20	190.29	138.91 305.05
02/05/00	Werribee South VIC	48	280	40	2.20 ± 0.22	1.76	0.08	45.8	26	89.65	67.40 117.53	499.83	325.97 1006.87
02/05/00	Woolnorth TAS	48	281	40	2.22 ± 0.23	0.95	0.04	24.6	26	67.19	54.49 81.48	370.95	272.08 574.89
23/02/00	Waite	72	280	40	3.67 ± 0.57	0.57	0.09	14.8	26	14.05	10.88 17.23	39.44	30.49 59.63
23/02/00	Nairne SA	72	280	40	2.20 ± 0.29	1.81	0.13	47.0	26	20.52	11.81 29.38	114.84	75.24 245.23
02/05/00	Waite	72	280	40	2.66 ± 0.50	1.12	0.17	29.2	26	29.65	16.03 40.83	123.07	90.18 220.94
02/05/00	Werribee South VIC	72	280	40	2.85 ± 0.29	3.68	0.16	95.6	26	56.38	37.02 78.90	212.98	136.72 515.60
02/05/00	Woolnorth TAS	72	282	40	3.27 ± 0.69	1.26	0.24	32.8	26	51.26	30.23 65.80	163.36	120.66 342.67

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

EMAMECTIN BENZOATE

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ng/ml)	95% confidence intervals		LC ₉₅ (ng/ml)	95% confidence intervals	
28/03/00	Waite	48	280	40	1.63 ± 0.19	2.41	0.14	62.6	26	27.64	17.25	42.43	283.54	141.03	1171.89
28/03/00	Manjimup WA	48	280	40	1.90 ± 0.21	1.04	0.05	27.1	26	80.77	63.35	107.83	592.98	359.82	1278.70
28/03/00	Waite	48	274	38	2.60 ± 0.26	3.06	0.13	79.5	26	38.80	27.86	55.87	166.37	100.71	441.13
28/03/00	Nairne SA	48	272	39	2.33 ± 0.36	1.41	0.14	36.7	26	79.20	56.94	107.66	401.81	244.37	1115.20
19/06/00	Waite	48	280	40	1.26 ± 0.17	1.02	0.08	26.7	26	158.49	106.99	284.13	3213.45	1233.66	17385.83
19/06/00	Werribee South VIC	48	280	40	1.59 ± 0.27	0.48	0.11	12.5	26	403.73	255.47	907.12	4348.17	1616.06	30598.52
19/06/00	Woolnorth TAS	48	281	40	1.38 ± 0.20	1.19	0.11	30.9	26	198.54	128.54	392.51	3080.59	1145.28	20433.78
19/07/00	Waite	48	281	40	2.24 ± 0.27	0.67	0.06	17.4	26	135.33	107.81	179.68	731.81	463.08	1488.99
19/07/00	Castlereagh NSW	48	280	40	2.21 ± 0.31	0.86	0.08	22.5	26	202.21	154.38	291.95	1122.79	648.63	2854.35
28/03/00	Waite	72	280	40	2.52 ± 0.34	1.86	0.15	48.4	26	10.04	6.28	13.75	45.14	30.27	96.71
28/03/00	Manjimup WA	72	280	40	2.13 ± 0.23	1.88	0.09	48.8	26	32.89	23.98	44.87	195.02	119.89	452.34
28/03/00	Waite	72	272	38	3.08 ± 0.35	1.46	0.08	37.9	26	16.40	13.25	20.05	56.06	41.12	93.43
28/03/00	Nairne SA	72	270	39	3.71 ± 0.83	1.30	0.27	33.9	26	31.28	19.20	39.23	86.90	64.72	194.16
19/06/00	Waite	72	281	40	2.65 ± 0.27	1.19	0.05	31.0	26	27.71	22.79	33.87	115.80	83.60	188.77
19/06/00	Werribee South VIC	72	279	40	1.50 ± 0.17	1.39	0.08	36.1	26	76.04	54.76	114.78	947.65	461.44	3247.76
19/06/00	Woolnorth TAS	72	278	40	2.65 ± 0.29	1.22	0.06	31.6	26	42.66	34.12	53.45	178.50	125.76	307.44
19/07/00	Waite	72	281	40	2.25 ± 0.31	3.85	0.30	100.2	26	49.66	25.82	82.18	267.18	138.00	1855.48
19/07/00	Castlereagh NSW	72	280	40	2.58 ± 0.37	1.24	0.11	32.2	26	71.44	54.39	93.23	310.35	203.53	673.04

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

FIPRONIL

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ppm)	95% confidence intervals	LC ₉₅ (ppm)	95% confidence intervals
15/03/00	Waite	48	242	40	2.49 ± 0.30	1.48	0.09	68.2	46	0.47	0.36 0.58	2.13	1.48 3.95
15/03/00	Nairne SA	48	280	40	2.02 ± 0.24	1.35	0.08	73.0	54	0.85	0.63 1.12	5.54	3.51 11.83
21/03/00	Waite	48	240	40	2.02 ± 0.26	1.20	0.08	55.1	46	0.73	0.58 0.94	4.78	2.95 10.95
21/03/00	Manjimup WA	48	280	40	2.17 ± 0.27	1.62	0.10	87.4	54	0.70	0.52 0.91	4.01	2.55 9.01
09/05/00	Waite	48	240	40	1.91 ± 0.25	1.11	0.08	50.9	46	0.74	0.58 0.95	5.34	3.24 12.46
09/05/00	Werribee South VIC	48	281	40	1.51 ± 0.16	1.03	0.05	55.7	54	1.25	0.95 1.64	15.47	9.29 33.22
09/05/00	Woolnorth TAS	48	280	40	1.59 ± 0.18	1.24	0.06	66.9	54	1.11	0.83 1.48	12.01	7.10 27.54
15/03/00	Waite	72	242	40	3.04 ± 0.36	1.18	0.07	54.4	46	0.29	0.23 0.34	0.99	0.77 1.45
15/03/00	Nairne SA	72	280	40	2.00 ± 0.29	1.62	0.14	87.7	54	0.54	0.36 0.73	3.57	2.18 9.50
21/03/00	Waite	72	240	40	2.64 ± 0.33	0.98	0.06	45.0	46	0.39	0.32 0.46	1.64	1.24 2.55
21/03/00	Manjimup WA	72	280	40	2.90 ± 0.45	1.21	0.12	65.6	54	0.47	0.37 0.56	1.73	1.25 3.17
09/05/00	Waite	72	240	40	2.28 ± 0.28	0.81	0.06	37.2	46	0.45	0.37 0.55	2.37	1.69 3.98
09/05/00	Werribee South VIC	72	281	40	1.34 ± 0.19	1.39	0.11	74.9	54	0.53	0.32 0.77	8.94	4.79 28.12
09/05/00	Woolnorth TAS	72	280	40	1.97 ± 0.27	1.19	0.09	64.4	54	0.61	0.45 0.79	4.18	2.68 9.02

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

INDOXACARB

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ppm)	95% confidence intervals		LC ₉₅ (ppm)	95% confidence intervals	
11/04/00	Waite	48	282	40	1.40 ± 0.15	0.89	0.05	23.3	26	23.57	16.92	35.03	354.41	182.10	954.65
11/04/00	Nairne SA	48	279	39	1.52 ± 0.17	1.16	0.06	30.1	26	31.18	21.68	48.73	379.91	187.51	1179.55
11/04/00	Manjimup WA	48	280	40	1.48 ± 0.17	3.04	0.16	79.0	26	32.42	17.85	78.14	418.40	143.09	4422.87
06/06/00	Waite	48	281	40	1.64 ± 0.24	0.75	0.08	19.5	26	66.05	46.22	108.81	668.05	313.80	2511.38
06/06/00	Werribee South VIC	48	279	40	1.37 ± 0.17	1.03	0.07	26.7	26	42.75	28.88	71.73	674.40	298.34	2546.96
11/04/00	Waite	72	282	40	1.34 ± 0.14	1.86	0.09	48.3	26	3.29	2.09	5.13	55.42	26.57	195.79
11/04/00	Nairne SA	72	279	39	1.37 ± 0.15	2.09	0.10	54.3	26	2.55	1.49	4.13	40.21	19.25	147.60
11/04/00	Manjimup WA	72	280	40	1.38 ± 0.15	1.77	0.09	46.0	26	3.36	2.11	5.25	52.62	25.59	180.68
06/06/00	Waite	72	281	40	1.24 ± 0.13	0.95	0.04	24.6	26	7.06	5.12	10.00	150.54	78.98	387.07
06/06/00	Werribee South VIC	72	279	40	1.15 ± 0.13	1.30	0.07	33.7	26	4.30	2.82	6.51	115.34	54.16	388.33

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

METHAMIDOPHOS

Date tested	Population	n	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ppm)	95% confidence intervals	LC ₉₅ (ppm)	95% confidence intervals
08/03/00	Waite	48	280	40	40	3.86 ± 0.41	3.02	0.14	78.5	26	175.40	134.66 - 226.38	467.64	334.86 - 891.03
08/03/00	Nairne SA	48	280	40	40	2.73 ± 0.28	0.95	0.04	24.7	26	197.09	166.45 - 231.78	788.12	606.30 - 1140.35
23/03/00	Waite	48	281	40	40	3.65 ± 0.47	2.02	0.14	52.6	26	124.31	93.94 - 156.40	350.80	256.06 - 648.07
23/03/00	Manjimup WA	48	281	39	39	2.85 ± 0.32	1.13	0.06	29.5	26	184.26	148.76 - 223.37	695.43	522.30 - 1071.29
10/05/00	Waite	48	280	40	40	4.09 ± 0.46	0.94	0.05	24.4	26	220.65	191.59 - 253.16	556.90	454.96 - 745.23
10/05/00	Werrbee South VIC	48	280	40	40	3.29 ± 0.34	1.58	0.07	41.1	26	371.97	300.07 - 456.27	1174.89	876.87 - 1864.26
10/05/00	Woolnorth TAS	48	280	40	40	3.53 ± 0.35	1.47	0.06	38.3	26	257.76	215.47 - 310.53	753.77	572.44 - 1150.32
13/07/00	Waite	48	280	40	40	3.52 ± 0.57	1.52	0.17	39.6	26	100.93	73.05 - 125.66	296.49	218.72 - 560.06
13/07/00	Castlereagh NSW	48	280	40	40	3.60 ± 0.35	1.25	0.05	32.6	26	245.60	208.49 - 290.63	702.60	547.38 - 1014.10

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

NOVALURON

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ppm)	95% confidence intervals	LC ₉₅ (ppm)	95% confidence intervals
10/04/00	Waite	48	280	40	1.10 ± 0.15	1.32	0.11	34.4	26	10.93	5.11 18.76	345.18	158.15 1385.56
10/04/00	Manjimup WA	48	280	40	1.05 ± 0.12	1.17	0.06	30.5	26	15.11	9.56 23.24	551.01	254.50 1845.71
10/04/00	Nairne SA	48	280	40	1.10 ± 0.11	1.09	0.05	28.3	26	10.14	6.49 15.18	317.55	163.18 848.48
31/05/00	Waite	48	280	40	1.39 ± 0.14	1.37	0.06	35.6	26	13.15	8.62 19.32	200.52	111.62 485.43
31/05/00	Werribee South VIC	48	280	40	1.48 ± 0.15	0.62	0.04	16.0	26	16.25	11.82 21.86	208.72	130.01 407.23
10/04/00	Waite	72	280	40	1.20 ± 0.14	2.97	0.16	77.3	26	2.22	0.69 4.78	52.00	21.16 291.15
10/04/00	Manjimup WA	72	280	40	1.26 ± 0.13	1.33	0.06	34.5	26	3.52	2.09 5.46	71.97	39.23 177.05
10/04/00	Nairne SA	72	280	40	1.19 ± 0.14	1.73	0.09	44.9	26	2.85	1.27 5.15	68.81	33.47 220.29
31/05/00	Waite	72	280	40	1.31 ± 0.18	0.78	0.08	20.3	26	3.90	2.05 6.12	70.38	41.82 156.89
31/05/00	Werribee South VIC	72	280	39	1.25 ± 0.12	2.74	0.11	71.2	26	5.69	2.75 10.46	118.14	51.05 522.44

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

PERMETHRIN

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ppm)	95% confidence intervals	LC ₉₅ (ppm)	95% confidence intervals
29/11/99	Waite	48	280	40	2.26 ± 0.28	1.49	0.10	38.8	26	20.96	14.26 27.98	112.41	76.19 216.93
29/11/99	Manjimup WA	48	280	40	1.25 ± 0.19	1.31	0.12	34.0	26	108.52	72.70 177.73	2245.28	880.26 14538.91
05/01/00	Waite	48	279	40	3.51 ± 1.03	0.73	0.33	19.1	26	11.64	5.26 15.10	34.22	26.34 76.21
05/01/00	Nairne SA	48	280	40	1.30 ± 0.17	1.45	0.11	37.8	26	124.32	82.11 177.62	2267.86	1092.16 9035.50
26/04/00	Waite	48	279	40	2.10 ± 0.35	0.39	0.11	10.2	26	3.15	1.84 4.39	19.09	13.60 33.27
26/04/00	Werribee South VIC	48	280	40	1.50 ± 0.18	1.80	0.11	46.8	26	34.10	22.24 48.58	424.54	222.93 1440.41
28/06/00	Waite	48	280	40	2.41 ± 0.35	0.93	0.08	24.1	26	4.39	2.99 5.75	21.14	15.57 33.83
28/06/00	Woolnorth TAS	48	280	40	1.91 ± 0.24	1.39	0.09	36.0	26	67.73	48.45 91.52	494.28	301.33 1158.31
20/06/00	Waite	48	279	40	2.83 ± 0.39	1.12	0.09	29.2	26	6.70	4.77 8.60	25.59	18.97 41.10
20/06/00	Castlereagh NSW	48	281	40	1.39 ± 0.19	1.85	0.14	48.2	26	144.83	96.55 269.65	2195.52	823.66 17516.57

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX B (continued)

LC₅₀ and LC₉₅ for ten insecticides tested on diamondback moth populations from WA, SA, VIC and TAS compared with the standard laboratory population (Waite) 1999/2000.

SPINOSAD

Date tested	Population	h	n	Control	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀ (ppm)	95% confidence intervals		LC ₉₅ (ppm)	95% confidence intervals	
18/01/00	Waite	72	280	40	3.43 ± 0.46	0.87	0.07	22.6	26	0.10	0.08	0.12	0.30	0.24	0.43
18/01/00	Manjimup WA	72	280	40	2.47 ± 0.36	1.33	0.12	34.5	26	0.09	0.06	0.12	0.42	0.29	0.80
15/02/00	Waite	72	280	40	1.93 ± 0.26	2.78	0.22	72.4	26	0.22	0.10	0.38	1.55	0.78	7.40
15/02/00	Nairne SA	72	280	40	2.63 ± 0.28	1.92	0.09	50.0	26	0.28	0.22	0.38	1.20	0.78	2.53
16/05/00	Waite	72	280	40	2.05 ± 0.23	3.60	0.19	93.6	26	0.21	0.13	0.32	1.30	0.69	5.75
16/05/00	Werribee South VIC	72	280	40	1.80 ± 0.21	4.21	0.23	109.4	26	0.24	0.12	0.42	1.94	0.89	13.80
16/05/00	Woolnorth TAS	72	278	40	2.69 ± 0.31	0.77	0.05	20.0	26	0.17	0.14	0.20	0.69	0.52	1.07

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

APPENDIX C

- a) Tolerance ratios (assuming parallel slopes for each test) with 95% confidence intervals for chlorfenapyr (48 h) tested on Australian populations of DBM in 1998/99. If parallel slopes could not be fitted for a particular assay, then tolerance ratio was calculated at LC₅₀. A tolerance ratio of 1 indicates that a field population is equivalent in susceptibility to the Waite population.

DBM population	State	Tolerance Ratio	95% c. i.		Generation tested	
			lower	upper		
Glenore Grove	QLD	1.16	0.64	2.16	F4	
Ebenezer	NSW	0.81	0.49	1.31	F1	
Mt Sylvia	QLD	0.60	0.41	0.85	F2	
Helidon	QLD	0.23	0.10	0.49	F2	Calculated at LC ₅₀
Castlereagh	NSW	1.58	1.13	2.23	F1	Calculated at LC ₅₀
Werribee	VIC	1.22	0.72	2.04	F2	
South Australia	SA	0.93	0.60	1.46	F1	
Devonport	TAS	0.68	0.37	1.21	F2	
Western Australia	WA	0.93	0.57	1.50	F2	

APPENDIX C (continued)

b) Baseline data for chlorfenapyr for Australian populations of DBM, 1998/99

Date tested	Population	State	h	n	Control	Slope \pm s.e.	Het.	g	χ^2	df	LC ₅₀ (ppm)	95% confidence intervals		LC ₉₅ (ppm)	95% confidence intervals	
25/02/98	Glenore Grove	QLD	48	162	40	2.03 \pm 0.32	1.90	0.21	26.6	14	23.75	13.58	34.51	153.79	86.64	615.99
25/02/98	Waite	lab	48	161	41	1.83 \pm 0.36	2.04	0.37	28.5	14	19.58	5.43	33.36	155.73	77.75	1678.46
17/11/98	Ebenezer	NSW	48	240	40	1.50 \pm 0.21	1.52	0.13	33.5	22	51.09	27.60	76.47	642.78	360.48	1921.18
17/11/98	Waite	lab	48	241	40	1.81 \pm 0.22	1.39	0.09	30.6	22	70.48	47.88	96.11	572.78	354.63	1292.90
8/12/98	Mt Sylvia	QLD	48	280	40	2.33 \pm 0.32	1.73	0.14	44.9	26	18.33	11.22	25.46	93.08	61.66	199.57
8/12/98	Helidon	QLD	48	282	40	1.11 \pm 0.19	1.11	0.13	28.8	26	7.48	2.25	14.16	228.00	126.43	669.17
8/12/98	Waite	lab	48	281	40	2.86 \pm 0.37	0.83	0.06	21.5	26	33.10	26.64	39.86	124.33	94.32	189.80
29/12/98	Castlereagh	NSW	48	280	40	1.60 \pm 0.17	2.21	0.10	57.6	26	69.46	44.32	104.18	739.34	394.56	2229.90
29/12/98	Waite	lab	48	280	40	2.30 \pm 0.27	1.00	0.06	26.1	26	43.85	34.64	54.66	228.49	160.31	391.34
23/02/99	Werribee	VIC	48	280	40	1.54 \pm 0.20	1.60	0.11	41.7	26	41.24	22.24	63.92	485.24	271.33	1351.64
23/02/99	South Australia	SA	48	281	41	2.31 \pm 0.28	1.42	0.09	36.8	26	36.79	26.91	47.85	190.13	127.86	371.65
23/02/99	Waite	lab	48	282	40	1.68 \pm 0.19	1.72	0.10	44.7	26	35.44	22.68	50.65	337.12	197.53	844.74
2/03/99	Devonport	TAS	48	280	40	1.42 \pm 0.16	2.21	0.12	57.4	26	47.12	26.59	73.41	677.85	338.89	2528.90
2/03/99	Western Australia	WA	48	279	40	1.58 \pm 0.17	1.20	0.06	31.1	26	66.31	47.86	89.39	734.84	447.12	1563.92
2/03/99	Waite	lab	48	280	40	1.45 \pm 0.17	1.77	0.10	46.0	26	70.01	41.75	106.99	951.12	499.62	2923.69

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

RESISTANCE BIOASSAYS (WA, 1997-98)
FRANÇOISE BERLANDIER

Levels of insecticide resistance in local DBM populations had not been monitored except for a few populations sent to Nancy Endersby (Agriculture Victoria) for resistance testing in 1997. In this study, we tested resistance levels to methamidophos and permethrin of five WA DBM populations.

Bioassays were conducted to determine levels of resistance in colonies of DBM collected from field sites in WA to two commonly used pesticides, permethrin (Ambush®) and methamidophos (Nitofol®). These chemicals were chosen to enable comparisons with similar bioassays conducted in Victoria by Nancy Endersby. Bioassays were carried out on colonies collected from Perth Metropolitan area (Anderson, White, Mariotti, Trandos) and from Manjimup (Phillips). Late 2nd instar larvae were used in the bioassays. DBM colonies were raised in controlled environment cabinets on canola plants. Each test included a susceptible population kindly supplied by Nancy Endersby (originally WAITE colony from SA).

Bioassay Method

Each bioassay included the susceptible colony and one or more of the field-collected colonies. The selected chemical (commercial formulation) was mixed to a concentration of 100,000 PPM, diluted to 1000 PPM and then diluted again to make a range of concentrations. Solutions were freshly made each time a bioassay was done. Cabbage leaves were cut into 7.5 cm discs and dipped into the chemical for five seconds. Each concentration was replicated five times. Dipped leaves were hung in a fume hood or in the open air next to an exhaust fan (permethrin only) to dry for 2 h. Leaf discs were then placed in individual petri dishes, and 8-12 DBM larvae were placed with the cabbage leaf. Petri dishes were labelled and sealed with Parafilm® to prevent larvae from escaping. The petri dishes were then incubated for 48 hours at 28 °C. After 48 hours the number of survivors from each petri dish was counted and recorded. If resistance was determined the bioassay was repeated with higher levels of the pesticide to determine the level of resistance.

Results

A total of 17 bioassays were conducted, and reliable results were obtained for methamidophos for all five of the field-collected colonies, and for three of these colonies for permethrin (Table 5).

Resistance to methamidophos was low in four populations and ranged from 2.2 to 3.4 times greater than the susceptible laboratory-reared population. The fifth population (White) was not found to be resistant to methamidophos.

For resistance to permethrin, reliable bioassay results were obtained for 3 of the populations, and resistance ranged from 1.2 to 6.4 times greater than the susceptible laboratory-reared population.

Table 5. Summary of resistance levels to methamidophos and permethrin found in five populations of DBM collected in Western Australia.

<i>Colony</i>	<i>Methamidophos</i>		<i>Permethrin</i>	
	<i>LD₅₀ (PPM)</i>	<i>RR*</i>	<i>LD₅₀ (PPM)</i>	<i>RR</i>
Susceptible (Waite, SA)	56.45		13.28	
Anderson (Baldivis)	138.65	2.5	results unreliable	
Mariotti (Wanneroo)	189.34	3.4	16.33	1.2
White (Mandogalup)	42.52	susc	85.51	6.4
Phillips (Manjimup)	124.94	2.2	55.20	4.2
Trandos (Wanneroo)	157.86	2.8	results unreliable	

* LD₅₀ for population/ LD₅₀ for Waite population.

Discussion

The LD₅₀ to both chemicals tested were higher in four of the WA populations than for the susceptible population. These low levels of resistance will develop into higher levels of resistance if left unchecked, and use of the IRM being promoted by this project can help to delay the onset of resistance.

In addition, these resistance results provide a baseline to which future DBM resistance results can be compared to monitor changes in resistance status.

Efficacy of five new insecticides and their relative toxicity on two parasitoid species of *Brassica* pests

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Introduction

In anticipation of the registration of five new insecticides, Regent® (fipronil), Secure® (chlorfenapyr), Success® (spinosad), Proclaim® (emamectin benzoate) and Avatar® (indoxacarb), field and laboratory experiments were conducted to determine their efficacy against DBM and relative toxicity to some natural enemies of *Brassica* vegetable pests. The toxicity tests were done in South Australia and Victoria. In South Australia, two parasitoid wasps were selected for the tests, *Cotesia glomerata* and *Diaeretiella rapae*. *C. glomerata* parasitises larvae of the Cabbage White Butterfly (*Pieris rapae*) and *D. rapae* parasitises several aphid species, including the Cabbage Aphid (*Brevicoryne brassicae*).

Methods

1. Efficacy against DBM

A field experiment was conducted between March 29 and April 9, 1999 in a commercial cabbage field in Virginia, SA. During the course of the experiment, the cabbages were of small to medium size. Three double-rows of the cabbage field were used for the experiment. The experiment was designed as complete randomised blocks. Six blocks were laid out in the experimental area, with 2 blocks along each double-row. Within each block, 6 plots each containing at least 30 cabbages were laid out. The 6 treatments, five insecticides and a control, were randomly assigned to the 6 plots of each block. The treatments were applied with 15 L knapsacks. Application rates for the five insecticides were based on their respective recommended rates (Table 1). In addition to the insecticides, each 15 L solution also contained 4 ml of the surfactant Citowel®. For the control, only the surfactant was added. Two applications of the treatments, separated by 8 days, were made. Numbers of larvae were assessed 1 day before the first application and 2 days after each application.

Table 1. Application rates

Treatment	Rate per 15 L	Rate per 1 L
Regent	3.75 ml	0.25 ml
Proclaim	4.5 g	0.3 g
Secure	6 ml	0.4 ml
Avatar	3.75 g	0.25 g
Success	6 ml	0.4 ml

2. Toxicity to parasitoids

Relative toxicity of the insecticides on the two parasitoid species were tested in ventilated cells (7 mm high and 25 mm in diameter) formed by 2 glass plates and foam pad. Ventilation was provided by a suction device and a tubing system connecting the cells. Treatment was provided as a leaf disc (larger than the cell) placed in between the foam pad and the lower glass plate. The leaf discs were cut from cabbage plants sprayed with the treatments 2 hours-7 days earlier. The application rates of the insecticides and the surfactant were the same as in the efficacy experiment (Table 1), with the control plants sprayed with water and the surfactant only.

In each experiment, 30 test cells were used, 5 for each of the 5 treatments and 5 for the control. Three to 8 adult parasitoids were introduced into each test cell. The experiment was run for 24 h under room temperature (21-23°C) and no direct sunlight, at the end of which, the number of the parasitoids surviving in

each cell was recorded. In some experiments, the survivors from each treatment were transferred to separate plastic bags containing droplets of 10% honey solution and observed daily for survival until all had died.

3. Data analyses

Data from the efficacy experiment were analysed with ANOVA. Differences among treatment means were separated using Duncan's multiple range tests (Zar, 1984). Data from the toxicity tests were analysed with chi-square proportion tests (Zar, 1984).

Results

1. Efficacy against DBM

Pre-treatment larval density in the 36 plots (6 treatment x 6 blocks) from 8.5 to 9.5 per 10 plants. There were no significant differences ($P > 0.05$) in larval density among treatments (Table 2).

Table 2. ANOVA of pre-treatment density of DBM larvae

Source	SS	DF	MS	F	P
Treatment	5.1389	5	1.0278	0.0945	0.9923
Block	213.8056	5	42.7611	3.9298	0.0091
Error	272.0278	25	10.8811		
Total	490.9722	35			

Two days after the first application of the treatments, larval density in plots treated with the 5 insecticides was reduced by 98-100%. However, there were no significant differences among the treatments ($P > 0.05$) (Table 3).

Table 3. Separation of means by Duncan's Multiple Range Tests ($\alpha = 0.05$). Two days after the first application.

treatment	Mean/10 plants	significance grouping
Success	0.5	A
Avatar	0.6667	A
Secure	0.8333	A
Regent	1.5	A
Proclaim	1.8333	A
Control	4.8333	B

Two days after the second application of the treatments, larval density in plots treated with the 5 insecticides was reduced by 79-94%. Again there were no significant differences among the treatments ($P > 0.05$) (Table 4).

Table 4. Separation of means by Duncan's Multiple Range Tests ($\alpha = 0.05$). Two days after the second application

treatment	Mean/10 plants	significance grouping
Proclaim	0	A
Secure	0	A
Success	0	A
Avatar	0.16667	A
Regent	0.5	A
Control	6	B

2. Toxicity to *D. rapae*

Two hours after the application of the treatments (Day 0), Regent[®] and Secure[®] showed significant toxicity ($P < 0.05$) to *D. rapae* in 4 of the 5 experiments performed (Figure 1). In contrast, Proclaim[®] and Avatar[®] were significantly toxic ($P < 0.05$) in only one experiment. The toxicity status of Success[®] was not as clear cut as the other 4 insecticides. It caused significantly higher mortality than the control in 3 experiments, but showed similar mortality to that in the control in the other two experiments.

Three days after the application of the treatments, Secure[®] showed significant toxicity ($P < 0.05$) in both experiments. Mortality caused by Regent[®] was higher than that by Success[®], Proclaim[®], Avatar[®] and the control in both experiments, but the differences were not significant ($P > 0.05$) (Figure 1).

Seven days after the application of the treatments, none of the insecticides showed significant toxicity to *D. rapae* (Figure 1). However, the mortality rate caused by Secure[®] and Regent[®] was still about twice as high as that caused by the control, whereas the mortality rates caused by the other 4 insecticides were comparable to the control.

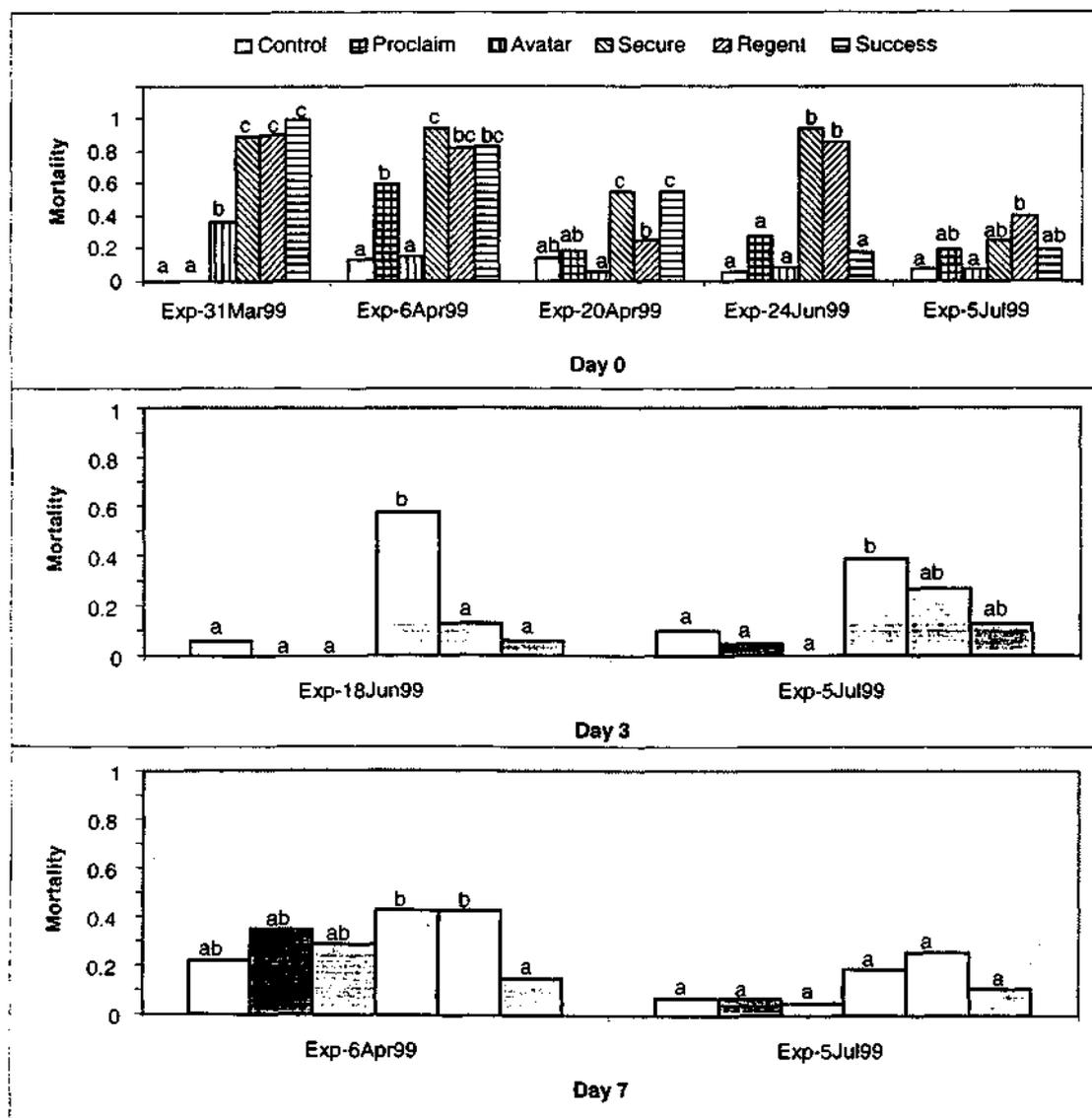


Figure 1. Toxicity tests of five insecticides, Proclaim[®], Avatar[®], Secure[®], Regent[®], and Success[®], to *Diaeretiella rapae*. Bars not sharing a common letter in the same experiments are significantly different at (≤ 0.05 (Chi-square proportion tests)).

3. Toxicity to *C. glomerata*

Two hours after the application of the treatments, Regent[®] caused 100% mortality in all five experiments (Figure 2). Compared with the controls, significantly higher mortality levels ($P < 0.05$) were detected in Secure in 3 experiments, in Proclaim[®] and Avatar[®] in 2 in experiments each, and in Success[®] in 1 experiment. The mortality level shown by Secure[®] was higher than those caused by Proclaim[®], Avatar[®] and Success[®] in 3 of the 5 experiments.

Data from two experiments were available for comparisons of the relative mortality levels 3 days and 7 days after the treatments. Three days after the treatments, Regent[®] and Secure[®] showed significantly higher mortality levels ($P < 0.05$) than controls in both experiments. The mortality levels shown by the other 3 insecticides were not significantly different than that by the control ($P > 0.05$) in one experiment, but were significantly higher than that by the control in the other experiment ($P < 0.05$). Seven days after the treatments, Regent[®] and Secure[®] showed significantly higher mortality level than the control ($P < 0.05$).

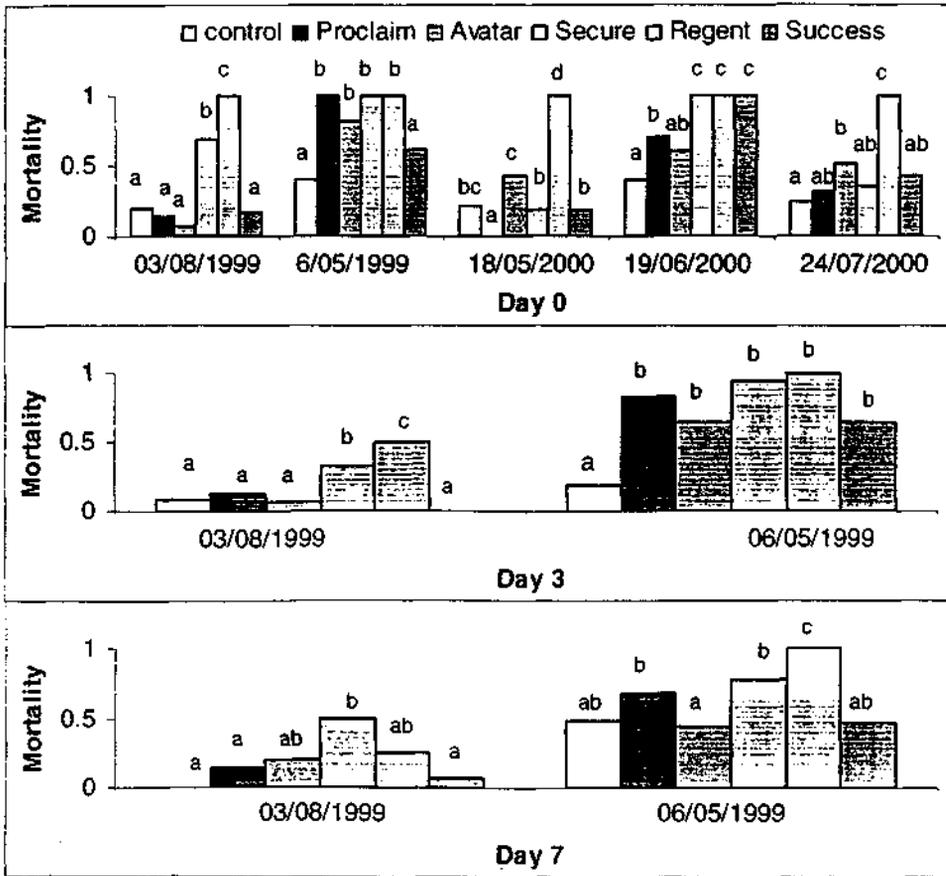


Figure 2. Toxicity tests of five insecticides, Proclaim[®], Avatar[®], Secure[®], Regent[®], and Success[®], to *Cotesia glomerata*. Bars not sharing a common letter in the same experiments are significantly different at (≤ 0.05) (Chi-square proportion tests).

Although Avatar[®] showed relatively low toxicity to *C. glomerata* in some experiments (Figure 2), those individuals surviving the toxicity tests to this insecticide suffered significant mortalities 1 day after being transferred to clean plastic bags containing droplets of 10% honey solution ($P < 0.05$) (Table 5). Secure[®] also showed significant delayed mortality of this wasp ($P < 0.05$). In Success[®], significant delayed mortality ($P < 0.05$) was consistently shown 3-days after the transfer (Table 5). Delayed mortality shown by Proclaim[®] was not consistent. Survivals from two experiments suffered significantly higher mortality ($P < 0.05$) than the control 1 day after the transfer and those from the other experiment showed similar mortality levels ($P > 0.05$) as the control both 1 day and 3 days after the transfer.

Table 5. Delayed mortality among individuals of *C. glomerata* surviving the toxicity tests. The survivors were transferred to clean plastic bags and provided with 10% honey solution. Numbers sharing a common letter in the same column were not significantly different at the significance level of 0.05 by chi-square proportion tests. n: sample size. n.a.: sample size too small for analyses.

	18/05/2000			19/06/2000			24/07/2000		
	n	1 d later	3 d later	n	1 d later	3 d later	n	1 d later	3 d later
Control	11	0.09a	0.27a	11	0.36a	0.73a	18	0.39a	0.89a
Proclaim	20	0.82bc	0.55ab	7	0.14a	0.86a	17	0.71b	1a
Avatar	5	1c	1c	6	1b	1a	9	0.89b	1a
Secure	10	0.6b	0.6ab	0	n.a.	n.a.	9	0.89b	1a
Success	13	0.38ab	0.69bc	0	n.a.	n.a.	11	0.91b	1a

Discussion

The results from this study showed that all five new insecticides were equally effective against DBM. They differ, however, in their toxicity on the two parasitoids. For *D. rapae*, Avatar[®] and Proclaim[®] appeared relatively non-toxic, whereas Regent[®] and Secure[®] were toxic for at least 3 days. The toxicity of Success[®] against this parasitoid is not consistent, with some experiments showing significant toxicity and other experiments showing no toxic effect. For *C. glomerata*, Regent[®] was still most toxic, followed by Secure[®]. Their toxic effects were detectable up to 7 days after the application of the treatments. Avatar[®] appeared more toxic to this parasitoid than Proclaim[®] and Success[®]. However, its toxic effect was more clearly seen after the wasps had been removed from the test arena, suggesting delayed toxic effect. Delayed toxic effects were not studied for *D. rapae*. Hence the seemingly non-toxic property of Avatar[®] to this parasitoid needs to be confirmed with similar post-test observations. In conclusion, Regent[®] and Secure[®] are relatively toxic to the two parasitoids whereas Proclaim[®] is relatively non-toxic. The toxicity levels of Avatar[®] and Success[®] need to be further investigated.

Acknowledgement

This study is part of a national project on the IPM of DBM funded by HRDC. We wish to thank Ms. C. Paull and Ms. K. Bell for maintaining parasitoid cultures and for assisting with the experiments.

Effect of New Insecticides on *Diadromus collaris* and *Diadegma semiclausum*, two parasitoids of *Plutella xylostella*

NANCY ENDERSBY AND PETER RIDLAND

Introduction

Many new insecticide groups have been registered or are under development for control of diamondback moth (DBM), *Plutella xylostella* (L.), in Australia. Information about the effects of new insecticides on the natural enemies of DBM and other pests of *Brassica* crops is required for better planning of insecticide application to enhance the effect of beneficial insects in the crop. The relative toxicity of some new insecticides on the ichneumonid wasp parasitoids of DBM, *Diadegma semiclausum* (Hellen) and *Diadromus collaris* (Gravenhorst) was studied.

Methods

Laboratory leaf dip bioassay of *Diadromus collaris* with seven insecticides

12 replicates 5 larvae per replicate for seven insecticides and a control. Squares of 70 mm by 70 mm were cut out of cabbage leaves and dipped for five seconds in aqueous solutions of formulated insecticide and wetting agent (Table 1). Leaf squares were allowed to dry for 2 h and were then rolled up to line glass vials as in the field experiment. Five wasps per vial were exposed to insecticide residues on leaf squares in a method based on that of Furlong *et al.* (1994).

Table 1. Rates of insecticide applied to cabbage leaf squares used to in a leaf dip bioassay to assess toxicity to *Diadromus collaris*. Each solution and the Control contained 0.1 ml/L X-77®.

Treatment	Rate per 1L
Regent®	0.25 ml
Proclaim®	0.30 g
Secure®	0.40 ml
Avatar®	0.25 g
Success®	0.40 ml
RimOn®	0.50 ml
Bulldock®	0.80 ml

Field-sprayed leaf residue experiment on *Diadromus collaris* and *Diadegma semiclausum*

Cabbage plants (cv. Green Coronet) (4 weeks after transplanting) were treated with six insecticides in a field experiment in May 1999 at the Institute for Horticultural Development, Knoxfield, Victoria. Each treatment was replicated four times on a double row of cabbage plants in a four metre plot. The treatments were applied with a hand pumped sprayer with a single nozzle. Application rates for the six insecticides were based on their respective recommended rates (Table 2). A 1000 L/ ha spray volume was assumed. In addition to the insecticides, each 4 L solution also contained 0.4 ml of the surfactant X-77®. For the control, only the surfactant was added.

Table 2. Rates of insecticide applied to field treated cabbage leaves used to assess toxicity to *Diadromus collaris* and *Diadegma semiclausum*

Treatment	Rate per 4L	Rate per 1L
Regent®	1.0 ml	0.25 ml
Proclaim®	1.2 g	0.30 g
Secure®	1.6 ml	0.40 ml
Avatar®	1.0 g	0.25 g
Success®	1.6 ml	0.40 ml
Bulldock®	3.2 ml	0.80 ml

Leaves were harvested from the field at regular intervals. Wasps were exposed to insecticide residues on leaf squares in a method based on that of Furlong *et al.* (1994). Leaf squares of 70 mm x 70 mm were used to line glass vials into which 5 wasps were placed. The ends of the vials were sealed with a square of muslin kept in place by a rubber band. 50% honey solution was streaked across the muslin. After 24 h the leaf was removed and the five wasps were put into one clean vial. Mortality was scored each day until all wasps were dead. Testing of *D. semiclausum* was limited because longevity of this wasp species was low in the laboratory colony.

Results

Laboratory leaf dip bioassay of *Diadromus collaris* with seven insecticides

RimOn® had no effect on survival of *D. collaris* in the leaf dip experiment (Figure 1). Proclaim® had a minimal effect on survival on *D. collaris*. Secure® and Regent® caused very high mortality of *D. collaris* at 24 h after first exposure. By 48 h, all wasps were dead in these treatments. Mortality reached 44% in the Success® treatment at 24 h after first exposure and reached 90% by 48 h. Avatar® and Bulldock® had caused no mortality by 24 h after first exposure, but by 48 h, mortality in both of these treatments approached 70%. Raw data are included in Appendix A.

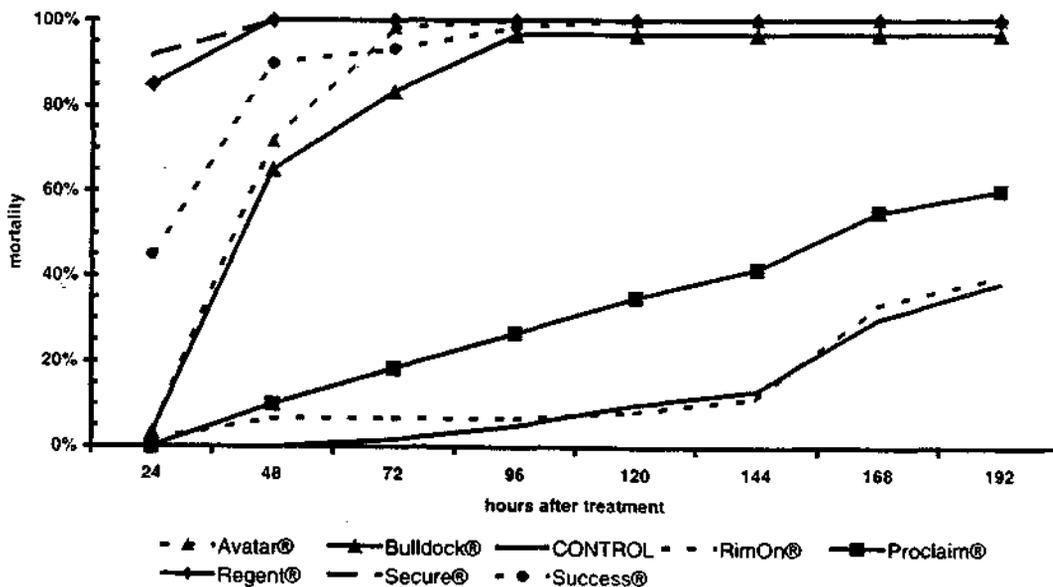


Figure 1. Effect of insecticides (field rate) on *Diadromus collaris* in a leaf dip bioassay

Field-sprayed leaf residue experiment on *Diadromus collaris* and *Diadegma semiclausum*

One day after the application of the treatments (Day 1), Regent® and Secure® showed high toxicity to *D. collaris* (Figure 2) one or 24 hours after first exposure to the leaf residue. None of the other insecticides tested caused mortality after one or 24 h.

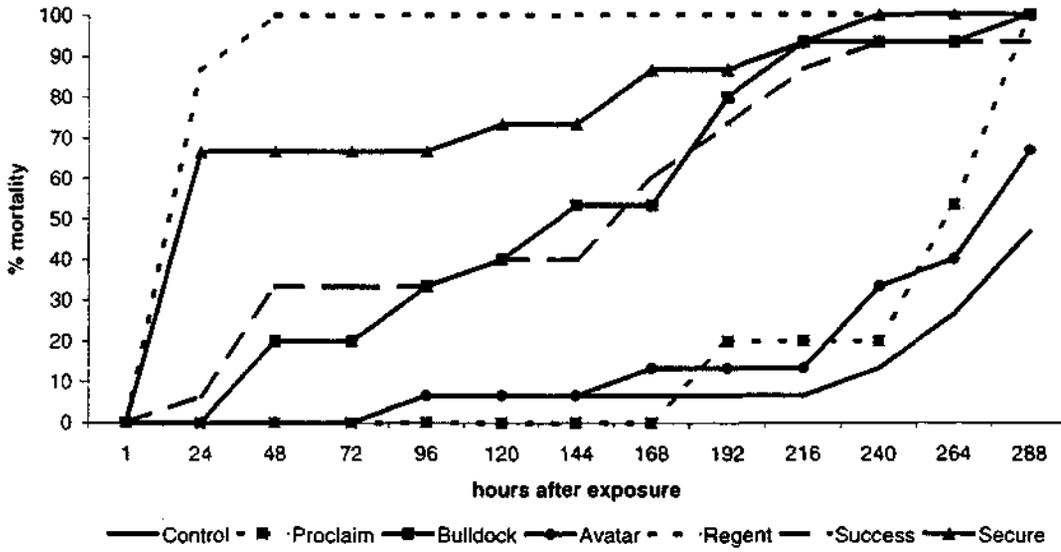


Figure 2. Effect of exposure to one-day-old leaf residues of insecticides on *Diadromus collaris*

D. collaris was exposed to three-day-old residues of Secure®. Mortality reached 70% by 96 h after first exposure (Figure 3). There was no mortality in the control. *D. semiclausum* was exposed to three-day-old residues of Regent® and Success® (Figure 4).

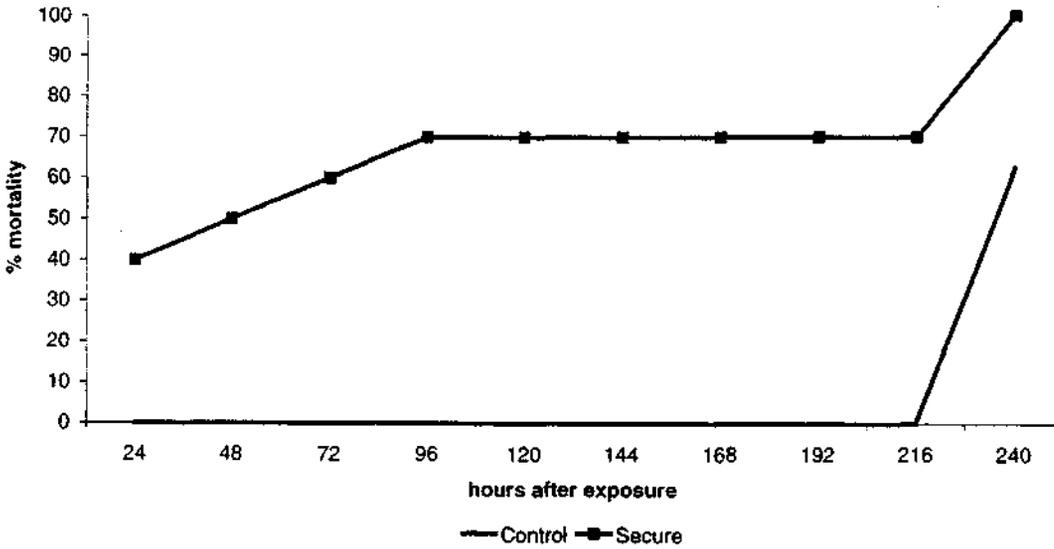


Figure 3. Effect of exposure to three-day-old leaf residues of Secure® on *Diadromus collaris*

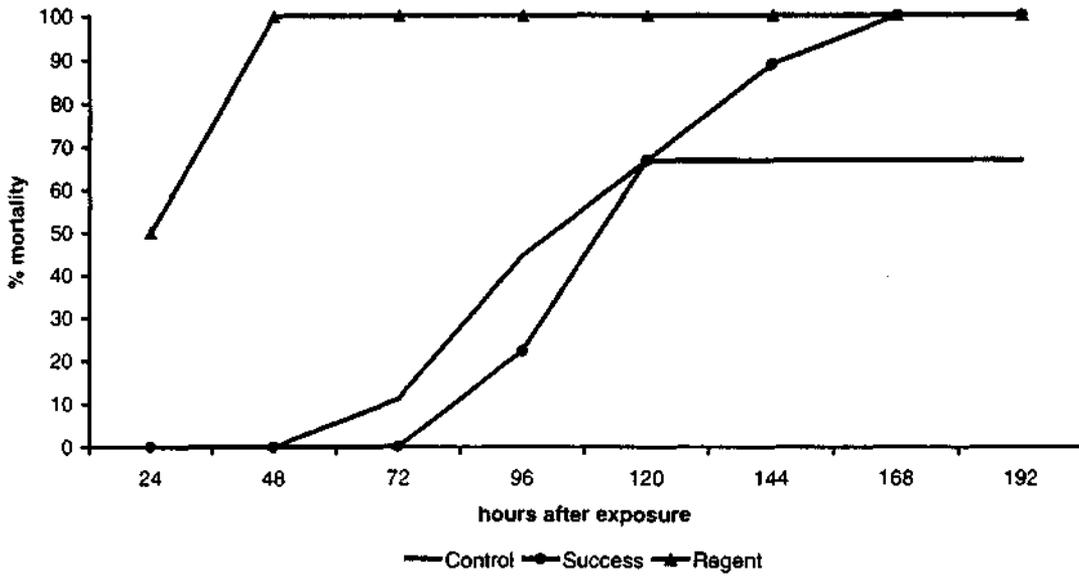


Figure 4. Effect of exposure to three-day-old leaf residues of Regent® and Success on *Diadegma semiclausum*

Seven days after the application of the treatments (Day 7), Regent® showed high toxicity to *D. collaris* (Figure 5) 72 h after first exposure to the leaf residue. Bulldoek® caused some mortality at 72 h. None of the other insecticides tested caused mortality to *D. collaris* after seven days.

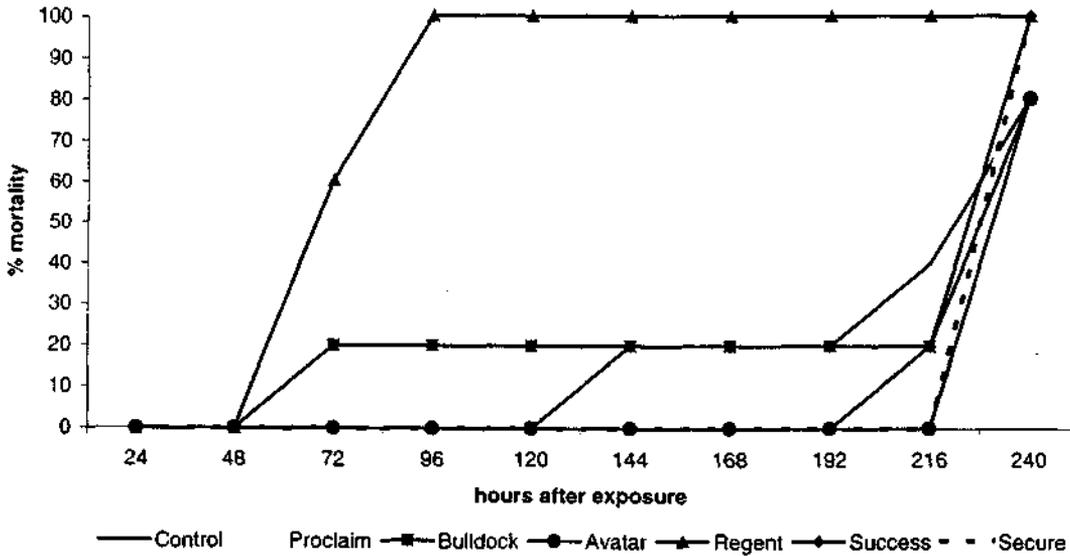


Figure 5. Effect of exposure to seven-day-old leaf residues of insecticides on *Diadromus collaris*

Seven-day-old leaf residues of Regent® showed high toxicity to *D. semiclausum* (Figure 6) 24 h after first exposure. Bulldoek® and Secure also caused some mortality at 24 h. None of the other insecticides tested caused mortality to *D. semiclausum* after seven days.

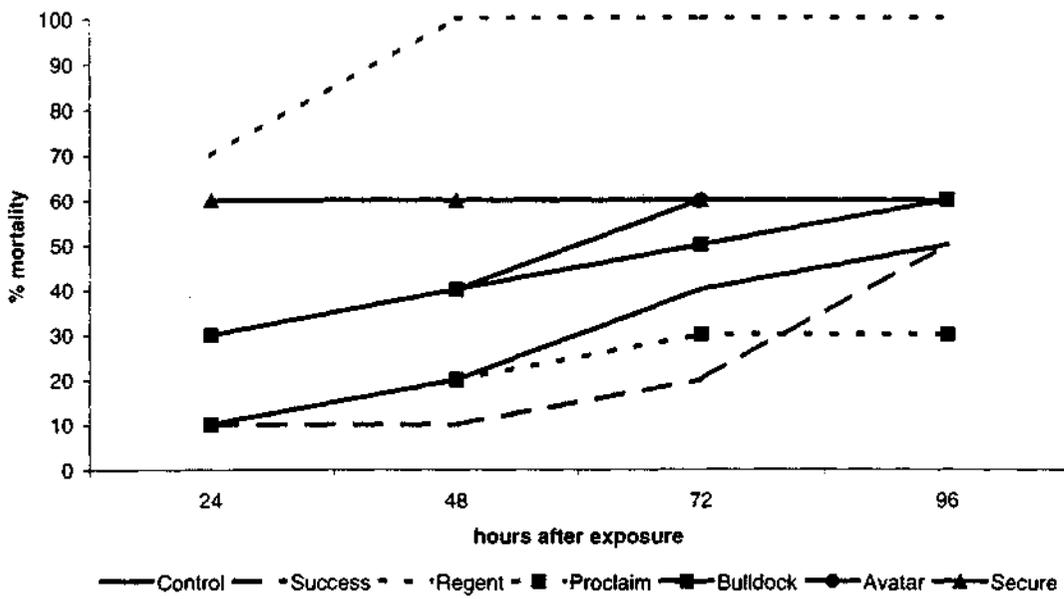


Figure 6. Effect of exposure to seven-day-old leaf residues of insecticides on *Diadegma semiclausum*

D. collaris was exposed to 14 day old residues of Regent[®] and Bulldock[®] because these compounds had caused mortality as seven day old residues. At 14 days, residues of Regent[®] were still causing mortality of *D. collaris* (Figure 7).

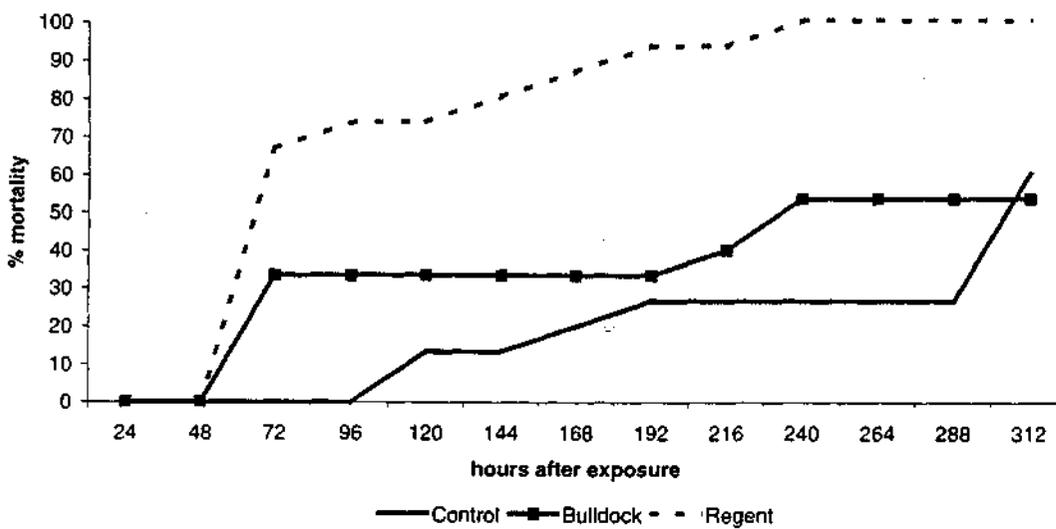


Figure 7. Effect of exposure to 14-day-old leaf residues of Bulldock[®] and Regent[®] insecticides on *Diadromus collaris*

Control mortality confounded the 14 day test of *D. semiclausum* with Bulldock[®] and Regent[®] (Figure 8).

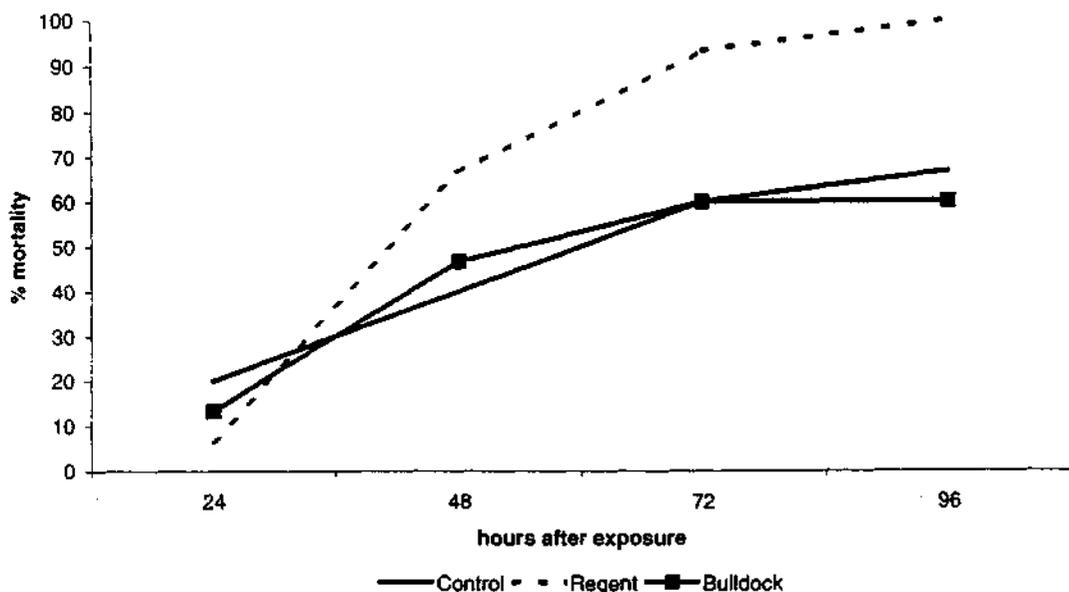


Figure 8. Effect of exposure to 14-day-old leaf residues of Bulldock® and Regent® insecticides on *Diadegma semiclausum*

At 144 h after first exposure to 22-day-old residues of Regent®, mortality of *D. collaris* was approaching 100% (Figure 9). Mortality in the Bulldock® treatment and the control was 40% at 144 h.

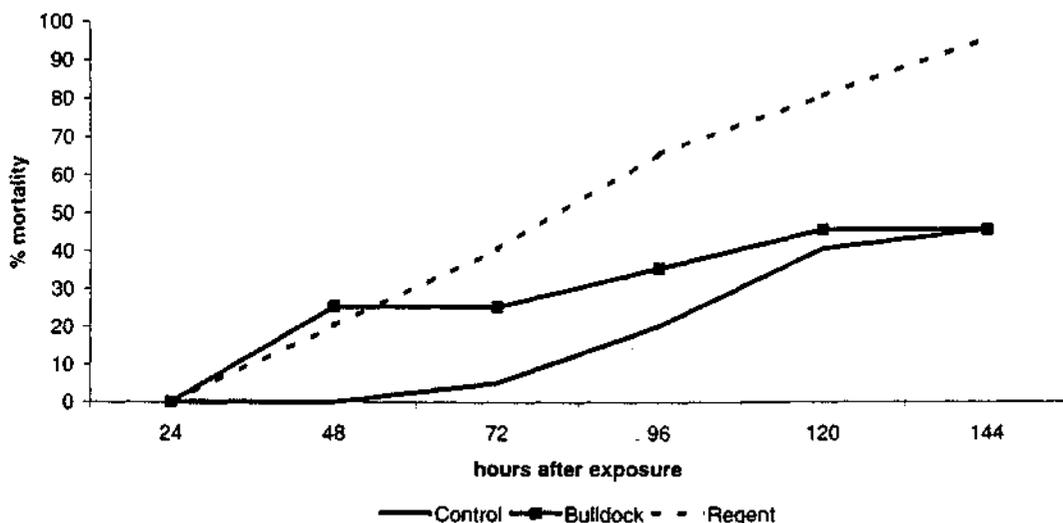


Figure 9. Effect of exposure to 22-day-old leaf residues of Bulldock® and Regent® insecticides on *Diadromus collaris*

Discussion

Results of the field trial have not been analysed statistically due to the low numbers of wasps available for testing. The extremely short lifespan of the laboratory culture of *D. semiclausum* made extensive testing impossible. Studies of longevity of the wasp were made (results available on request), but the problem was not rectified during the lifetime of the project. Results presented give indications of general trends, but ideally more testing of these species should be conducted in the future.

Results of the laboratory bioassay of *D. collaris* showed that residues on leaves of most of the insecticides tested caused high mortality of *D. collaris*. The exceptions were RimOn[®] which showed no effect on longevity of this species and Proclaim[®] which caused a low level of mortality. Sub-lethal effects of these two insecticides, such as fecundity and fitness of subsequent generations, were not evaluated. The high levels of mortality observed in the laboratory experiment were observed to a similar extent in the field trial for those insecticides tested. General trends suggest that residues of Regent[®] may persist longer at levels toxic to *D. collaris* than those of the other insecticides tested.

Acknowledgements

This study is part of a national project on the IPM of DBM funded by HRDC. We wish to thank Ms. K. Green for maintaining parasitoid cultures and Mr J. Zhang for assisting with the experiments.

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Appendix A – Mortality of *Diadromus collaris* in a leaf dip bioassay of seven insecticides

Number of dead wasps out of 60 individuals tested, at 24 to 192 h after first exposure

h	24	48	72	96	120	144	168	192
Avatar [®]	2	43	59	60	60	60	60	60
Bulldock [®]	2	39	50	58	58	58	58	58
CONTROL	0	0	1	3	6	8	18	23
RimOn [®]	1	4	4	4	5	7	20	24
Proclaim [®]	0	6	11	16	21	25	33	36
Regent [®]	51	60	60	60	60	60	60	60
Secure [®]	55	60	60	60	60	60	60	60
Success [®]	27	54	56	59	60	60	60	60
Grand Total	138	266	301	320	330	338	369	381

SPRAY TRIAL (1999-2000)

FRANÇOISE BERLANDIER

Introduction

An effective technique to delay the onset of resistance in *P. xylostella* is to employ an insecticide resistance management strategy. The strategy developed for WA *Brassica* growers employs a two-window system whereby use of certain chemical groups is restricted six months of the year. In addition, chemical groups are rotated within each window.

The practicality of this strategy on-farm was tested over the summer of 1999/2000, and the trial is reported here was designed to determine the effect of recommended spray regimes in controlling diamondback moth numbers.

Materials and Methods

A plot trial was set up at Medina Research Support Unit, located 30 km south of Perth. The plots were situated on light grey sands of the Swan coastal plain, and seedlings were planted on four sequential planting dates, timed four weeks apart. Pre-planting fertilisers used were superphosphate (1000kg/ha) and trace elements (150kg/ha). Post planting fertilisers were applied by boomspray and included ammonium nitrate (60kg/ha), potassium sulphate (20kg/ha) and magnesium sulphate (50kg/ha).

Plots in planting 1 were 18.5 m x 4.5 m (sprayed plots) and 8 m x 4.5 m x 2 (unsprayed plots). For plantings 2, 3 and 4, these were 17.5 m x 4.5 m (sprayed plots) and 10 m x 4.5 m x 2 (unsprayed plots). Plots were separated by 2 m wide bare earth buffers. Treatments were replicated four times (Table 6) using four sequential plantings of cabbage planted four weeks apart, with the first planting in October 1999. Foliar sprays of pesticides were applied by boomspray (Table 7).

Table 6. Treatments use for cabbage spray trial at Medina Research Support Unit.

<i>Spray treatment</i>	
A	Control (nil spray), until 17/02/00 after which two sprays of Nitofol [®] were applied.
B	Bt's only until 8/12/99 when alternate sprays of Regent [®] , Xentari [®] , Secure [®] , DiPel [®] , Bt and Nitofol [®] were applied until the end of the survey.
C	Following RMS*, lower threshold (mean of 2 larvae/plant).
D	Following RMS, higher threshold (mean of 6 larvae/plant).
E	Bt's first, then new product Success [®] (spinosad). Bt was used for the first two weeks, followed by a combination of Bt, Success [®] , Secure [®] , Xentari [®] , Regent [®] , Fastac [®] , DiPel [®] and Nitofol [®] for the remainder of the trial period.

*Resistance management strategy

The numbers of DBM eggs, small, medium and large larvae and pupae per ten cabbage plants were counted on a weekly basis between 16/12/99 and 14/3/00 (Table 3). One or two plantings were sampled according to the developmental stage of cabbage in each planting at the time (starting with planting 1 and ending with planting 4). Ten cabbage plants per treatment plot (A, B, C, D and E) were randomly selected and numbers and stages of DBM per plant were recorded. The plant stage and crop age was also recorded. Each week a summary of the *in situ* DBM counts was used to determine the next spray application.

In addition, sticky traps bearing a DBM pheromone [active ingredients (z)-11-Hexadecenyl acetate and (z)-11-hexadecenal (1:1)], positioned at opposite corners of planting 3 (north-east and south-west), were used to attract and capture adult DBM. The sticky traps were replaced weekly, and the numbers of moths found on the traps were recorded (Table 2). Pheromone lures were replaced monthly.

Table 7. Spray regime for controlling DBM damage on cabbage at Medina between 28/10/99 and 8/03/00.

Date	Treatment								
	A (Control)	B (Bt's)		C (RMS low)		D (RMS high)		E (Bt + Success®)	
		P*1		P1		P1		P1	
28/10/99	-	Bt		Bt		Bt		Bt	
4/11/99	-	Bt		Bt		Bt		-	
9/11/99	-	Bt		Bt		Bt		Bt	
15/11/99	-	Bt		Success®		Success®		Success®	
		P1	P2	P1	P2	P1	P2	P1	P2
18/11/99	-	-	Bt	-	Bt	-	Bt	-	Bt
24/11/99	-	Bt	Bt	-	Bt	-	Bt	-	Bt
1/12/99	-	-	Bt	Success®	Bt	Success®	-	Success®	Bt
8/12/99	-	Secure®	Xentari®?	Secure®	Xentari®?	Secure®	Xentari®?	Secure®	Xentari®?
16/12/99	-	Secure®	Secure®	Secure®	Secure®	-	Secure®	Success®	Success®
		P2	P3	P2	P3	P2	P3	P2	P3
5/01/00	-	Regent®	Bt	Regent®	Regent®	Regent®	Regent®	Success®	Regent®
12/01/00	-	Xentari®	Xentari®	-	Regent®	Regent®	Regent®	Success®	Success®
18/01/00	-	-	Xentari®	-	-	-	-	-	-
		P3	P4	P3	P4	P3	P4	P3	P4
25/01/00	-	-	-	-	-	-	-	-	-
2/02/00	-	-	-	Regent®	Xentari®	-	Xentari®	-	Xentari®
9/02/00	-	DiPel®	DiPel®	Fastac®	Fastac®	-	Fastac®	DiPel®	Fastac®
17/02/00	Nitofol® (P3 & P4)	-	Nitofol®	Nitofol®	Nitofol®	Nitofol®	Nitofol®	Success®	Success®
8/03/00	Nitofol® (P4 only)	-	Nitofol®	-	Nitofol®	-	Nitofol®	-	Nitofol®

*P = Planting

Results

Pheromone traps

The highest number of DBM captured on the sticky traps was recorded on 29/11/99, when 130 DBM were counted on the north-east trap and 117 counted on the south-east trap (Fig. 1).

In crop counts

The highest number of *P. xylostella* in the plots was in November (almost 30/plant), and the lowest numbers were recorded in late November. No larvae were found in any plots on 1/03/00, which was unexpected because no pesticide had been applied since 17/02/00. On the same date the number of pupae counted on all plots was not much lower than previous weeks, although the number of larvae in planting 4 was reasonably low. The previous week's survey (23/02/00) also produced a low larva count, with a total of 3 larvae counted (in plot A). Another data entry of interest was an absence of larvae in plots B and E in planting 2 on 18/01/00. A week earlier, plot B had received an application of Xentari®, and plot E had been sprayed with Success®. On 17/02/00, no larvae were found on plot B, planting 4, which had received an application of DiPel® one week earlier. On 23/02/00, no larvae were counted in plot E, planting 3, which had been sprayed with Success® the previous week.

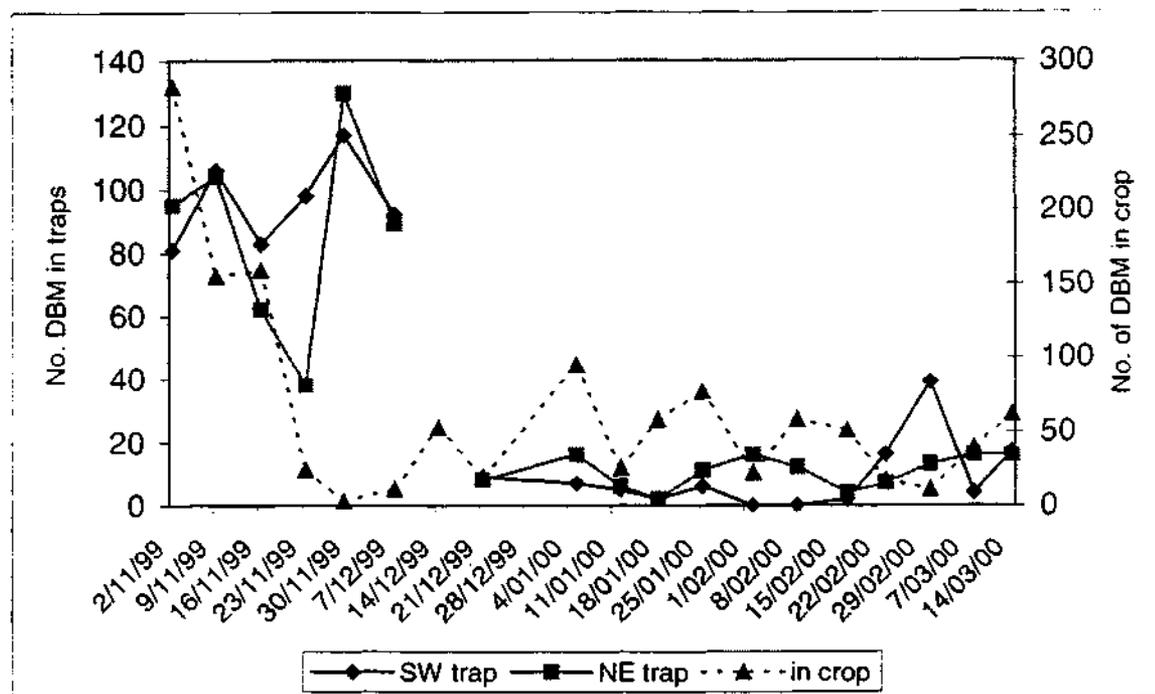


Fig. 1. Numbers of *P. xylostella* in sticky pheromone traps and in crop at Medina in 1999-2000. Counts of in crop *P. xylostella* include all immature morphs/10 plants in unsprayed plots.

Discussion

We attempted to make decisions to spray for treatments C and D using numbers of immature DBM counted in each plot. The chemicals used were those recommended in the current WA metropolitan RMS window system. There was intensive DBM pressure during the trial, making it necessary to apply frequent (weekly) sprays, particularly in November for Planting 1. The trial proved to be a useful exercise which helped us to better understand the constant DBM pressure that commercial *Brassica* growers have to deal with. The trial also revealed that to keep DBM numbers below the economic threshold, growers must make vigilant monitoring an absolute priority at least twice a week during times of heavy pest pressure. Limited resources available during this trial only allowed us to conduct weekly monitoring, whereas twice weekly would have been the preferred option. Despite high numbers of larvae in the plots, numbers of DBM caught in the pheromone traps diminished from mid-December, and remained low (<20/ trap except for 1 March 2000, 39 DBM caught) until the end of the trial.

GENERAL DISCUSSION

Information contained within this report has been used in presentations to WA *Brassica* growers to inform them of the activity of beneficial insects (parasitoid wasps) in their crops, likely periods of maximum pest pressure, and the resistance levels currently noted for WA populations of DBM. This information, presented along with the insecticide resistance management strategy developed in conjunction with the national project team, has resulted in a better informed group of growers whose awareness of these issues helps to improve management of DBM in horticultural *Brassica* crops in WA.

Acknowledgement

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Survey of pest management practices amongst Victorian *Brassica* growers, 1998

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ABSTRACT

The following topics were addressed in a telephone survey of 50 *Brassica* growers from Victoria:

- crop statistics
- pest problems
- insecticide usage
- deployment of *Bacillus thuringiensis* (*Bt*)
- insecticide rotations and mixtures
- spray application
- understanding of insecticide resistance issues
- pest monitoring
- non-chemical control practices
- irrigation practices
- attitude to IPM implementation

Growers identified diamondback moth (DBM), *Plutella xylostella*, as the most serious pest of *Brassica* crops. *Bt* is currently being used widely by *Brassica* growers in Victoria, but the practice of mixing it with other insecticides for DBM control is common. Fipronil (a fiprole) was used by 56% of growers in its first season of availability. Organophosphate and synthetic pyrethroid insecticides are also being used widely for DBM control.

Most growers reported that they practised weed control, management of crop residues and rotation with non-*Brassica* crops. Few growers were implementing a summer break in production or planting seedlings away from old crops. Clear requirements for more information and training of growers were indicated in the areas of crop monitoring, deployment of insecticides for effective insecticide resistance management and implementation of an IPM program.

INTRODUCTION

A telephone survey of vegetable *Brassica* producers in Victoria was undertaken between April and June 1998. The survey was designed to determine the current pest management practices of Victorian growers and to investigate their attitudes to and understanding of insecticide resistance and integrated pest management (IPM). Information collected about pest management practices and attitudes will be used during the course of the Horticultural Research and Development Corporation project "Advancing the integrated management of diamondback moth in *Brassica* vegetables".

METHODOLOGY

A telephone survey was made of 50 growers, selected at random from 3 regional lists of *Brassica* growers (approximately 300 growers in all) compiled and held at the Institute for Horticultural Development, Knoxfield. We weighted the sample with respect to region (2 Western: 2 South-Eastern: 1 East Gippsland) to reflect the numbers of growers in each region. This task highlighted the inadequacies of existing vegetable industry statistics in Australia. Each selected grower was interviewed in a standardised, 45 minute, telephone interview about pest management, insecticide resistance and Integrated Pest Management (IPM). Management of diamondback moth (DBM), *Plutella xylostella*, was the focus of the questions. The survey form is attached (Appendix A). All information collected applied to the 12-month period leading up to the June 1998 interviews. Interviewing, interviewer and response errors were minimised by taking care to ask questions in their exact wording, including a standardised way of stressing key words, explaining response scales and checking scale understanding before recording answers. The same interviewer conducted all interviews. The questionnaire was adapted to the 'audible only' telephone mode. A standard definition of IPM was given before asking IPM questions to ensure that all respondents knew the

same concept before answering IPM questions. The IPM concept was not introduced until all other pest management questions were answered.

Key areas covered in the survey were:

- crop statistics
- pest problems
- chemical usage
- deployment of *Bacillus thuringiensis* (Bt)
- rotations and mixtures
- spray application issues
- understanding of insecticide resistance issues
- pest monitoring
- non-chemical control practices
- attitude to IPM implementation

RESULTS

A. Crop statistics

A most notable regional difference was that cauliflowers were predominant (85%) in the Western region (Table 1).

Table 1. Area (ha) of crops in the ground on average at any one time, over the last 12 months

Crops	West (n=21)	South-East (n=20)	Gippsland (n=10)	Total (n=51)
Broccoli				
Number of growers	12	6	5	23
Total area (ha)	124.5	138.1	93.2	355.8
Average area (ha)	10.4	23.0	18.6	15.5
Cabbage				
Number of growers	7	12	4	23
Total area (ha)	49.0	118.2	49.3	216.5
Average area (ha)	7.0	9.9	12.3	9.4
Cauliflower				
Number of growers	17	2	5	24
Total area (ha)	162.9	3.2	25.4	191.5
Average area (ha)	9.6	1.6	5.1	8.0
Brussels sprouts				
Number of growers	0	3	1	4
Total area (ha)	0	18.2	4.0	22.2
Average area (ha)	0	6.1	4.0	5.6
Chinese cabbage				
Number of growers	0	3	2	5
Total area (ha)	0	3.6	14.5	18.1
Average area (ha)	0	1.2	7.25	3.62
Kohlrabi growers	0	2	0	2
Radish growers	0	6	1	7
Turnip growers	0	2	0	2

Principal non-*Brassica* crops grown varied between regions and were less diverse in the Western area (Table 2).

Table 2. Cropping patterns over the last 12 months (crops grown by $\geq 20\%$ of growers and listed in decreasing frequency).

West	South-Eastern	East Gippsland
Lettuce	Parsnip	Capsicum
Onions	Lettuce	Beans
Fennel	Onions	Sweet corn
Capsicum	Carrot	Peas
	Celery	Lettuce
	Leek	
	Parsley	
	Silver beet	
	Beetroot	

B. Pest Problems

From a list of potential pests, growers were asked to identify those pests that they sprayed last year (Table 3). They then identified those insects that caused the most damage over the last 12 months (Table 4). Diamondback moth (DBM), aphids and cabbage white butterfly (CWB) were most common pests and clearly DBM was identified as the most serious pest in each region.

Table 3. Insects controlled in last 12 months in each region.

Pest	West	South-East	Gippsland	Total	%
Diamondback moth	21	20	9	50	98
Aphids	21	20	9	50	98
Cabbage white butterfly	18	18	9	45	88
Thrips	13	7	3	23	45
Cutworm	15	5	2	22	43
<i>Helicoverpa</i>	8	5	5	18	35
Cabbage centre grub	8	9	1	18	35
Looper caterpillar	4	4	1	9	18
Sample size (n)	21	20	10	51	

Table 4. Pest types reported as causing most damage over the last 12 months.

Pest	West	South-East	Gippsland	Total	%
Diamondback moth	20	20	9	49	96
Aphids	7	5	2	14	27
Cabbage white butterfly	1	2	1	4	8
Cutworm	1	0	2	3	6
<i>Helicoverpa</i>	1	0	0	1	2
Thrips	0	1	0	1	2
Looper caterpillars	1	0	0	1	2
Cabbage centre grub	0	0	0	0	0
Sample size (n)	21	20	10	51	

C. Insecticide Usage

Some 84% of growers used *Bt* as part of their spray program. Of these growers, 59% used *Bt* only (always or often) when the crop is young, while 31% always or often used *Bt* throughout the crop. The remaining 10% used *Bt* sporadically.

Growers tended to use several different *Bt* products:

Delfin (67%), DiPel Forté (60%), MVP (40%), Xentari (35%) and Biobit (2%).

Growers frequently mixed *Bt* with other insecticides:

[ALWAYS 25%, OFTEN 23%; SOMETIMES 16%; RARELY 14%; NEVER 23%]

Their reasons for using mixtures included:

Aphid control 71%; contact kill 51%; residual kill backup 31%; *Bt* used as a backup for synthetic insecticide 14%; kill DBM moths 11%; *Bt* was old 3%; saving labour 3%.

The mean number of sprays per crop is given in Table 5 and the most common spray interval used by growers during summer was 7-10 days.

Table 5. Mean number of sprays (*Bt* and synthetic insecticides) per crop during the year (Spring - Christmas, Christmas -Autumn, Winter).

Time of Year	Mean number of sprays per crop	
	<i>Bt</i>	Other insecticides
Before Christmas	4.0	5.3
After Christmas	4.9	6.6
Winter	0.9	2.3

The main synthetic insecticides used by growers in the last twelve months are listed in Table 6. Mevinphos and methamidophos were the most commonly used OPs, while permethrin and cypermethrin were the most commonly used SPs. It was noteworthy that many growers (56%) have used fipronil in its first season of availability. The major regional differences concerned endosulfan (12 of 14 users were from Western region) and methomyl (7 of 9 users from South-East region). Note that methomyl is not registered in Victoria for DBM. Both these compounds were frequently mixed with *Bt*. We have not accessed spray records directly so we have not been able to estimate amounts of each product used.

Table 6. Percentage of growers using synthetic insecticides for control of Lepidoptera in the last 12 months. (Organophosphates=OP; Synthetic pyrethroids=SP, organochlorines=OC; Carbamates=Car; Phenyl pyrazole=PP)

OP	SP	OC	Car	PP
mevinphos (58%)	permethrin (44%)	Endosulfan (28%)	Methomyl (18%)	Fipronil (56%)
methamidophos ^T (48%)	alpha-cypermethrin (26%)			
chlorpyrifos ^T (30%) ^T	deltamethrin (18%)			
parathion-methyl ^T (20%)	cyfluthrin (18%)			
diazinon ^T (2%)	lambda-cyhalothrin (16%)			
methidathion ^D (8%)	esfenvalerate (12%)			
prothiofos ^D (2%)	tau-fluvalinate (8%)			

^T = Thioate OP; ^D = Dithioate OP

D. Insecticide rotation

Growers were asked: "In the last 12 months, how often have you used insecticides in rotation on your *Brassica* crops? Please answer using the words: 'always', 'often', 'sometimes', 'rarely', or 'never'."

Their responses were as follows:

ALWAYS 52%; OFTEN 24%; SOMETIMES 14%; RARELY 8%; NEVER 2%

Details of their rotation strategies are shown in Table 7. The task of promoting a rational rotation strategy remains high priority.

Table 7. Insecticide rotation categories and number of growers in each category. Categories are not mutually, i.e. some growers' practices fit into more than one category. (*Bt* = *Bacillus thuringiensis*, OP = organophosphates, SP = synthetic pyrethroids)

Insecticide rotation	West	South-East	East Gippsland	All (n=50)	% of All
No set rotation	5	4	3	12	24
<i>Bt</i> 1st, then OP, then SP	3	1	2	6	12
<i>Bt</i> 1st then haphazard or non standard rotation	8	6	2	16	32
<i>Bt</i> important component, non standard rotation	8	11	4	23	46
<i>Bt</i> used, but not first	2	6	5	13	26
<i>Bt</i> 1st then SPs rotated	3	0	0	3	6
<i>Bt</i> mixed with other DBM insecticides	6	8	0	14	28
<i>Bt</i> , OP rotation	4	1	1	6	12
<i>Bt</i> mixed with aphicide	5	1	0	6	12
Rotation without <i>Bt</i> , program	2	4	0	6	12
SP, OP rotation	1	3	4	8	16
SPs used only	0	1	1	2	4
Mainly endosulfan	3	0	0	3	6
OPs used only	1	1	0	2	4
Regent [®] , SP rotation	2	1	1	4	8
Phosdrin [®] used each time	1	1	0	2	4
Phosdrin [®] major component of program	1	6	0	7	14
Phosdrin [®] minor component of program	7	11	2	20	40
SP products rotated	3	5	2	10	20

24% of growers had no set spray rotation. 44% of growers were using *Bt* on the early stages of the crop. 20% of growers were erroneously rotating synthetic pyrethroid products.

E. Spray Application

Apart from 1 grower who used a Silvan Turbomiser, all growers used boom sprayers. A minority (26%) of the booms was air assisted. Hardie and Goldacres were the dominant manufacturers (81%) in the Western region while Silvan was dominant in the South-East (50%). Overall, these 3 manufacturers had 90% of the market.

Cone nozzles were used by 58% of growers, while 36% used flat-fan nozzles and 6% used both types. Most (70%) growers used plastic nozzles (on average, 20.0 months between changes) while 17% used ceramic nozzles (on average, 28.5 months between changes) and 13% still used brass nozzles (on average, 28.5 months between changes).

Standard calibration of spray rigs was done by 64% of growers, with 12.1 months between calibrations, on average. Spray records were always kept by 64% of growers (although quality of records could not be assessed). Only 20% of growers either rarely or never kept records.

F. Crop Monitoring

Growers were asked how they decide when to spray their crops. While 84% used some form of monitoring, 90% had a regular spray program that suggested that their monitoring had little influence on their actual decision to spray. Some growers (12%) relied on monitoring only in the low-pressure part of the season. Some 38% used the weather forecast as a guide. This is most likely related to the fine-tuning of timing, e.g. whether to spray today or tomorrow if rain, wind, etc. is forecast. While most growers [ALWAYS 38%; OFTEN 26%] monitored for pest presence before spraying insecticide, they employed a considerable variety of methods.

Of the growers who monitored, only 21% counted larvae while the remaining 79% only looked for presence or absence of larvae as well as damage. The sampling strategy varied greatly. The median number of plants looked at was 20 (range 100 plants to 1 plant) and the median number of sites inspected was 4 (range from 15 locations to 1).

G. Sources of Information

Growers were asked about their sources of information about pest management (Table 8), their most important sources of information (Table 9) and those issues they considered when deciding which insecticide spray to use (Table 10). The clear message is that the chemical resellers play a vital role in information transfer. This reinforces the need for the project team to work very closely with the resellers in disseminating pest management information arising from the project.

Table 8. Sources of pest management information used by growers.

Information source	No. of growers	%
Chemical reseller	50	100
Own knowledge & experience	43	86
Other growers	35	70
Trade journals & newsletters	29	58
Department of Agriculture	28	56
Spray contractor	2	4
Private consultant	1	2
Sample size (n)	50	

Table 9. Source of pest management information nominated by growers as their most important source.

Information Source	No. of growers	%
Chemical resellers	37	74
Chemical resellers & other growers	1	2
Chemical resellers & own knowledge	2	4
All sources equally important	1	2
Department of Agriculture	1	2
Other growers	2	4
Private consultant	1	2
Own knowledge	2	4
Own knowledge & other growers	1	2
Trade journals and newsletters	2	4
Sample size (n)	50	

Table 10. The percentage of growers that considered the following issues when deciding what insecticide spray to use.

Decision aids	No. of growers	%
Chemical reseller	39	78
Past experience	35	70
Pest type	32	64
Crop stage	23	46
Pest pressure	20	40
Other growers	10	20
Label information	8	16
Withholding period/toxicity	4	8
Department of Agriculture	3	6
Journals and newsletters	2	4
Spray contractor	2	4
Monitoring contractor	1	2
Sample size (n)	50	

H. Non-chemical Pest Management Practices

Growers were asked a series of questions about cultural control methods they may be employing on their properties. Weed control, management of crop residues and rotation with non-*Brassica* crops was all practised commonly (Table 11). However, there is no information on the quality of their implementation of these practices. Nearly all growers are also using transplants from specialist nurseries. More specific practices such as planting seedlings away from old crops and employing a summer break from brassicas were used much less frequently. Protection of beneficial insects appeared to be only from using *Bt*, rather than providing refugia.

Table 11. Cultural control / non-chemical pest management practices employed by growers.

Cultural Control	Total	%
Controlling weeds in/around the crop fields	49	98
Ploughing in crop residues after harvest	48	96
Rotating brassicas with non- <i>Brassica</i> crops	45	90
Using seedlings from specialist nurseries	42	84
Nursery seedlings grown on premises	7	14
Seed used only (radish grower)	1	2
New seedlings away from older crops - sometimes	11	22
New seedlings away from older crops - always	8	16
Summer production reduced/(break) because of DBM	9	18
Summer production break - other reason	6	12
Encouraging naturally present insect predators	6	12
Sample size n	50	

I. Irrigation Practices

Growers were asked a series of questions about their irrigation practices. The average number of irrigation events in summer was 2.7 per week with the average irrigation time in summer being 5.4 hours per irrigation event. Information on timing of irrigation events is given in Table 12. 74% of growers irrigated at night.

Table 12. Timing of irrigation

Growing area	No. of growers	%
Morning	9	18
Day	2	4
Late afternoon	2	4
Evening to midnight	12	25
Evening to am	17	35
Midnight to am	7	14
Sample size n	49	

Overhead irrigation may be timed to coincide with peak DBM oviposition and activity times, known to occur between dusk and midnight in the Northern Hemisphere (McHugh and Foster 1995). Three growers reported that they find timing irrigation helps with DBM control. Their individual irrigation practices are shown in Table 13. Grower 1 is irrigating at an appropriate time to coincide with peak DBM activity.

Table 13. Schedules of growers who use irrigation timing to control DBM

Grower	1	2	3
Usual irrigation period	Evening to 12:00 am (also late afternoon)	Evening to am	Evening to am
Exact irrigation hours	7/ 8:00 pm-10:00 pm & from 3/4:00 am	-	-
Average number of irrigation events per week in summer	3.5	2	1.5
Average irrigation time in summer	6	2.5	3

J. Attitudes to Insecticide Resistance

A list of statements about insecticide resistance was read to each grower. They were asked to choose a point on a 1 - 5 point scale depending on how much they agreed or disagreed with each statement. Their responses are given in Table 13.

Table 13. Grower understanding of insecticide resistance issues.

Statement	Absolutely disagree	←	Uncertain	→	Absolutely agree
1. Resistance means that pests survive spraying	3	3	7	9	27
2. Resistance is caused mainly by excessive spraying	7	0	11	11	20
3. Resistance may be slowed down by rotation of insecticides	1	0	4	10	34
4. Resistance can be slowed down by spraying less often	9	11	11	5	13
5. Resistance can be slowed down by non-chemical controls	5	6	9	15	14
6. Pests could develop a resistance to <i>Bt</i>	2	1	27	8	11

The growers generally agreed with statements 1, 2, 3 and 5. Many (40%) disagreed with the fourth proposition that resistance can be slowed down by spraying less often, while most were uncertain about whether pests could develop resistance to *Bt*.

K. Attitudes to IPM

After being read a series of statements about IPM, growers were read a list of reasons some growers have for not using IPM. They were asked to think about their own reasons for not using IPM, and then to choose a point on a 1-5 point scale depending on how much they agreed or disagreed with each statement.

Their responses (Table 14) indicated a great desire for more information (both printed and from growers' nights) and hands-on training, some uncertainties about value of IPM programs and some polarisation between growers keen to pursue IPM programs and growers still relying on full pesticide programs.

Table 14. Grower attitudes to issues relating to IPM adoption.

Statement	Absolutely disagree	←	Uncertain	→	Absolutely agree
1. I don't know about IPM	7	5	15	7	14
2. I don't have hands on training in IPM	5	6	8	6	23
3. I don't have time to spare for IPM	6	9	19	9	5
4. I think it is too risky to use less chemicals	10	6	15	8	9
5. I am happy with existing controls, so why change?	13	6	10	9	10
6. I have lack of advice available to me to set up an IPM program	9	4	10	6	19
7. I want to wait & see other people in the industry use IPM first	14	7	13	6	8
8. I don't want to spend any extra money on pest control	11	4	7	6	20
9. I would like printed information about IPM	0	1	4	6	27
10. I would like to go to an IPM grower night in my area	0	1	6	11	20

MAJOR FINDINGS AND KEY RECOMMENDATIONS

A. Crop Statistics

The South-Eastern region shows the most diverse range of vegetables grown. Of the *Brassica* crops, 85% of the area planted with cauliflowers was found in the Western region. Overall, the largest area of land was planted with broccoli.

B. Pest Problems

Diamondback moth (DBM), aphids and cabbage white butterfly (CWB) were identified as the most common pests in each of the three regions. Thrips and cutworm were also common in the West. The pest causing the most damage in each region was DBM.

C. Insecticide Usage

1. Deployment of *Bacillus thuringiensis* (Bt)

Bt is currently being used widely by *Brassica* growers in Victoria. 84% of growers listed it as part of their spray program. The practice of mixing *Bt* with other insecticides for DBM control was common [ALWAYS 25%, OFTEN 23%; SOMETIMES 16%; RARELY 14%; NEVER 23%] and will need to be addressed through extension activities.

2. Deployment of synthetic insecticides

Fipronil (a fiprole) was used by 56% of growers in its first season of availability. Regional differences in the use of endosulfan and methomyl were obvious, with a preference for endosulfan use in the West and for methomyl in the South-East. OPs and SPs are also being used widely for DBM control.

D. Insecticide Rotation

Growers are aware of the importance of insecticide resistance management, but many are deploying strategies of rapid rotation or alternation that will lead to simultaneous selection of resistance to multiple compounds. 20% of growers were erroneously rotating synthetic pyrethroid products. Promotion of a rational rotation strategy is of major importance.

E. Spray Application

Although many growers are replacing spray nozzles, calibrating sprayers and keeping spray records, these are still areas in which improvements can be made.

F. Crop Monitoring

The survey revealed that many growers (84%) were checking their crops for pests and/ or pest damage, however, monitoring appeared to have little influence on their decision to spray. Sampling strategies varied greatly.

G. Sources of Information

Growers nominated chemical resellers as their most important source of pest management information. For effective extension it will be most important for the National DBM project team to work closely with resellers in disseminating pest management information arising from the project.

H. Non-chemical Pest Management Practices

Most growers reported to be practising weed control, management of crop residues and rotation with non-*Brassica* crops. Few growers were implementing a summer break in production or planting seedlings away from old crops.

I. Irrigation Practices

The average number of irrigation events in summer was 2.7 per week. The average number of irrigation hours in summer was 5.4 hours per irrigation event. 74% of growers were irrigating at night. Three growers were using timing of irrigation to assist with control of DBM.

J. Attitudes to Insecticide Resistance

Most growers agreed that resistance means that pest survive spraying, is caused by excessive spraying and may be slowed down by rotation of insecticides. 40% disagreed that development of resistance can be slowed down by spraying less often and were uncertain as to whether pests could develop resistance to *Bt*. These data indicate that growers need more information on the 'mechanics' of insecticide resistance.

K. Attitudes to IPM

Growers' responses indicated a great desire for more information about IPM (both printed and from growers' nights) and hands-on training. Many are uncertain about the value of IPM programs and there is some polarisation between growers keen to pursue IPM programs and those still relying on full pesticide programs. Certainly there are clear signals for our continued emphasis on improving information flow and training to growers.

ACKNOWLEDGEMENTS

We thank the 50 *Brassica* growers who participated in the survey.

REFERENCES

- McHugh Jr., J.J. & Foster, R.E. (1995). Reduction of Diamondback Moth (Lepidoptera: Plutellidae) Infestation in Head Cabbage by Overhead Irrigation, **Journal of Economic Entomology** 88:162 - 168.

APPENDIX A
**PEST MANAGEMENT SURVEY OF VICTORIAN BRASSICA
 GROWERS, May 1998
 SURVEY QUESTIONNAIRE**

[SPRAY EQUIPMENT SECTION]

The first question is about spraying equipment.

1. Could you please tell me what type and brand of sprayer you have?

[TICK]
Boom sprayer
air assisted
not air assisted
Silvan turbomiser
Mister
Air assisted Hardi twin sprayer
CDA sprayer
other

[BRAND].....

[IF BOOM]

2. Are the nozzles used for insecticide spraying:

cone or flat fan?	
ceramic, plastic, or brass?	

3. Could you please tell me what spray volumes do you use, either in gallons/acre or l/ha?

.....

[PROBING]

Is this the same or different for BT?

[CROP SECTION]

The next question.

4. Can you please tell me what crops have you grown in the last 12 months?

5. Can you please tell me how many acres of [B. CROPS] do you have in the ground on average at any one time, over the last 12 months?

[IF GIPPSLAND]

Given the drought this summer.

How different is this from the previous 12 months please?

[TICK]	[AREA] (acres)	[BRASSICAS VARIETY]		AREA B/DALE
		[SUMMER]	[AUTUMN]	
cauliflower				
broccoli				
cabbage				
Brussels sprouts				
Chinese cabbage				
Chinese broccoli				
onions				
lettuce				
celery				
carrots				
parsnips				
leeks				
other				

6. Which varieties of [MAIN CROP] do you grow in summer and which do you grow in the autumn?

[PEST SECTION]

The next question. I will read a list of pests.

7. Please tell me if you had to control these in your [MAIN CROP] in the last 12 months?

Please say "don't know" if you are not sure.

It's ok not to know, some of these pests are very minor.

Please tell me if you had to control aphids in your [MAIN CROP] in the last 12 months?

	[Y/N/DON'T KNOW]	[IF SERIOUS]
aphids		
cabbage white butterfly		
diamondback moth /cabbage moth		
heliiothis		
thrips		
cabbage centre grub		
looper caterpillar		
cutworm		
other		

8. Which of these cause potentially the most damage? [TICK]

[BT & INSECTICIDE SECTION]

The next few questions are about spraying.

[NO RIGHT OR WRONG ANSWERS] [IMPORTANCE TO GET ACCURATE INFO]

9. Can you please tell me what insecticides have you sprayed on your [MAIN CROP] in the last 12 months?

.....

.....

[PROBING]

Are there any other ones? Anything else?

[FILL OR ASK]

10. Which BT products, if any, have you used in the last 12 months please?

	[TICK]
Delfin	
DiPel Forté	
MVP	
Xentari	
Biobit	
When did you first start using BT?	

[IF NO BT]

Please tell me if BT was ever used on your farm?

.....

[IF USED IN THE PAST]

What was the reason you stopped using BT please?

.....

11. The next few questions are about spray rotations and spray mixes.

When I ask the questions, please answers by using the words:
always [1] often [2] sometimes [3] rarely [4] never [5]

In the last 12 months, how often have you used:

insecticides in rotation on your <i>Brassica</i> crops [REPEAT ANSWERS 2x]	
[IF BT USED]	
BT in mixes with other insecticides on your <i>Brassica</i> crops	
used mixes of insecticides without BT on your <i>Brassica</i> crops	
BT only when the crop is young ?	
BT throughout the life of a crop ?	
kept spraying records ?	
sprayed insecticides only after first checking for pests' presence	

[IF ROTATIONS]

12. Could you please describe your typical insecticide rotation program for Brassicas?

.....
 [IF BT MIXED]

13. Can you please tell me what insecticides you mix with BT?

.....
 [IF BT MIXED]

14. What is the reason you mix BT with other insecticides please?

.....
 [IF BT USED]

15. On average, how many BT sprays do you have to use on each [MAIN CROP] crop before and after Christmas?

.....

On average, how many BT sprays on each crop in winter?

.....

16. On average how many insecticide sprays other than BT do you have to use on each [MAIN CROP] crop before and after Christmas?

.....

On average, how many would that be in winter?

.....

17. Can you please tell me how do you decide what spray to use?

[PROBING] Where does your spray program come from?
 How do you put it together?

18. Can you please tell me how do you decide when to spray?

.....

[PROBING] How do you find that out?

19. Please tell me if you monitor/or don't monitor for pest presence before you spray?

.....

[IF MONITORING]

How do you monitor?

How many plants do you check each time?

At how many locations?

P/A or counts?

20. Please tell me how often you calibrate your spraying equipment?

21. Please tell me how often you change the spray nozzles?

[THANK]

NON-CHEMICAL PRACTICES & RESISTANCE

The next question is about non-chemical controls.

To make things easy and quick, I will read out a list.

Please answer Yes or No depending on what you do.

22. Please tell me if over the last 12 months, you have/or have not been:

	[Y/N]
rotating your [MAIN CROP] with other non-brassica crops	
ploughing [MAIN CROP] in crop residues after harvest	
controlling weeds around the crop fields	
using [MAIN CROP] seedlings from specialist nurseries	
planting new [MAIN CROP] seedlings away from older crops	
stopped growing Brassicas in summer to avoid DBM	
encouraging naturally present insect predators	
[IF YES ASK HOW]	

Anything else you would like to add?

23. The next question is about your opinions about pest control.

I will read through a list of statements. There are no right or wrong answers.

Please choose a point on a scale from 1-5 to show your opinion.

Or, answer "don't know" if you feel that you know nothing about the statement.

It is perfectly OK to not know. Many growers may not know.

Please choose:

if you absolutely disagree 1 2 3 4 5 if you absolutely agree

[CHECK UNDERSTANDING OF SCALE]

[STATEMENT] how much do you agree/or disagree with that? [SCALE 2x]

insecticide resistance means that pests survive spraying		[DON'T KNOW]
insecticide resistance is caused mainly by excessive spraying		
insecticide resistance <u>may be</u> slowed down by using <u>different insecticide families in rotation</u>		
insecticide resistance can be slowed down by spraying less often		
insecticide resistance can be slowed down by using non-chemical controls such as crop rotation and biological controls		
pests could develop a resistance to BT		

[IPM SECTION]

The next question is about Integrated Pest Management, or IPM, and what you think of it. After that, we are just one minute from the end.

Integrated pest management is a new concept for many people. So, I will describe it using one possible definition. I will then ask a few questions about your opinions about IPM.

Is that Ok?

So, the definition:

IPM is a mixture of pest & disease control methods used together.

IPM is a move away from relying on chemicals as the only or as the main control.

Cultural and biological controls are used. Chemicals are also used, but less of them.

Monitoring of pests is a basic building block of IPM.

IPM is often set up in gradual steps over several years, but it does not have to be.

The first step is the fine tuning of chemical sprays via monitoring.

IPM generally reduces the need to spray.

Can I go to the question now?

24. Because IPM is a fairly new concept, it is easy to understand why people have reservations about using it.

I will read out a list of reasons some growers have for not using IPM.

Please think about your own reasons for not using IPM and then please choose a point on a 1-5 point scale depending on how much you agree or disagree with each statement.

Please choose:

if you absolutely disagree 1 2 3 4 5 if you absolutely agree
or please answer don't know if you wish.

[STATEMENT] how true is that of you (3x)/

how much do you agree or disagree with each statement?

I don't know about IPM [REPEAT SCALE 2x]

I don't have hands on training in IPM

I don't have time to spare for IPM

I think it is too risky to use less chemicals

I am happy with existing controls, so why change

I have lack of advice available to me to set up an IPM program

I want to wait & see other people in the industry use IPM first

I don't want to spend any extra money on pest control

I would like printed information about IPM

I would like to go to an IPM grower night in my area

[THANK FOR TAKING TIME & RE-STATE INFO VALUE]

[END SECTION]

[IF FAST INTERVIEW]

Now just a few more minutes of your time.

27. Please tell me how often do you usually irrigate [MAIN CROP] in summer?

.....
.....

28. For how many hours do you usually irrigate it each time in summer?

.....
.....

[PROBING IF TIME] What inches of water would that be?

29. What time of day or night do you usually irrigate?

.....
.....
.....

30. The very last question.

Please tell me where do you get your pest control advice from?

I will read out a list.

- Your own knowledge & experience
- Chemical re-sellers, such as Muirs
- Dpt. Of Agriculture
- Other growers
- Trade journals & newsletters
- any other?
- [DON'T ASK/TICK]
- Spray contractor, Internet, Private consultant

	1	
	2	
	3	
	4	
	5	
	6	

31. Which of these is your most important source of advice? [GO BACK & TICK]

[CONCLUSION]

Thank you very much for your time and for the information.

A summary of the results and the pest management manual will be sent to you in August when this project is finished.

Is there anything you would like to ask me?

.....
.....

Would you like to be on our mailing list?

ADDRESS CHECK

Again, thank you so very much for your time.

A survey of pest management practices amongst *Brassica* seedling producers in Victoria in 1998

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ABSTRACT

The following topics were addressed in a telephone survey of 8 *Brassica* seedling nurseries from Victoria:

- seedling production statistics
- pest and disease problems
- insecticide and fungicide usage
- deployment of *Bacillus thuringiensis* (*Bt*)
- pesticide rotations and mixtures
- spray application
- understanding of pesticide resistance issues
- pest monitoring
- non-chemical control practices
- attitude to IPM implementation

Most growers identified diamondback moth, *Plutella xylostella*, as the most serious pest of *Brassica* seedlings. All nurseries named downy mildew as their potentially most damaging *Brassica* disease. *Bt*, synthetic pyrethroids and dimethoate are in frequent use. The new insecticide, Regent® is also being used in nurseries. Promotion of a rational insecticide rotation strategy in seedling nurseries is of major importance. The only widely used cultural pest control was weed control around the nursery and waste heap, but most nurseries expressed interest in IPM. Clear requirements for more information and training of seedling growers were indicated in the areas of crop monitoring, deployment of insecticides for effective insecticide resistance management and implementation of an IPM program.

INTRODUCTION

Eight *Brassica* vegetable seedling producers in Victoria were interviewed by telephone about pest management, insecticide resistance and Integrated Pest Management (IPM). Management of diamondback moth (DBM), *Plutella xylostella*, was the focus of the questions. The interviews were designed to supplement the main survey of 50 Victorian *Brassica* vegetable growers ('Survey of pest management practices amongst Victorian *Brassica* growers, 1998').

The survey was undertaken to collect information about pest and disease management practices in *Brassica* seedling nurseries. The data collected in the survey will be used to assess the information requirements of this integral part of the vegetable industry so that effective pest management advice can be given.

METHODOLOGY

We undertook to survey the ten main *Brassica* seedling nurseries from the three main areas of Victorian *Brassica* vegetable production. Two nurseries declined to be interviewed, giving a response rate of 80%. Representatives from four nurseries in Werribee, two in the Cranbourne district and two in Gippsland were interviewed. Each nursery representative was interviewed in a standardised, 45 minute, telephone interview about pest management practices and Integrated Pest Management (IPM). All information collected applied to the 12-month period leading up to the June 1998 interviews.

Instrumentation error was minimised through questionnaire design. Interviewing, interviewer and response errors were minimised by taking care to ask questions in their exact wording, including a

standardised way of stressing key words, explaining scales and checking scale understanding before recording answers. The same interviewer conducted all interviews. The questionnaire was adapted to the 'audible only' telephone mode. The questionnaire is provided in Appendix B.

A standard definition of IPM was given before asking IPM questions to ensure that all respondents knew the same concept before answering IPM questions. The IPM concept was not introduced until all other pest management questions were answered.

Key areas covered in the survey were:

- production statistics
- pest and disease problems
- chemical usage
- deployment of *Bacillus thuringiensis* (*Bt*)
- rotations and mixtures
- spray application issues
- understanding of pesticide resistance issues
- pest monitoring
- non-chemical control practices
- attitude to IPM implementation

Where results are presented for each nursery, a random order was assigned to each site. A different code was used in each table so that Site 1 in one table is not necessarily the same as Site 1 in the next table.

RESULTS

Results are presented as tables and summary paragraphs which relate to each question in the survey. Numbers in brackets refer to the number of growers who gave the particular answer to the survey question.

A. *Brassica* crops grown

Brassica seedling crops grown by the eight nurseries were: cauliflower, broccoli, cabbage (8); Brussels sprouts (4); Chinese cabbage (2); Chinese broccoli (2) and kohlrabi, turnip, rocket, mizuna, kale and all other *Brassica* lines (1). Tables 1 and 2 summarise the annual *Brassica* seedling production, annual seedling production per crop type and the number of nurseries growing each crop variety.

Table 1. Annual *Brassica* seedling production of eight nurseries in Victoria

Reference	Annual seedling production	Annual tray production @ 200 cells/ tray
1	93,600,000	468,000
2	25,000,000	125,000
3	25,000,000	125,000
4	13,500,000	67,500
5	9,000,000	45,000
6	2,800,000	14,000
7	1,500,000	7,500
8	320,000	1,600
Average total	21,340,000	106,700
Sum Total	170,720,000	853,600

Table 2. Annual *Brassica* seedling production (trays/ year) of eight nurseries in Victoria

Site	Cauliflower	Broccoli	Cabbage	Brussels sprouts	Chinese cabbage	Chinese broccoli
1	198,900	187,200	35,100	14,040	14,040	14,040
2	25,000	18,750	75,000	6,250	0	0
3	2,250	4,500	750	0	0	0
4	10,000	112,500	2,500	0	0	0
5	4,200	6,300	2,800	238	238	238
6	512	512	512	64	0	0
7	16,875	33,750	16,875	0	0	0
8	11,250	22,500	11,250	0	0	0
Sum Total	268,987	386,012	144,787	20,592	14,278	14,278

B. *Brassica* diseases controlled

All eight nurseries controlled downy mildew and nominated it as their potentially most damage causing disease in brassicas (Table 3). The following diseases were also controlled: powdery mildew (5), damping off/ *Pythium* (5), *Rhizoctonia* (4), Bacterial spot (1), and *Botrytis* (1). No other disease was nominated as potentially causing the most damage.

Table 3. *Brassica* diseases identified by eight nurseries in Victoria

Disease	Controlled the disease in the last 12 months	Identified as potentially causing the most damage
Downy mildew	8	8
Powdery mildew	5	-
Damping off /or <i>Pythium</i>	5	-
<i>Rhizoctonia</i>	4	-
Bacterial spot	1	-
<i>Botrytis</i>	1	-

C: *Brassica* pests controlled

All eight nurseries had to control DBM and the cabbage white butterfly (Table 4). Seven nurseries controlled aphids, five controlled slugs and snails, four controlled thrips and three controlled heliothis. Pests reported by nurseries to cause the most damage were DBM (7), Cabbage white butterfly (4), slug/ snails, heliothis, and fungus gnats/ shore flies (1).

Table 4. Number of nurseries identifying *Brassica* pests and rating severity of their damage.

Pest	Controlled in the last 12 months	Don't know the pest	Identified as causing the most damage	No control needed
diamondback moth	8	-	7	-
cabbage white butterfly	8	-	4	-
aphids	7	-	-	1
slugs/snails	5	-	1	3
thrips	4	-	1	4
heliothis	3	3	1	2
fungus gnats/sciarid flies	3	2	1	3
cabbage centre grub	2	3	-	3
cutworm	3	0	-	5
looper caterpillar	2	2	-	4
whitefly	2	1	-	5
other	-	-	-	-

D: Spraying equipment & calibrating practice

All spray units were modified to fit nursery conditions and were motorised, i.e. fitted onto a forklift or a Kubota tractor. One nursery applied both insecticides and fungicides through the irrigation system. Spray unit types are shown in Table 5.

The nurseries reported to change nozzles as follows:
 every 12 months (3); every 18-24 months (1) ; never changed nozzles (2)
 airshear unit (no nozzles) (1)

The calibration practice varied. Two nurseries calibrated weekly, one calibrated monthly, one every 3-4 months, one every eight months, one every 2 years and two nurseries never calibrated their spraying equipment.

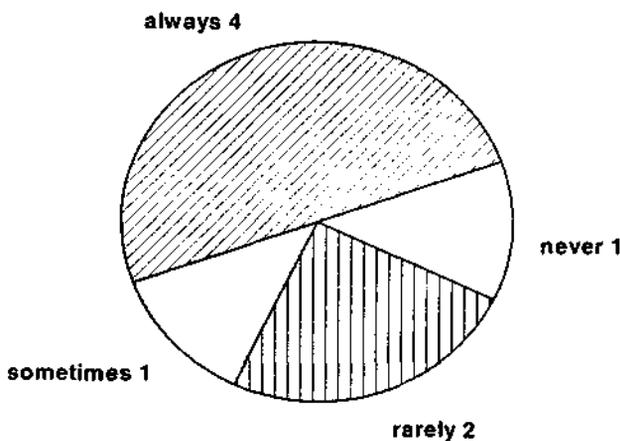
Spray volumes applied by each type of spray unit are shown in Table 5.

Table 5. Spray volumes used for both *Bacillus thuringiensis* (Bt) and synthetic insecticide applications in eight *Brassica* nurseries in Victoria

Site (random)	Synthetic insecticide spray volume l/ha	Bt spray volume l/ha	Spray unit type
1	2876	2876	hand held gun/& via irrigation
2	1668	833	boom
3	700	700	mister
4	700	700	boom
5	606	606	mister
6	606	606	mister-airshear
7	412	535	boom
8	200	n/a	mister
Average boom	927	689	
Average mister	528	637	

E: Spray record keeping

Nurseries were asked to answer either: 'always', 'often', 'sometimes', 'rarely', or 'never' to describe how often they kept spraying records over the last 12 months. The answers are shown in Figure 1.



Survey of *Brassica* seedling producers in Victoria, IHD Knoxfield 1998

Figure 1. Nurseries' response to the question: How often do you keep spraying records?

F: Fungicides used by nurseries

Nurseries used the following fungicides:

- Ridomil® (6)
- Dithane®, Previcur® (5)
- Bravo®, Acrobat® (4)
- Agriofos®, Alliette®, Folifos® (3)
- Sumisclex®, Benlate®, Uperin® (2)
- Fungarid®, Zineb®, Previt®, Rovral®, Bavistan®, Antracote®, Terraquat®, Copper kocide® (1)

G: Fungicides mixed with Bt

Seven of the eight nurseries used *Bt*, five nurseries mixed at least some fungicides with *Bt* in order to save labour, one nursery did not mix *Bt* with any fungicides.

Fungicides mixed with *Bt* were:

- Ridomil® (4); Previcur®, Dithane®, Acrobat® (3); Uperin®, Folifos®, Benlate®, Agriofos® (2)
- Sumisclex®, Previt®, Bravo®, Bavistan®, Alliette® (1)

H: Fungicide spray program, spraying frequency & disease monitoring

The fungicide spray programs were reported by the eight nurseries:

- (8) regular spray program in spring/autumn
- (5) regular spray program in summer/winter
- (2) monitoring based spray program in winter *
- (1) monitoring based spray program summer *
- (6) spray program is backed up with regular disease monitoring
- (2) did not monitor diseases.

Seasonal spraying frequency is shown in Table 6.

Table 6. Seasonal spraying frequency in seedling nurseries in Victoria

Spring/autumn	Summer	Winter
5 days (1)	5 days(1)	5 days (2)
6 days (1)	7 days (3)	7 days(2)
7 days (3)	5-10 days (1)	5-10 days (1)
5-10 days (1)	14 days(2)	21 days, at 2-3 week crop stage only (1)*
10 days (1)	no regular frequency (1)*	no regular frequency (1) +(1)*
14 days (1)		

I: Insecticide use

Answer to question: How do you decide when to spray?

Seven nurseries used a regular insecticide spray program. One nursery used monitoring as its main way to decide when to spray. Nurseries also reported to consider other factors in deciding when to spray, these were:

- back up monitoring (3)
- monitored but did not report it as a factor in deciding when to spray (3)
- past experience of when pest numbers were high (2)
- weather forecast (2)
- stage of the crop (1)
- customer news from commercial vegetable production (1)
- spraying at dusk when insect activity was observed to be the highest (1)

The pest spray threshold is reported in Table 9. The threshold concept seemed new to most respondents. Zero pest level and damage were aimed for by most.

Answer to question: How do you decide what insecticide to use?

Nurseries considered chemical re-sellers advice (7); past experience (5), pest type (5), pest pressure (4), crop stage (2), Agriculture Victoria advice (2), trying to rotate insecticide families (2), weekly information from customers about their pest problems (1), information directly from pesticide companies (1), label information (1) and use of broad spectrum and low cost insecticides (mainly Karate®) (1).

J: Synthetic insecticides used

The insecticides used by most growers were:

Ambush® (6), Perfekthion®/Dimethoate® (6), Regent® (5), Pirimor® (4), Lorsban®/Metasystox® (3). Mavrik®, Karate®, Talstar®, Orthene®, Confidor® were each used by two nurseries.

Table 7. Insecticide brands and family used by nurseries in Victoria

Insecticide brand	Number of nurseries	Insecticide family
Ambush®	6	SP
Karate®	2	SP
Mavrik®	2	SP
Talstar®	2	SP
Dominex®	1	SP
Hallmark®	1	SP
Pyranica®	1	phenyl pyrazole-miticide
Regent®	5	phenyl pyrazole
Lorsban®	3	OP Thioate
Metasystox®	3	OP Thioate
Orthene®	2	OP Thioate
Chlorofos®	1	OP Thioate
Phosdrin®	1	OP Phosdrin® group
Perfekthion®/ Dimethoate®	6	OP Dithioate
Supracide®	1	OP Dithioate
Folimat®	1	OP
Endosulfan®	1	OC
Confidor®	2	Nitroguanidine
Pirimor®	4	Carbamate

K: Synthetic insecticides mixed with Bt

Of the seven nurseries that used *Bt*, three routinely mixed *Bt* with synthetic insecticides, two mixed *Bt* occasionally and two did not mix *Bt* with synthetic insecticides. The reasons given for mixing *Bt* with synthetic insecticides were aphid kill (4), contact kill back up for *Bt* (2) and saving of labour (3).

The synthetic aphicides reported to be mixed with *Bt* were Perfekthion®, Confidor® (2) Pirimor®, Metasystox®, Dimethoate® (1). The synthetic larvicides reported to be mixed with *Bt* were Karate®, Ambush®, Regent® and Phosdrin®

L: *Bt* use

Seven of the eight nurseries used *Bt*. One nursery reported to use *Bt* briefly in 1997, but had since discontinued use because the owner thought it to be ineffective given the frequent irrigation requirements of seedling crops. *Bt* was first used in 1997 by one nursery, in 1996 (2), in 1995 (2), in 1992 (1). Two nurseries were not asked the question. The *Bt* types used were DiPel® Forté (6), Delfin® (4), MVP® (4), Xentari® (2), Biobit® (2)

M: *Bt* & Synthetic insecticide spraying frequency & pest monitoring

Seven nurseries used a regular insecticide spray program. The spraying frequency varied considerably (Table 8). Seven nurseries used *Bt*; one did not use *Bt* in the last 12 months. Six of the seven nurseries had a regular back up pest monitoring program (presence/ absence and damage checks (5). Two nurseries used pest counts). One nursery only monitored pests when seedlings were 10-14 days from the point of sale. One nursery (*) did not have a regular spray program but monitored daily using presence/ absence and damage checks, yellow sticky traps and pheromone traps. Insecticides at this nursery were applied via the irrigation system. The monitoring procedures are summarised in Table 11. Four nurseries used yellow sticky traps and one used DBM pheromone traps.

Table 8. *Bt* and synthetic insecticide spraying frequency per *Brassica* crop batch for eight nurseries in Victoria

Site	Spring to Christmas		Summer after Christmas		Winter	
	<i>Bt</i>	synthetic	<i>Bt</i>	synthetic	<i>Bt</i>	synthetic
1	2	1	3	2	1	0-1
2	-	5	-	5	-	5
3	4	4	4	4	1	1
4	4	3	5	4	2	0-1
5	3	8	3	8	?	8
6	7	7	7	7	0	0-1
7	5	8	8	8	0	3
8	4	4	20	8	0	1

Table 9. Pest monitoring procedures of eight *Brassica* nurseries in Victoria

Site	Monitoring frequency in summer	Description	No of seedlings checked/ area	No of locations	Spray threshold (pests/ total area)
1	daily (2 h/ day)/ traps weekly	p/a/d, count. y.traps	45 /660m ² (22 areas)	10-12	1
2	daily	p/a/d, count	75/ nursery	5-6	3
3	nearly daily	p/a/d	117/0.4 ha	45	1
4	daily	p/a/d, y. traps, p. traps	45/2 ha	10	4-5 damaged plants
5	3x week	p/a/d, egg count, y. traps	1.5 trays/50m ²	4	1
6	daily/traps weekly	damage, y.traps	2.5-5 trays/?	3	1
7	2-3x week	p/a/d	100/ 1.2 ha	10-12	none used
8	10-14 days before sale	p/a/d	Could not tell	10-12	1

Note: P/a/d = presence/absence/damage check monitoring, y. traps = yellow sticky traps

(*) Monitoring only/ no regular spray program

(**) one leaf checked on each seedling in a tray

N: Insecticide rotation

Three nurseries had no set insecticide rotation program. Four nurseries attempted to rotate insecticides (Table 10). Four nurseries used *Bt* first. One nursery did not use *Bt*.

Table 10. Typical insecticide rotation used by eight *Brassica* seedling nurseries in Victoria

Nursery	Typical insecticide rotation described
1	<i>Bt</i> 2x, Ambush® or Talstar® 1x, <i>Bt</i> 2x, Orthene® 1x; Regent® replaces Orthene® or Ambush® at peak times in summer;
2	Regular 3 week cycle: Ambush®, Mavrik®, Talstar®; in summer DiPel® is also used every 15-20 days, occasionally also Folimat®
3	Karate® 2x, <i>Bt</i> (DiPel®) or other <i>Bt</i> 4x, Regent® 4x, <i>Bt</i> (Delfin®) or other <i>Bt</i> , Hallmark® 4x, <i>Bt</i> (MVP®) 4x
4	No set rotation Karate® is used as much as possible; from time to time other sprays are used; full information was not available, spray records were not kept
5	<i>Bt</i> is used throughout, also Ambush® 1x, Perfekthion® 1x, Regent® 1x (Regent® is occasionally used more often)
6	<i>Bt</i> (MVP®) with Perfekthion® 1x, then Regent® with Perfekthion® 1x; this is repeated; other chemicals are used as 'a quick fix' from time to time
7	No set rotation <i>Bt</i> 1x, then any of the insecticides listed 1x, then <i>Bt</i> again 1x
8	No set rotation, but try to use different sprays from one application to the next

O: Cultural controls

The use of cultural controls is reported in the Table 11. All nurseries (8) reported control of weeds and seven controlled weeds also in the nursery waste heap. One nursery reported use of fine mesh over much of 1.2 ha area to exclude insects, but did not seem to reduce spraying practices to take advantage of the insect exclusion. Two nurseries used *Trichoderma* and two avoided morning irrigation in order to reduce downy mildew spore germination, one reported to do so consciously in order to reduce fungal infestation. Six nurseries irrigated in the morning. One nursery irrigated after 6.15 pm, all others had completed their irrigation by that time. Irrigation practices are reported in Table 12. All eight nurseries reported to spray fungicides either early in the morning or in the afternoon, two of these also sprayed fungicides in the evening to midnight period and one reported spraying insecticides at dusk to be most effective in *Brassica* pest control.

Table 11. Number of nurseries using cultural control methods for pest and disease management

Cultural control	No. of nurseries
Controlling weeds around the nursery	8
Controlling weeds in the nursery waste heap, n=7	7
<i>Trichoderma</i> use: (1-small scale trials)	2
Glasshouse screening	1
Encouraging naturally present beneficial insects (active effort to reduce spraying & switch to <i>Bt</i>)	1
Releasing commercially produced beneficial insects	0
Avoiding morning irrigation to reduce downy mildew	2
Timing insecticide application to dusk	1
Timing irrigation to evening to midnight period	1

Table 12. Irrigation practices of eight *Brassica* seedling nurseries in Victoria

Site (random)	Number of times/ day	Duration of each irrigation (minutes)	Time of day
1	3	10-15	6am to 6pm, 9-10pm if hot
2	2	25	1am & 10am
3	2	5	morning & evening from 7 pm
4	4	4	6am, 2pm, 4pm, 5pm
5	2	0.5	day to 4 pm (morning/ night avoided)
6	2-3	60	morning to 4pm
7	2	4	afternoon to 7 pm
8	3-4	10	4.30am, 5pm (night avoided)

Nursery distance from the nearest commercial *Brassica* vegetable production is given in Table 13.

Table 13. Nursery distance from the nearest commercial *Brassica* vegetable area

No. of nurseries	km
1	20
2	10
2	4
2	2.5
1	0.5

P: Grower understanding of insecticide resistance

Six growers agreed that insecticide resistance results in pests surviving spraying, two were undecided about what insecticide resistance means to pest survival. Seven growers agreed that development of insecticide resistance may be slowed down by using different insecticide families in rotation, one grower was undecided. Four growers agreed that insecticide resistance is caused mainly by excessive spraying, four were undecided. Four growers were aware that pests could develop resistance to *Bt*, while four were undecided or disagreed. These were the better understood insecticide resistance issues.

Three of the growers agreed that development of insecticide resistance can be slowed down by spraying less often, five growers were undecided or disagreed that that could be so. Two of the growers thought that development of insecticide resistance can be slowed down by using non-chemical controls, while six were undecided or disagreed.

Q: Growers' attitudes to Integrated Pest Management

IPM training issues:

Four growers knew about IPM, three were undecided and one grower did not know about IPM. Three growers thought they had 'hands-on' practical IPM training, two were undecided and three thought they did not have practical IPM training. Two growers agreed that they had advice available to them to set up an IPM program, four were undecided, two reported to lack IPM advice.

Interest in IPM:

Five growers felt strongly that they had time to spare for IPM, two were undecided. Lack of time for IPM was recorded for one grower. Four growers did not consider reducing chemical use as economically risky, one was undecided and three growers thought that it was too risky to use less chemicals. Two growers were happy with existing controls, three were undecided and three were not happy with their existing pest controls. Four growers wanted to see other people in the industry use IPM first and four did not. Four growers were willing to spend extra money on pest control while four growers were not.

IPM information requirements:

Five growers agreed that they would like printed information about IPM, three were undecided. Five agreed that they would like to attend an IPM grower night, one was undecided and one disagreed.

R: Sources of pest management advice

All eight nurseries nominated chemical re-sellers among their most important source of advice. Besides this, the following sources were also nominated as the most important: own knowledge and experience (2), other growers (2), Department of Agriculture (1), Trade journals & newsletters (1).

All eight nurseries wanted to be on the IHD mailing list, seven wanted a consultation with IHD about their pest management practices, one was undecided, wishing to see the survey report first.

MAJOR FINDINGS

- Most nurseries named DBM as the potentially most damaging pest in brassicas
- All nurseries named downy mildew as their potentially most damaging disease in brassicas
- Most nurseries were calibrating spray equipment regularly, but two nurseries never calibrated
- Spray volumes applied ranged from 528 to 927 l/ha
- Most growers are using rapid rotation or alternation of insecticides
- *Bt*, synthetic pyrethroids and dimethoate are in frequent use. The new insecticide, Regent[®], is also being used in nurseries
- Promotion of a rational rotation strategy is of major importance
- A need for more information on the 'mechanics' of insecticide resistance is indicated
- Improvement in spray record keeping is required by many of the nurseries surveyed
- The only widely used cultural pest control was weed control around the nursery and waste heap
- Chemical resellers were identified as the main source of pest management advice
- Most nurseries expressed interest in IPM
- Most nurseries would like to receive printed information on IPM and to attend a grower night

CONCLUSION

It will be important to provide effective advice to this integral part of the industry. Of particular relevance to resistance management issues is the widespread use of fipronil in nurseries in its first season, together with examples of extremely heavy use of *Bt* over summer.

ACKNOWLEDGEMENTS

We thank the representatives of the eight nurseries who participated in this survey.

APPENDIX B
PEST MANAGEMENT SURVEY OF VICTORIAN *BRASSICA*
NURSERIES, May 1998

SURVEY QUESTIONNAIRE

[SPRAY EQUIPMENT SECTION]

The first question:

1. Could you please tell me what type and brand of spraying set up you have?

[TICK]
Hand boom/ boom
Fogger
Mister
Knapsack back up
Silvan turbomiser
Air assisted Hardi twin sprayer
CDA sprayer
other

[BRAND]

.....
[IF BOOM/KNAPSACK]

2. Are the nozzles for insecticide spraying:

cone or flat fan?	
ceramic, plastic, or brass?	

3. Could you please tell me what spray volumes do you use?

.....
[PROBING]

What area does that cover?

Is this the same or different for BT?

[CROP SECTION]

The next question.

4. Can you please tell me what Brassicas have you grown in the last 12 months?

5. For the [INSERT CROP], could you please tell me what proportion of your annual BRASSICA production has that crop represented in the last 12 months?

6. Which main varieties of [INSERT CROP] do you grow in summer and which do you grow in the autumn/winter? [UP TO 10 FOR EA]

[TICK]	[Proportion of Brassica production]	[BRASSICAS VARIETY]	
		[SUMMER]	[AUTUMN]
cauliflower			
broccoli			
cabbage			
Brussels sprouts			
Chinese cabbage			
Chinese broccoli			

[PEST & DISEASE SECTION]

The next question is about pests.
I will read a list of pests.

7A. Please tell me if you had to control these in your Brassica seedlings in the last 12 months?
Please answer 'don't know' if you are not sure.
It's ok to not know, some of these pests are very minor.

	[Y/N/DN]	[IF SERIOUS]
aphids		
cabbage white butterfly		
diamondback moth /cabbage moth		
heliothis		
thrips		
cabbage centre grub		
looper caterpillar		
cutworm		
fungus gnats/sciarid flies		
whitefly		
slugs/snails		
other		

7B. Which of these cause potentially the most damage to your Brassica seedlings? [TICK]

8A.

The next question is about diseases.

Like before, I will read a list.

Please tell me if you had to control these in your Brassicas in the last 12 months?

Please answer 'yes', 'no', or 'not sure'.

	[Y/N/DN]	[IF SERIOUS]
Downy mildew		
Powdery mildew		
Damping off /or <i>Pythium</i>		
<i>Rhizoctonia</i>		
Other [wilts, root rots, bacterial, viruses, etc]		

8B. Which of these potentially cause the most damage to your Brassica seedlings? [TICK]

[BT/INSECTICIDE SECTION]

The next few questions are about insecticides.

Please remember there are no right or wrong answers.

9. Can you please tell me what insecticides have you sprayed on your Brassicas in the last 12 months?

[PROBING]

Are there any other ones? Anything else? [2X]

Which BT products, if any, have you used?

	[TICK]
Delfin®	
DiPel® Forté	
MVP	
Xentari®	
Biobit®	
When did you first start using BT?	

[IF NO BT]

Please tell me if BT was ever used at your nursery?

[IF USED IN THE PAST]

What was the reason you stopped using BT please?

10.

Could you please describe your typical INSECTICIDE rotation program for Brassicas?
If you have one.

[FUNGICIDE SECTION]

11. Can you please tell me what fungicides have you sprayed on your Brassicas in the last 12 months?

[PROBING] Any soil drenches such as fungarid, or others?
Are there any other ones? Anything else? [2X]

12.

Please tell me, if you have/or have not a regular fungicide spraying program?
Yes/ NO

What is your fungicide spraying frequency in BRASSICAS in:

spring/autumn	
winter	
summer	

What time of day or night do you spray fungicides?

morning	
day	
afternoon to 7pm	
evening from 7pm to midnight	
evening to day break	

13.

Please tell me if you have/or have not a regular disease monitoring program?
Yes/ NO

14.

Please tell me how often over the last 12 months have you kept spraying records.
Would that be always, often, sometimes or never.

[BT SECTION PLUS]

15. Can you please tell me what insecticides, IF ANY, and what fungicides, IF ANY, you mix with BT?

insecticide

fungicide

16. What is the reason you mix BT with other insecticides please?

[PROBE] Any other reason? Anything else?

[IF BT USED]

17. How many times do you have to spray each Brassica batch with BT before Christmas and how many times after Christmas?

On average.

How many BT sprays on each batch in winter? On average.

18. How many times do you have to spray each Brassica batch with insecticides other than BT before Christmas and how many times after Christmas?
On average.

.....
On average, how many would that be in winter?
.....

19. When you spray. Can you please tell me how do you decide what insecticide spray to use?

.....
[PROBING] Where does your spray program come from?
What else do you use to decide?
Anything else? {2x}

20. Can you please tell me how do you decide when to spray insecticides?

.....
[PROBING]
Regulars spraying program/ how often?
What else do you use to decide?
Anything else? {2x}

[DONT ASK-TICK] monitor

How many seedlings do you check per spraying area?

What area would that be?

At how many locations, in that area, do you check?

How often do you monitor?

P/A or counts?.....

At what DBM infestation do you decide to spray?

Please tell if you have/or have not been using [INSERT] in the last 12 months:

Yellow sticky traps	
Pheromone traps	

21. Please tell me how often you calibrate your spraying equipment?
.....

22. Please tell me how often you change the spray nozzles?

NON-CHEMICAL PRACTICES & RESISTANCE

The next question is about non-chemical controls.

To make things easy and quick, I will read out a list.

Please answer 'Yes', 'No' or 'Sometimes' depending on what you do.

23. Please tell me if, over the last 12 months , you have/or have not been:

	[Y/N/S]
controlling weeds around the nursery	[Y/N/S]
controlling weeds in the nursery waste heap	
using Trichoderma	
releasing commercially produced beneficial insects	
encouraging naturally present beneficial insects in any way at all	
[IF YES ASK HOW]	
Anything else?	

How far away from your nursery is the nearest commercial *Brassica* growing area?

.....

24. The next question is about your opinions about pest control.

I will read through a list of statements. There are no right or wrong answers.

Please choose a point on a scale from 1-5 to show your opinion.

Or, answer don't know if you feel that you know nothing about the statement.

It is perfectly OK to not know. Many growers may not know.

Please choose:

if you absolutely disagree 1 2 3 4 5 if you absolutely agree

[CHECK UNDERSTANDING OF SCALE]

[STATEMENT] how much do you agree/or disagree with that? [SCALE 2x]

<u>insecticide resistance</u> means that <u>pests survive spraying</u>		[DONT KNOW]
<u>insecticide resistance is caused mainly by excessive spraying</u>		
<u>insecticide resistance may be slowed down by using different insecticide families in rotation</u>		
<u>insecticide resistance can be slowed down by spraying less often</u>		
<u>insecticide resistance can be slowed down by using non-chemical controls such as crop rotation and biological controls</u>		
<u>pests could develop a resistance to BT</u>		

[IPM SECTION]

The next question is about Integrated Pest Management, or IPM, and what you think of it.

After that, we are just two minutes from the end.

Integrated pest management is a new concept for many people. So, I will describe it using one possible definition. I will then ask a few questions about your opinions about IPM. Is that Ok?

So, the definition:

IPM is an mixture of pest & disease control methods used together.

IPM is a move away from relying on chemicals as the only or as the main control.

Cultural and biological controls are used. Chemicals are also used, but less of them.

Monitoring of pests is a basic building block of IPM.

IPM is often set up in gradual steps over several years, but it does not have to be.

The first step is the fine tuning of chemical sprays via monitoring.

IPM generally reduces the need to spray.

Can I go to the question now?

25. Because IPM is a fairly new concept, it is easy to understand why people have reservations about using it.

I will read out a list of reasons some growers have for not using IPM.

Please think about your own reasons for not using IPM,

and then please choose a point on a 1-5 point scale depending on how much you agree or disagree with each statement.

Please choose:

if you absolutely disagree 1 2 3 4 5 if you absolutely agree

or please answer don't know if you wish.

[STATEMENT] how true is that of you (3x)/

how much do you agree or disagree with each statement?

I don't know about IPM [REPEAT SCALE 2x]

I don't have hands on training in IPM

I don't have time to spare for IPM

I think it is too risky to use less chemicals

I am happy with existing controls, so why change

I have lack of advice available to me to set up an IPM program

I want to wait & see other people in the industry use IPM first

I don't want to spend any extra money on pest control

I would like printed information about IPM

I would like to go to an IPM grower night in my area

[END SECTION]

[IF FAST INTERVIEW]

Now just a few more minutes of your time.

26. Please tell me how often do you usually irrigate *Brassica* seedlings in summer?

27. For how long do you usually irrigate them each time in summer?

28. What time of day or night do you usually irrigate?

Morning

Day

Afternoon (till 7 pm)

Evening to midnight (from 7pm)

Midnight to day break

Other time [ASK WHEN]

29.

Please tell me where do you get your pest control advice?

I will read out a list.

Your own knowledge & experience

Chemical re-sellers, such as Muirs

Dpt. Of Agriculture

Other growers

Trade journals & newsletters

any other?

[DONT ASK/TICK]

Spray contractor, Internet, Private consultant

	1	
	2	
	3	
	4	
	5	
	6	

30. Which of these is your most important source of advice? [GO BACK & TICK]

31. The very last question.

Could you please tell me what is the total annual BRASSICA tray production of your nursery?

[PROBE] What is the total size of your growing and stock holding areas under BRASSICA production please? (acres or ha)

[CONCLUSION]

Thank you very much for your time and for the information.

A summary of the results and the pest management manual will be sent to you in August when this project is finished.

Would you like to be on our mailing list?

Would you like an opportunity to discuss the results with us?

Is there anything you would like to ask me?

ADDRESS CHECK

Again, thank you so very much for your time.

A survey of pest management practices amongst growers of organic *Brassica* vegetable crops in Victoria in 1998

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ABSTRACT

The following topics were addressed in a telephone survey of seven producers of organically grown brassicas from Victoria:

- crop statistics (area under *Brassica* crops at peak production time & crop varieties)
- pest problems
- deployment of *Bacillus thuringiensis* (*Bt*)
- pest monitoring
- non-chemical control practices
- information requirements

Growers identified cabbage white butterfly as the most serious pest of *Brassica* crops. Crops are mainly monitored using pest or damage presence/ absence assessments. Most growers use *Bt* for control of caterpillar pests, but a minority use 1. fish emulsion spray mixed with pyrethrum, 2. Lime sulphur & coconut oil. Some organic producers use a summer production break as their main pest management strategy. Although all growers reported to encourage naturally present beneficial insects by provision of refugia and avoidance of broad-spectrum insecticides, they had little specific knowledge of the types of beneficial insects they were protecting. All growers surveyed were interested in receiving printed information on pest management and attending a grower night.

INTRODUCTION

We surveyed seven 'organic' *Brassica* vegetable growers, by telephone, in Victoria, who grew at least 1.5 acres of *Brassica* vegetables during their peak production time. The interviews were conducted to gather information about non-chemical pest management practices and the pest management information needs of 'organic' growers in Victoria. The interviews were designed to supplement the main survey of 50 'conventional' *Brassica* vegetable growers (Survey of pest management practices amongst Victorian *Brassica* growers, 1998).

METHODOLOGY

A sample of seven growers was selected from a membership list provided by NASAA (National Association for Sustainable Agriculture Australia) and BFA (Biological Farmers Association). Most growers were telephoned and asked qualifying questions about their crops and the size of their production. The survey form is in Appendix C. Telephone interview times were arranged with growers who grew at least 0.6 hectares of brassicas during their peak production time, until the sample of seven was reached.

Care was taken to minimise instrumentation error through careful questionnaire design. Interviewing, interviewer and response errors were minimised by conducting the interview in a standardised way, taking care to ask questions in their exact wording, including a standardised way of stressing key words and a standardised way of explaining scales and checking scale understanding before recording answers. The same person conducted all interviews. Care was taken to adapt the questionnaire to the 'audible only' telephone mode.

Key areas covered in the survey were:

- crop statistics (area under *Brassica* crops at peak production time & crop varieties)
- pest problems
- deployment of *Bacillus thuringiensis* (*Bt*)
- pest monitoring
- non-chemical control practices
- information requirements

RESULTS

Results are presented as tables and summary paragraphs which relate to each question in the survey. Numbers in brackets refer to the number of growers who gave the particular answer to the survey question.

Area under *Brassica* crops at peak production time & crop varieties grown

The total area under 'organic' *Brassica* production at peak production time was 16 ha. Four growers with 9.4 ha in total, grew brassicas commercially in summer. Three growers, 6.6 ha, avoided summer production, using this as their chief pest management strategy. The *Brassica* crops grown: Cauliflower (4), Broccoli (3), Cabbage (3), Brussels sprouts (2), Turnips (1) and the respective areas of each by individual growers are given in Table 1. The crop varieties grown are given in Table 2.

Table 1. Area under *Brassica* crops at peak production time for seven organic vegetable growers in Victoria

Reference	Area under <i>Brassica</i> crops at peak production time (ha)	Cauliflower	Broccoli	Cabbage	Brussels sprouts	Turnips
summer 1	1.6	0.8		0.8	0.1	
summer 2	2.4	1.2		1.2		
summer 3	3.4		3		0.4	
4	1		1			
5	4					4
summer 6	2	0.2	1.6	0.2		
7	1.6		1.6			
Total (ha)	16	2.2	7.2	2.2	0.5	4
No of growers		4	3	3	2	1

Table 2. *Brassica* varieties grown by six organic growers in Victoria (numbers in brackets refer to the numbers of growers who grow the variety)

	Summer grown	Autumn/winter/spring grown
Cauliflower	Prestige (1) Don't know (2)	Don't know (2)
Broccoli	Greenbelt (1) Marathon (1)	Marathon (3) Maverick (1) Don't know (1)
Cabbage	Grandslam (1) Green Coronet (1)	Sugar Loaf (1) Red Rookie (1)
Brussels sprouts	Oliver (1) Uniline (1)	

Brassica pests causing damage

None of the 'organic' *Brassica* growers identified DBM as the pest causing the most damage. This was in contrast to the 'conventional' growers who all identified DBM (diamondback moth) as the pest causing most damage (n=50). Only one 'organic' grower reported DBM to cause any damage at all, but only early in the season before naturally present biological control build up. Cabbage white butterfly (CWB) was the main pest identified by organic *Brassica* growers. Six growers reported that CWB caused damage to their *Brassica* crops, but only two growers identified it as the pest which causes most damage. Aphids were the second main pest identified. Table 3 summarises the results.

Table 3. Numbers of organic growers identifying *Brassica* pests and rating the severity of their damage.

Pest	Causing damage in the last 12 months	Don't know the pest	Pest identified as causing most damage	No damage caused
diamondback moth	1	2	-	4
cabbage white butterfly	6	-	2	1
aphids	3	-	1	4
thrips	2	1	-	4
heliiothis	-	1	-	6
cabbage centre grub	-	3	-	4
cutworm	-	1	-	6
looper caterpillar	-	1	-	6

Bt use & pest monitoring procedures

Four growers used *Bacillus thuringiensis* (*Bt*). The *Bt* types used were: Delfin (2), DiPel Forté (2), Xentari (1). Three growers did not use *Bt* at all. One of these growers grew brassicas throughout the year including summer. The remaining two growers avoided summer production. Three growers in total avoided summer production, four growers grew brassicas throughout the year. All growers monitored for pest presence.

Avoiding summer production:

Three growers chose to avoid growing brassicas in summer. This was the basis of their pest management strategy. Two used no *Bt* at all. One used, on average, 2 *Bt* sprays on the last spring crop. No other sprays were used by these growers except for one grower, who used lime sulphur in a regular fortnightly program and an occasional spray of bluestone/Bordeaux mix. All three growers monitored pest presence while they were harvesting crops either weekly (2) or every 2-3 days (1), presence/absence and crop damage checks, not pest counts, were done.

Summer production:

Four growers grew brassicas throughout the year including summer. All extended considerable effort to monitor pest presence. Two growers further monitored for beneficial insect presence, two used yellow sticky traps, one used DBM pheromone traps, two employed a private pest management consultant, one of which kept monitoring records and set spray thresholds. Two growers used a monitoring based *Bt* program, one used a regular *Bt* spray program and one grower used no *Bt* at all. Two growers kept *Bt* spray records. Two growers used a regular spray program of fish emulsion to deter pests from egg laying and disrupt pest host plant location. Tables 4 & 5 list spraying frequency and monitoring procedure for each grower.

Table 4. Number of *Bt* and other sprays used per each *Brassica* crop by seven organic growers

Grower	Spring to Christmas		Summer after Christmas		<i>Bt</i> spray volume (l/ ha)	Sprayer type
	<i>Bt</i>	Other sprays	<i>Bt</i>	Other sprays		
summer 1	2	2*	3	3*	400	Boom
summer 3	2	-	5	-	114	Cluster spray unit
summer 6	3	-	2	-	1500	Boom
7	2	-	2	-	400	Boom
summer 2	-	6**	-	6**	0	Boom
4	-	14***	-	14***	0	Boom
5	-	-	-	-	0	Boom

* Biotech® fish emulsion spray

** Biotech fish emulsion spray mixed with Botanical pyrethrum spray 1-2x per crop

***Lime sulphur & LOC® coconut oil

No grower sprayed any product in winter.

Table 5. Pest monitoring procedures used by seven organic growers in Victoria in 1998

Grower reference	Monitoring frequency (days)	Monitoring type	Total number of plants checked	Number of locations	Threshold used
1 summer	7	P/a/d & count/ consultant	?	?	5 eggs/10 plants, 3 instars/10 plants
2 summer	1	P/a/d	6 per 1.5 acres	6	1 instar
3 summer	1/3-4	P/a/d	all harvested	-	?
4	2-3	P/a/d & count	35	2	-
5	7	P/a/d	all harvested	-	-
6 summer	7-14	don't know/ consultant	?	?	?
7	7	P/a/d	12	5	1-3 instars

Note: P/a/d-presence/absence/damage monitoring

Cultural and biological controls

Crop rotation (6), ploughing in/feeding to stock crop residues (6), buying in *Brassica* seedlings from specialist nurseries (5), and controlling weeds which are potential hosts for *Brassica* pests (6) were the most frequently used cultural control practices. Avoiding *Brassica* pests by ceasing cultivation over the summer period was the main control strategy for three growers. Two growers used clover mulches and two reported to pay fine attention to balancing soil and plant nutrition to enhance natural host plant resistance. Both used the same private consultant to achieve this, and both asserted this to be the foundation of their pest management strategy (both grew brassicas over summer). The use of Biotech® fish emulsion both as a foliar fertiliser and as an insect repellent spray aimed at confusing pest host plant location was reported to be a key control strategy for two of the four growers who grew brassicas over summer.

By contrast, inter-cropping, planting new seedlings away from older crops and partial polyculture cropping were each used by only one grower. No growers made use of trap crops, row covers or barriers, or attempted to time overhead irrigation to coincide with peak DBM oviposition and activity times, known to occur between dusk and midnight in the Northern hemisphere (McHugh and Foster 1995).

All seven growers reported that they encouraged naturally present beneficial insects. This was done by providing habitat and refuge areas for beneficial insects; ie: pasture, bushland areas, windbreak/ tree planting, buckwheat and oats planting, and growing a range of diverse vegetable and other crops.

The use of broad-spectrum insecticides was avoided by all growers with the exception of one grower who used botanical pyrethrum, but only 1-2 times per crop. Little else was done to encourage beneficial insects. Buckwheat plantings adjacent to brassicas were observed to contain a large number and diversity of beneficial insects (1). One grower allowed some brassicas to seed in an attempt to encourage *Brassica* pest predators and parasites. No other plants were consciously grown as a nectar source for beneficials. Commercial yeast preparations to feed beneficials were not used. One grower reported releasing commercially reared beneficials, but not in the last 12 months. Growers had only a general knowledge of beneficial insects (Table 6). Table 6 lists the cultural and biological practices used by each grower.

Table 6. Cultural and biological practices used by seven organic growers in Victoria

Pest management practice	No. of growers using the technique	Grower						
		1	2	3	4	5	6	7
Rotating brassicas with other non- <i>Brassica</i> crops	6	yes	yes	yes	yes	-	yes	yes
Inter-cropping brassicas with rows of other crops	1	yes	-	-	-	-	-	-
Growing brassicas in a polyculture set up	0	-	-	-	-	-	some	-
Ploughing in <i>Brassica</i> residues after harvest/ feeding to stock	6	yes	yes	yes	yes	yes	yes	-
Controlling weeds that are potential hosts for pests	5	yes	yes	-	yes	yes	yes	some
Using <i>Brassica</i> seedlings from specialist nurseries	6	yes	yes	yes	yes	n/a	yes	yes
Planting new <i>Brassica</i> seedlings away from older crops	0	-	-	-	-	-	-	-
Using row covers or barriers for <i>Brassica</i> crops	0	-	-	-	-	-	-	-
Timing overhead irrigation to control DBM	1	-	-	-	-	yes	-	-
Stopped growing brassicas in summer to avoid DBM	3	-	-	-	yes	yes	-	yes
Using trap crops for <i>Brassica</i> pests	0	-	-	-	-	-	-	-
Using clover mulches	2	-	yes	yes	-	-	-	-
Releasing commercially reared beneficial insects	1	-	-	-	-	-	yes	-
Encouraging naturally present beneficial insects	7	yes	yes	yes	yes	yes	yes	yes
HOW?		a,b,+	c	c, d, e	d	d	f	g
Commercial yeast preparations to feed beneficial insects	0	-	-	-	-	-	-	-
Beneficial insect habitat and refuge areas	6	yes	-	yes	yes	yes	yes	yes
Nectar crops for beneficials	2	yes	-	yes	-	-	-	-
What nectar plants?		a	-	e	-	-	-	-
Beneficials considered most important	0	learning	d/n	d/n	some	d/n	some	d/n
Fish emulsion foliar fertiliser used to disrupt pest host plant location	2	yes	yes	-	-	-	-	-

a Buckwheat crop planted next to brassicas supporting large number of predatory insects, b Pasture, c Balanced soil fertility/plant nutrition seen as a foundation to host plant resistance/beneficial insects, d Windbreak tree plantings & pasture

e "Four field rotation": brassicas/oats/grass seed/clover ploughed in at 4th year, f Some *Brassica* crops allowed to flower/mature, g Natural bushland surroundings + botanical pyrethrum use is avoided

Sources of pest management advice

Organic growers consulted a wide range of sources to obtain information about pest management (Table 7). When asked to nominate their most important source of advice, three growers nominated private consultants. Consultants named were Ian Munro, Pootilla, Vic and Paul Horne, IPM Technologies, Vic. Two growers nominated their own knowledge and experience, one nominated a chemical reseller and two nominated trade journals and newsletters as their most important source of advice. The journals quoted as most useful were Good fruit & vegetable grower, Acres Australia, Weekly times and a local organic club newsletter.

Table 7. Sources of pest management advice

Grower	1	2	3	4	5	6	7	Total
Chemical Re-seller	1	0	1	1	0	1	1*	5
Own Knowledge/Experience	1	1	1	1*	1*	1	1	7
Dept of Agriculture	0	1	1	0	0	0	0	2
Other Grower	1	1	1	0	0	1	0	4
Trade Journals and newsletters	1	1	1*	0	0	0	1*	4
Private consultant	1*	1*	0	0	0	1*	0	3

*-most important source of advice

Grower pest management information requirements

Growers were asked to rate what information about pest management they needed that would really benefit their business. Table 8 shows the linear numeric scale score from 1-5 to each question designed to test grower need for specific pest control information. The question asked was 'I need.....'. Growers were asked to respond on a scale from 1-5 : absolutely disagree= 1, 5=absolutely agree'. All growers (7) were strongly interested in obtaining printed information and attending a grower night. Four growers absolutely agreed that they would like to host a grower field day/ two were undecided and one did not wish to host a grower day (Table 8).

Table 8. Grower pest management information requirements

Grower	1	2	3	4	5	6	7
Information need	Linear numeric scale score						
Information about pest monitoring	5	5	5	2	5	5	2
Information about cultural controls	5	5	5	5	5	5	4
Information about beneficial insects	5	5	5	1	5	5	4
Information about releasing commercially produced beneficials	5	5	5	1	2	5	-
Printed information	5	5	5	5	5	5	5
Grower night attendance	5	5	5	5	5	5	5
Hosting a grower field day	5	5	1	5	5	3	3

MAJOR FINDINGS

- Cabbage white butterfly was reported as the main pest damaging organically grown brassicas
- All growers monitor their crops. Most monitoring consists of pest or damage presence/ absence assessments
- Four out of seven growers use *Bt*
- Other alternatives to synthetic insecticides used by a few growers were 1. Biotech[®] fish emulsion spray mixed with Botanical pyrethrum, 2. Lime sulphur & LOC[®] coconut oil
- Some organic producers use a summer production break as their main pest management strategy
- Growers had only a general knowledge of beneficial insects
- All growers reported to encourage naturally present beneficial insects by provision of refugia and avoidance of broad spectrum insecticides
- All growers are interested in receiving printed information on pest management and attending a grower night

ACKNOWLEDGEMENTS

We thank the seven growers who participated in this survey.

REFERENCES

McHugh Jr., J.J. & Foster, R.E. (1995). Reduction of Diamondback Moth (Lepidoptera: Plutellidae) Infestation in Head Cabbage by Overhead Irrigation, *Journal of Economic Entomology* 88:162 - 168.

APPENDIX C
PEST MANAGEMENT SURVEY OF VICTORIAN ORGANIC BRASSICA
GROWERS, May 1998, SURVEY QUESTIONNAIRE
[CROP SECTION]

The first question is about crops.

1. Can you please tell me what crops have you grown in the last 12 months?
2. Can you please tell me how many acres/or ha of [INSERT B.CROPS+SWEETCORN] do you have in the ground on average at any one time, over the last 12 months?

[TICK]	[AREA] (acres)	[SUMMER]	[BRASSICA VARIETY]	[AUTUMN]
cauliflower				
broccoli				
cabbage				
Brussels sprouts				
Chinese cabbage				
Chinese broccoli				
Mizuna/rocket				
Turnips				
Kohlrabi				
Radish				
Sweetcorn		What time of year do you grow sweetcorn please?		

3. Which varieties of [B. CROP] do you grow in summer and which do you grow in the autumn/winter?

[CULTURAL & BIOLOGICAL CONTROLS]

The next question is about cultural and biological controls. To make things easy and quick, I will read out a list. Please answer either Yes/No/or Sometimes depending on what you do.

4. Please tell me if over the last 12 months, you have/or have not been: [Y/N/S]

rotating Brassicas with other non-brassica crops	[Y/N/S]	
inter-cropping Brassicas with rows of other crops		
growing Brassicas in a polyculture set up		
ploughing in Brassica crop residues after harvest		
controlling weeds (that are potential hosts for pests) around the crop fields		
using Brassica seedlings from specialist nurseries		
planting new Brassica seedlings away from older crops		
using row covers or barriers for Brassica crops		
timing overhead irrigation to control DBM		
stopped growing Brassicas in summer to avoid DBM		
using trap crops for Brassica pests WHAT?		
using clover mulches		
releasing commercially reared beneficial insects		
encouraging naturally present beneficial insects		
HOW?	using commercial yeast preparations to feed beneficial insects	
	providing beneficial insect habitat and refuge areas	
	providing nectar crops for beneficials What nectar plants?	
What do you consider to be key beneficials, IF ANY, for Brassica pest control?		
	Parasitic wasps for DBM	
	Parasitic wasps for CWB	
	Lace wings	
	Spiders	
	Syrphids/Coccinellids	

Anything else at all you would like to add?

[SPRAY EQUIPMENT SECTION]

5. Could you please tell me what type and brand of spraying equipment do you use to spray Bt?

[TICK]
Boom sprayer
air assisted
not air assisted
Silvan turbomiser
Mister
Air assisted Hardie twin sprayer
CDA sprayer
other

[BRAND].....

[IF BOOM]

6. Are the nozzles:

cone or flat fan?	
ceramic, plastic, or brass?	

7. Could you please tell me what BT spray volumes do you use, either in gallons/acre or l/ha?

[PEST SECTION]

The next question.
I will read a list of pests.

8A. Please tell me which of these pests caused damage in your CRUCIFER/Brassicas over the last 12 months?

Please answer either Y/N/or DN, if you are not sure.

It's ok to not know, because some of these pests are pretty minor.

	[Y/N/DON'T KNOW]	[IF SERIOUS]
aphids		
cabbage white butterfly		
diamondback moth /cabbage moth		
heliiothis		
thrips		
cabbage centre grub		
looper caterpillar		
cutworm		
other		

8B. Which of these cause potentially the most damage? [TICK]

[IF SWEETCORN]

9A. Please tell me which of these pests caused damage in your sweetcorn over the last 12 months? Again I will read from a list. Please answer either Y/N/or DN.

Please tell me if you had to control heliothis in your sweetcorn in the last 12 months?

	[Y/N/DON'T KNOW]	[IF SERIOUS]
heliothis		
cutworm or wireworm [seedling stage]		
aphids		
thrips		
army worms		
other		

9B. Which of these cause potentially the most damage? [TICK]

Which months is the heliothis most damaging?

[BT & SPRAY CONTROL SECTION]

10. Which BT products, if any, have you used in the last 12 months please?

	[TICK]
Delfin	
DiPel Forté	
MVP	
Xentari	
Biobit	
When did you first start using BT?	

[IF NO BT]

Please tell me if BT was ever used on your farm?

11. Can you please tell me what other insecticidal or repellent sprays, besides BT, have you used on your crucifers in the last 12 months? [oils, soaps, natural pyrethrum]

[PROBING] Are there any other ones? Anything else?

12. On average, how many BT sprays do you have to use on each Brassica crop before and after Christmas?

On average, how many BT sprays on each crop in winter?

13. On average how many other sprays other than BT do you have to use on each Brassica crop before and after Christmas?

On average, how many would that be in winter?

14. Can you please tell me how do you decide when to spray BT or other sprays?

[PROBING] Do you have a regular Bt spraying program over summer?
If so, how often do you spray?

15. Please tell me if you have or have not [INSERT STATEMENT] over the last 12 months.
Please answer either Y/N/or Sometimes.

monitored for pest presence?	
monitored for beneficial insect presence?	
kept monitoring records?	
kept Bt and other spraying records?	
Yellow sticky traps	
Pheromone traps	

16. [IF MONITORING]

How many times in a week/month do you monitor?
Please tell me how many Crucifer plants do you check in total each time?
At how many locations? Over what total area?
P/A or counts?
At what DBM infestation would you decide to spray BT?

GROWER INFO NEEDS

The next question is about your opinions about pest control and about the pest control information you need that would really benefit your business.
After that we are just 1 minute from the end.

17. I will read out a list of statements.

Please choose a point on a 1-5 point scale depending on how much you agree or disagree with each statement. Please choose:

if you absolutely disagree: 1 2 3 4 5 if you absolutely agree

[STATEMENT] how true is that of you (2x)/

how much do you agree or disagree with each statement?

I need information about pest monitoring methods

I need information about cultural controls

I need information about beneficial insects

I need information about releasing commercially reared beneficial insects

I would like printed information on these topics

I would like to go to an organic grower night/or field day on these topics

I would like to host an organic grower night/or field day at my farm

What other pest and disease control information would you like that would really benefit your business?

18. Please tell me where do you get your pest control advice? I will read out a list.

Your own knowledge & experience

NASAA/or BFA

Other growers

Trade journals & newsletters

Dpt. Of Agriculture

Chemical re-sellers, such as Muirs

Internet

Private consultant

any other source?

19. Which of these is your most important source of advice? [GO BACK & TICK]

[PROBE]: What journals do you find useful for p/d advice?

[END SECTION]

[IF FAST INTERVIEW]

Now just one more minute of your time.

20. Please tell me if you have overhead irrigation for your Brassicas?

[IF OVERHEAD IRRIGATION]

21. Please tell me how often do you usually irrigate Brassicas in summer?
.....

22. For how many hours do you usually irrigate Brassicas each time in summer?
.....

[PROBING IF TIME] What inches of water would that be?

23. What time of day or night do you usually irrigate Brassicas?

Morning	
Day	
Afternoon (till 7 pm)	
Evening to midnight (from 7pm)	
Midnight to day break	
Other time [ASK WHEN]	

[CONCLUSION]

Thank you very much for your time and for the information.

A summary of the results, the pest management manual, and information about non-chemical controls will be sent to you in August when this project is finished.

Is there anything you would like to ask me?
.....
.....
.....

Would you like to be on our mailing list?

ADDRESS CHECK

SEASONALITY OF DBM POPULATIONS IN SOUTHWEST WESTERN AUSTRALIA

FRANÇOISE BERLANDIER

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Introduction

Prior to this work being done, little published information existed on the activity of WA populations of DBM. The two main areas of *Brassica* production in Southwest WA are the Perth Metropolitan area and Manjimup, where the focus is on cauliflower production. Field surveys were conducted in these two areas in 1997/98.

Materials and Methods

Moth sampling

Moths were trapped on a weekly basis, and two traps were operated at each site. The traps consisted of a stiff piece of card covered with Tacgel[®], baited with a pheromone [active ingredients (z)-11-Hexadecenyl acetate and (z)-11-hexadecenal (1:1)] lure and sheltered by a cardboard roof suspended from a wooden stake.

Larvae sampling

Every week the crop at each study site was inspected and the number and size of DBM eggs, larvae and pupae were recorded. At each site, 50 plants were inspected for the first 4 weeks, then 30 for the next 4 weeks and 20 for the remaining visits. This reduction in numbers of plants assessed corresponded with increases in the size of the plants over time.

1997-98

DBM larvae and adults were sampled in *Brassica* crops on 5 horticultural properties within the metropolitan area of Perth on a weekly basis. Properties were surveyed for three cycles (two properties/ cycle) between late spring and autumn (Table 1).

Table 1. Details of sites surveyed for DBM in metropolitan region of Perth in 1997-98.

Cycle	Grower	Location	Observation Dates	Crop
I	Anderson	Baldivis (south)	23/10/97 – 24/12/97	Cauliflower
	Tedesco	Wanneroo	23/10/97 – 23/12/97	Chinese Cabbage
II	Trandos (I)	Wanneroo	5/1/98 – 25/2/98	Broccoli
	Calameri	Baldivis	5/1/98 – 10/2/98	Cauliflower
III	Trandos (II)	Wanneroo	25/2/98 – 28/4/98	Broccoli
	White	Mandogalup (south)	25/2/98 – 28/4/98	Cabbage

1998-99

DBM larvae and adults were sampled weekly in commercial broccoli crops on two horticultural properties within the metropolitan area of Perth. Properties were surveyed for four cycles between late spring and autumn (Table 2).

Table 2. Details of sites surveyed for DBM in metropolitan region of Perth in 1998 -99.

Grower	Location	Cycle I	Cycle II	Cycle III	Cycle IV
Galati	Wandi (south)	30 Oct – 7 Jan	7 Jan – 18 Feb	18 Feb – 1 Apr	1 Apr – 29 Apr
Jambanis	Carabooda (north)	30 Oct – 24-Dec	24 Dec – 4 Feb	4 Feb – 1 Apr	1 Apr – 29 Apr

Results & Discussion

1997-98

Moth numbers peaked in late November, decreased over the hotter summer months of December and January, and rose again in February and remained high (up to 400/trap) until sampling ended in April. Generally, numbers of larvae in crops peaked in early December, mid-January and again in late March. All crops monitored were sprayed according to individual farmer practice, and most growers used a range of chemicals, at times a cocktail of up to three active ingredients in a spray.

1998-99

As in 1997/98, moth numbers peaked in late November, declined over the hotter summer months of December and January, and rose again in February and remained high (over 200/trap/week) until sampling ended in April.

Generally, numbers of larvae in crops peaked in early December, mid-January and again in late March. This time, growers were provided with faxed summaries of pest levels in their crops, and spray recommendations within 24 hr of each count. The growers were keen to receive this information, but we did not evaluate their actions in response to this information, nor its influence on their pest management strategies. Note that growers sprayed the crops being monitored with a range of chemicals, some used cocktails of up to three active ingredients in a tank mix.

PARASITOID ACTIVITY IN WESTERN AUSTRALIA (WA, 1998-99) FRANÇOISE BERLANDIER

Biological control mechanisms play an important role in suppressing DBM numbers, and form part of the IPM strategy being promoted by this project. The surveys reported here sought to determine DBM parasitoid wasp in *Brassica* crops situated in the Perth Metropolitan Area.

Prior to this work being done, little quantitative data existed on the species and activity of DBM parasitoids found in WA. To encourage Industry to adopt integrated pest management strategies for control of DBM, it is important that we establish the activity and species of DBM parasitoids present.

Materials and Methods

1998-99

Parasitoids were surveyed by collecting DBM eggs, larvae and pupae from five properties in the Metropolitan area every fortnight, starting in summer (December 3rd, 1998) and ending in mid-autumn (April 23rd, 1999). In addition, a few collections made from crops in the Manjimup region located some 300 km southeast of Perth. During each visit to the Metropolitan sites, immature DBM collected in a 30-minute period were returned to the laboratory, sorted and counted then caged on 6-8 week old canola plants at 22 °C. Following this, emergence cages were checked every 1-2 days and any adult moths or wasp parasitoids were removed for a period of 3 weeks. Parasitoids were preserved and identified to species level.

1999-2000

Samples of immature DBM were collected from cabbage grown at one property at Medina, located 30 km south of Perth every week, beginning in summer (November 2nd, 1999) and ending in mid-Autumn (April 4th, 2000). During each visit, immature DBM collected over a 20 minute period were taken back to the laboratory to rear out into either parasitoids or moths. At the start (November 2nd, 1999) collections were made from nil spray cabbage plots (plot A) until February 17th 2000 and March 8th 2000, when these plots (planting 4 only) were sprayed with Nitofol®. After this, larvae were collected from plots of all treatments to make up the numbers.

Immature DBM collected were caged on potted cabbage plants and set up at 25°C and lit by 400W metal halide globes (approximately 400W/plant). Emerged parasitic wasps were removed and preserved every 2-3 days. After February 23rd 2000, the rearing procedure was altered, with weekly collections separated into larvae and pupae, and the pupae kept in specimen jars at room temperature and larvae placed onto the potted cabbage in the insectary as before. Parasitoids were identified to species level.

Results

1998-99

A total of 1,802 *P. xylostella* were collected, of which 234 (13%) were parasitised. Live specimens (moths or parasitoids) failed to emerge from 34% of *P. xylostella* collected. Seven species were found parasitising DBM, of which *Diadegma semiclausum* Hellen, followed by *Apanteles ippeus* Nixon were the dominant species found in the metropolitan area (Table 3). *Diadegma semiclausum* also emerged from DBM collected in Manjimup. Of interest were the large numbers (33) of *Cotesia plutellae* reared from DBM, collected from the Manjimup site.

Other species of parasitoids recovered in small numbers were *Diadegma rapi* Cameron, *Trichomalopsis* sp., *Diadromus collaris* Gravenhorst, *Brachymeria phyta* plus one other (undetermined species, damaged specimen).

The *P. xylostella* from which moths or parasitoids were not recovered may have been exposed to insecticides prior to being collected, and had died after being collected. Interestingly, 20% of *P. xylostella* collected from the Carabooda site were parasitised, despite a weekly spray application program including Ambush®, Phosdrin® and Dominex®.

1999-2000

A total of 715 immature DBM were collected, of which 22% were parasitised. In total, 149 wasps comprising five species emerged from collected DBM larvae and pupae (Table 5). However, due to a number of missing specimens, only 137 wasps were identified. The most abundant were *Diadegma semiclausum* (79%), followed by *Diadegma rapi*, *Diadromus collaris*, *A. ippeus*.

Over 50% of the DBM larvae and pupae collected subsequently produced DBM moths or parasitoid wasps (Table 6). An estimate is given, as a count was not made of the number of DBM in the first collection. The highest number of DBM moths emerged from cage 1, with 82 emerged moths (original number of larvae collected unknown), but only 4 parasitic wasps emerged from this cage. Cage 1 yielded the highest proportion of DBM to parasitic wasps of any cage.

The highest relative proportion of wasps to moths came from cage 4, with 7 wasps and only 1 DBM emerging.

Table 3. Relative abundance of wasp parasitoids collected from WA in 1997-98 and 1999-2000.

Site	1998-99	1999-2000
<i>Apanteles ippeus</i>	37%	1%
<i>Diadegma semiclausum</i>	53%	79%
<i>Diadegma rapi</i>	4%	9%
<i>Diadromus collaris</i>	5%	9%
<i>Brachymeria phya</i>	1%	0%
<i>Trichomalopsis</i> sp.	0%	1%
Other (undetermined)	1%	0%

Table 4. Number of larvae and pupae collected and the number and percentage of emerged DBM moths and wasps for each cage in 1999-2000.

Cage no.	Date of cage set-up*	DBM larvae	DBM pupae	Total DBM collected	No. emerged DBM (%)	No. emerged wasps (%)
1	2/11/99	20	0	unknown	82 (-)	4 (20)
2	9/11/99	59	0	59	26 (44)	33 (56)
3	16/11/99	68	0	68	24 (35)	11 (16)
4	23/11/99	27	0	27	1 (4)	7 (26)
5	7/12/99	47	0	47	1 (2)	1 (2)
6	15/12/99	31	0	31	4 (13)	2 (6)
7	5/01/00	12	7	19	0 (0)	1 (5)
8	5/01/00	12	7	19	5 (26)	6 (32)
9	18/01/00	38	29	67	23 (34)	3 (4)
10	25/01/00	23	28	51	23 (45)	16 (31)
11	2/02/00	19	3	22	3 (14)	3 (14)
12	9/02/00	16	3	19	2 (10)	7 (37)
13	16/02/00	24	6	30	10 (33)	4 (13)
14	23/02/00	0	14	14	0 (0)	3 (21)
15	1/03/00	8	10	18	0 (0)	2 (11)
16	8/03/00	24	21	45	4 (9)	8 (18)
17	14/03/00	13	16	29	3 (10)	8 (28)
18	21/03/00	26	22	48	10 (21)	11 (23)
19	28/03/00	18	22	40	10 (25)	14 (35)
20	4/04/00	22	20	42	4 (10)	11 (26)

*Within a day of collection

Discussion

In 1999-2000 parasitoid wasps were recovered from every DBM collection, and recovery rates indicated a range of 4 to 56% parasitism. The most common species found was *Diadegma semiclausum*, a similar result to the 1998/99 survey when this species was also dominant. Similarly, *Trichomalopsis* sp. was again found but very rare (only one specimen recovered in each year). In addition, higher overall percent parasitism in 1999-2000 (22%) indicates that parasitoid wasps have better parasitism and survival rates when attacking DBM in unsprayed cabbage crops.

Final report from Tasmania
LIONEL HILL, JULIA FRENCH AND FELICITY WARDLAW

Plan, implement and assess an IRM Strategy

- Seven samples of larvae (four from food crops and three from forage crops) were sent to Knoxfield for the IRM monitoring program. High levels of parasitism prevented some of these samples from yielding sufficient moths for insecticide resistance testing.
- Results from successful tests were circulated by group-fax to 20 crop consultants.
- General concepts of IRM were extended within the Extension Outputs that are listed below.
- There has been some adoption of novel pesticides but its extent has not been quantified.

- Two DPIWE-IPM agronomists and one technical officer were trained in-house in *Brassica* pest issues, insect identification and research techniques.
- Two DPIWE-IPM agronomists completed study tours to Knoxfield and Waite.
- Establishment of a network of industry contacts was commenced and a group-fax method was used to communicate with about 20 crop consultants who service the vast majority of fresh, processing and seed growers.
- Statistics on the various sectors of the Tasmanian *Brassica* industry and their specific pest issues were updated as a guide to planning an IPM strategy. This work is continuing.
- Several rough estimates of parasitism in sprayed food-brassica crops suggest that very high levels of parasitism occur by late summer and warrant more detailed investigation in the second project.

The levy paying *Brassica* industry in Tasmania appears to comprise fresh-market and processing growers. There are also many seed growers. These three sectors represent a \$20M industry with approximately 300 growers. There is probably 50% overlap for fresh-market and processing grower groups. There are also newer canola, mustard seed and large-scale forage crops as well as numerous traditional small-crop forage growers. Please note that the following table is far from definitive and currently being updated.

Table 1: Our current knowledge of industry structure.

	Processing	Fresh	Seed	Forage	Other
Crops	Broccoli, Cauliflower, Sprouts Mostly summer plantings	Broccoli, Cauliflower, Cabbage, Sprouts, export-sweedes salad mixes All-year Often sequential	Seed of Broccoli, Cauliflower, Cabbage, Sprouts, Swedes, Chinese cabbage	Turnip Kale etc. Mainly dryland	Canola, Mustard seed, Biofumigants for slugs
Companies	Simplot McCains	Perfecta swedes Harvest Moon Houstons Fehlberg Red Knight Badcock Chaplin Parker	South Pacific Seeds Hendersons Bijou Laker	Woolnorth & many small crops especially in Circular Head	
Ha	600	?00	160	2000	
Production	9000T	?	300kg		new
Crop consultants	9	6	9	5	2
Growers	130	120	90	200	?
Agronomy	Serve-Ag Roberts Agronico, Websters	Serve-Ag Harvest Moon Spec. Ag Services Agronico Roberts	SPS Serve-Ag Nick Finlay	Roberts Serve Ag	DPIWE
Pest issues	<i>Plutella</i> , slugs, Cabbage white butterfly, aphids	<i>Plutella</i> , slugs, Cabbage white butterfly, aphids	<i>Plutella</i> Pollination Rutherglen bug	<i>Plutella</i> Cutworms RLEM	<i>Plutella</i>

Assess the method used to encourage adoption

A discussion with the grower representative for the state *Brassica* industry indicated that increasingly lower tolerances demanded by the two major supermarket buyers during 1999 was forcing growers who had adopted IPM in recent years to revert to more frequent calendar spraying.

IPM has only been promoted in a generic form because we are still defining the critical issues and key players specific to the various sectors of the Tasmanian industry. Achieving good adoption will be an iterative process.

Ongoing discussions with various crop consultants and growers continue to confirm that pest management practices can be most efficiently influenced by focussing bilaterally on key stakeholders and that individual growers will not respond to advice if it conflicts with demands and advice from key stakeholders (buyers, processors) and crop consultants. We will be defining this situation in much more detail, including some benchmarking, in the first year of the second national *Plutella* IPM project.

Crop monitoring was conducted in two commercial crops in 1998/99 at Wesley Vale and Gawler. Little pest activity and no spraying occurred in the spring crop of broccoli at Wesley Vale. Results from a summer crop at Gawler are given at the end of this report.

Large-scale forage crops in far north-west Tasmania were inspected on several occasions in spring and summer to seek causes for the strong contrast in pest pressure observed concurrently in food

crops at the eastern end of the north-west coastal vegetable district as mentioned in preceding item. Factors such as locally overwintering versus immigrant sources of spring-infestation, reservoir hosts and irrigation regimes may explain the contrast in pest pressure.

Long-term monitoring of *Plutella* flight activity by light trapping was continued and now covers eight years. Results were group-faxed to 20 crop consultants in the form of pest forecasts and circulated to the project researchers.

MEDIA RELEASES AND ARTICLES

SOUTH AUSTRALIA

GOOD FRUIT & VEGETABLES ARTICLE OCTOBER 1998

Effective diamondback moth control for the future

By PAULA SMITH (Edited by Greg Baker)

Diamondback moth (DBM) is a huge problem for crucifer growers around the world causing annual losses of \$1 billion. As the first agricultural insect to develop resistance to DDT in the 1950's, DBM has since developed resistance to almost all chemicals used against it said director in IPM developments at Cornell University and consultant in South East Asian, Professor Tony Shelton.

Professor Shelton was recently in Australia as a guest at the first workshop held by researchers working on a Horticultural Research and Development Corporation (HRDC) funded pest management strategy that focuses on the resistance strategy itself and introduces the concept of crop monitoring.

"South East Asia has been a 'hot spot' for DBM problems for the past 20-30 years. Resistance to new insecticides has sometimes occurred within 2-3 years. They are now realising that they have to go to a multi-component strategy using both cultural and chemical control."

Australia has the opportunity to bring in new chemistry to combat DBM and it is important that it is brought in as a part of a management strategy, he said.

The first phase of the HRDC project is to initiate a rotational strategy where by the use of certain chemicals is restricted to certain times of the year ie either early or late in the season. This 'window strategy' reduces insecticide resistance and has been successfully used against cotton boll worm, said South Australia Research and Development Institute (SARDI) researcher Greg Baker.

Preservation of resistance is vital to maintain the effectiveness of two new insecticides, Regent (released last Christmas) and Secure (soon to be released). These insecticides belong to totally different classes of chemicals to those previously used and do not show any signs of cross-resistance.

In addition to the window strategy growers are being encouraged to monitor their crops for DBM and to limit spraying to times when caterpillar numbers exceed the threshold. The vegetable industry has been slow to embrace crop monitoring and integrated pest management (IPM) and this small component of the project will focus initially on training crop monitors in the Werribee area of Victoria. If successful the project will be expanded to promote the concept in other vegetable growing areas.

Professor Shelton was surprised that monitoring of vegetable crops in Australia was relatively unheard of. "In New York monitoring has grown over the last 15 years so that almost 100% of crucifers have some level of monitoring by either the grower, private scout or pesticide company scout," he said.

The hardest task is trying to change the way that growers think. Twenty years ago universities and extension officers recommended growers spray regularly, now they are attempting to teach them to minimise the number of sprays.

Traditional understanding of the inherent risks of pest management has growers believing that they are putting their bottom line in jeopardy by reducing the number of sprays. They don't realise the benefits and savings that can be achieved and that vegetables can be of better quality. We need to stress these points said Mr Baker.

"Cabbage IPM programs have shown a 50% reduction in weekly spraying with growers only treating plants when necessary. This in turn has lead to a 50% increase in the efficacy of those sprays used," said Professor Shelton.

Like previous programs in the USA, the Victoria crop monitoring program will finance scouts while growers adapt to the new concept and realise the value of the service.

"It took 5 years for growers to appreciate the value of the scouts in the States," said Professor Shelton. "The real test was seeing if growers valued the information enough to pay for it themselves - they did and it is now an integral part of crop management.

Government authorities and retailers in the States are supporting the trend towards IPM. In California growers have to prove they have had some assessment before they can use a particular spray. The idea of using pesticides without any restriction is changing a lot," said Professor Shelton.

"Ten years ago food safety and pesticide resistance were hot issues as a result of the Alar scare in the States. Now there has been a move away from residues because 99% of produce has no detectable residue and the focus is on the environment, and overall method of production," said Professor Shelton .

"Wegmans, a small supermarket chain considered to be an industry leader in the States has introduced a label for IPM grown produce. Wegman's theme 'Food you feel good about' stresses freshness, nutrition and IPM. The IPM label says you can feel good about this because it has been grown in a responsible fashion.

"Growers have to follow certain guidelines that encompass the time from purchase of the plants through to harvesting. The guidelines work on a points system where points stress the importance of crop monitoring," said Professor Shelton.

Australia has not yet experienced these consumer demands, but world trends indicate that it cannot be far away. Adoption of IPM is crucial to the crucifer industry if they are to beat DBM.

"Single component strategies will fail against DBM," said Professor Shelton.

The Australian project is looking at a number of complimentary methods of control that can be used in a fully integrated system. One area is the role of seedling distributors and the production of 'clean' seedlings without using insecticides, so that they are free of chemical resistant DBM. The use of *Trichogramma* wasps which parasitize DBM eggs is being investigated as an alternative to chemicals in the nursery.

Professor Shelton has a research team examining the potential use of the fungal pathogen *Beauveria*.

"It is currently registered for use on other crops and would involve an expansion of the label to crucifers. It has a totally different mode of action and can be excellent if used as a component of a bigger system such as the restricted use in glasshouses to prevent field resistance," said Professor Shelton.

Novel methods of control are also being trialed in Australia. 1993/94 was a particularly difficult season for DBM. One large Brussels sprout grower bought a cotton harvester and customised it with large suction fans to draw the moths out of the crop and into the fans where they were macerated. While not conclusive, initial results have show it to reduce moth numbers by 70%, and trials are continuing, said Mr Baker.

DBM has proved itself to be an innovative insect that has the ability to develop resistance quickly. If crucifer growers are to successfully control this pest they are going to have to work together to implement a multifaceted approach that incorporates cultural methods such as using clean seedlings that are free of resistant DBM, crop monitoring and restricting the use of chemicals to times when pest levels exceed the threshold.

The Bad News: Bigger-than-usual Pest Invasion Is Now Underway

Each year in mid-spring the main pest of brassica vegetables, diamondback moth[†] (DBM), migrates from brassica weeds and canola crops to vegetable crops. This migratory flight takes place in response to the drying off of the weeds and canola.

In 1999 the DBM infestations on these weed and canola host-plants have been much higher than usual. DBM densities of 10 to 100 times those normally observed in canola crops have been reported across much of South and Western Australia. This has resulted in a much bigger-than-usual influx of DBM into brassica vegetable crops since about mid-October. This invasion could possibly continue until mid to late November.

The Good News: These DBM Invaders Are Controllable

Fortunately these DBM invaders have generally not been intensively sprayed, and hence are thought to have, at worst, only low levels of insecticide resistance.

Most brassica weeds are not sprayed with insecticide, and canola crops are at the most sprayed once with one of several synthetic pyrethroid insecticides. Some recent testing of DBM collected from a number of canola crops on Yorke Peninsula indicated no pyrethroid resistance in these samples.

Our recommendation is to monitor crops once to twice weekly to ensure that spraying is timed to target each new batch of very young larvae. Monitoring will also allow you to judge the effectiveness of each spray treatment.

These invaders should be well controlled with Bt (*Bacillus thuringiensis*) products and with older organophosphate (OP) and synthetic pyrethroid (SP) insecticides. Therefore the new DBM insecticides can be kept in reserve to be used to control the OP and SP resistant DBM that develop as the summer season progresses.

Further Good News: New DBM Insecticide Now Available

The third new DBM insecticide, Dow Agrosiences' Success™, has recently been registered for use in Australian brassica vegetable crops.

As with Regent™ and Secure™, Success™ has been slotted into the "Two Window" Insecticide Resistance Management Strategy. Success™ has been placed with Secure™ to be available for DBM control in the September to January time-window.

It is anticipated that the fourth new DBM insecticide, Novartis' Proclaim™, will become registered in early 2000, and be available with Regent™ for controlling DBM in the February to August time-window.

A fifth new insecticide, DuPont's Avatar™, is expected to be available in early 2001. Each of the new products has a unique mode of action and shows no cross-resistance to any other.

All growers are urged to adhere to the "Two Window" Resistance Management Strategy to help preserve the effectiveness of these valuable new products for as long as possible.

[†] Also known as cabbage moth.

What's Currently Happening in the HRDC DBM Project?

Three main studies are currently underway in the HRDC DBM project in South Australia.

- Field trials designed to measure the dispersal distance of DBM moths are continuing. These findings will be used to design improved insecticide resistance management strategies.
- More efficient crop monitoring methods are being devised.
- Trials comparing the effectiveness of the new insecticides for DBM control and their impact on beneficials are underway.

Results and future plans will be presented at a grower field day scheduled for late February or March 2000.

“News Flash” - Fungal Disease Slays DBM in Canola

Humid crop conditions produced by October rains resulted in a fungal disease (*Zoophthora radicans*) attacking DBM infestations in canola. Heavy DBM infestations were observed to be decimated by this pathogen.

Samples have been sent to the Insect Pathology group in CSIRO Entomology to isolate the particular fungal strain involved. This group is investigating the possibility of using *Zoophthora radicans* for commercial control of DBM.

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"THE GROWER" ARTICLE JANUARY 1999

Sarah Washington (Edited by Greg Baker)

An increasing resistance to pesticides over the past decade has elevated the diamondback moth (DBM) to the number one pest in Brassica vegetables.

The bane of growers world-wide, DBM could result in huge crop losses and huge pesticide costs in trying to control it.

"Internationally, there's over a \$1 billion of pesticide sold annually to try to combat this one species." South Australian Research and Development Institute entomologist Greg Baker said.

"Resistance is most acute in the tropic and sub-tropic regions, but increasingly problems are being experienced in more temperate parts of the world, including southern Australia.

In 1991, significant levels of resistance by DBM populations to a number of synthetic pyrethroid (SP) and organophosphate (OP) insecticides in the Northern Adelaide Plains and in the Adelaide Hills was first documented.

"Growers have really only had those older SPs and OPs and the *Bacillus thuringiensis* products available to them, they've had to continue to use those frequently and levels of resistance have continued to climb," he said.

But a new project funded by the Horticultural and Development Corporation geared toward improving the management of the pest looks set to change all that.

Mr Baker said part of the approach involves a resistance management strategy involving the progressive release of five new insecticides to help growers combat DBM.

Secure, launched last month, was the second to be released following Regent's release last year.

Mr Baker said the strategy was rotational, based on a two window concept.

"What we're directing growers to do is to limit the use of those two products into respective time windows," he said.

Secure would be limited to September through to mid January, and Regent from mid-January to August.

The time frame was based on traditional spray usage patterns giving each product a reasonably even market share.

The program, which had received the backing of Avcare's Insecticide Resistance Action Committee, would be modified as the other three insecticides become available for use.

"This is quite unique in that each one of these five insecticides have a distinctly different mode of action and current evidence suggests there's not likely to be any cross resistance," Mr Baker said.

Nor should cross resistance develop between the five new chemicals and those currently being used, such as the OPs and SPs, which have already reached high levels of resistance.

Mr Baker said that the release of these new chemicals was a remarkable opportunity for brassica growers, a chance to wipe the slate clean and start afresh with DBM control.

"If the new pesticides are managed responsibly there is a real potential to be able to provide quite effective control of DBM for many years to come, but that will be contingent on growers taking this resistance management challenge seriously," he said.

"As a word of warning, in parts of South East Asia, where no resistance management window strategy was in place, DBM has become resistant to one of the new pesticides which hasn't yet been registered in South Australia."

"If we're not smart in our own management of these new products there's no reason why the insect won't repeat the trick here."

Mr Baker said growers generally were aware of the importance of managing pesticides to reduce the insects' ability to become resistant to them.

The other ingredient in the success of this project was the willingness of chemical resellers to support the project and encourage growers to adhere to the strategy, which Mr Baker said, was happening.

Brassica IPM in New Zealand

NEW ZEALAND entomologist Graham Walker recently visited the entomology team at the South Australian Research and Development Institute (SARDI) at Urrbrae.

He had a very positive message for SA brassica vegetable growers.

Diamondback moth (DBM), the main pest of brassica crops in SA, is being successfully controlled in New Zealand with as little as half the number of sprays that were used in the past.

The extraordinary news is that this change has been achieved simply by crop scouting.

The end result is superior pest control and production of quality vegetables.

As in Australia, Mr Walker

said DBM was a key pest for brassica growers in New Zealand because of its ability to build up resistance to chemical controls.

"We've been a few years behind the rest of the world in the development of resistance because we're a more temperate country and so resistance has taken longer to build up," Mr Walker said.

"We started getting major problems only three or four years ago."

A great deal of work has been done with Integrated Pest Management (IPM) and biological control in brassica crops.

"We're just learning from the problems and the mistakes from overseas and seeing the problem of • continued next page



New Zealand entomologist Graham Walker with SARDI senior entomologist Greg Baker.

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keeps produce fresher, longer

NZ given time to prepare for DBM

• from previous page resistance build up," Mr Walker said. "Because we knew the problem would arise, we were able to do quite a bit of research before it did.

"The key thing is IPM — using a compatible combination of controls instead of just spraying. What we're talking about is protecting crops and being able to have good value produce without just spraying all the time."

Mr Walker said there were now a number of new sprays which were more "environmentally-friendly" and selective in targeting DBM and other caterpillar pests.

The breakthrough in New Zealand is a program using compatible combinations of

controls to overcome DBM in brassica. It's about maximising the attack on the pests — through the introduction of natural enemies, parasites which attack only the pest species, and improving the range of other predators and beneficial insects around the crops.

Mr Walker said the secret was to know exactly what was in the crop and in what numbers. A scouting program had been developed to aid in identification and to determine the level of infestation.

"With this information growers can feel confident to make the decision of what's in there and whether they need to spray or not," he said. "We have worked out a

spray threshold for DBM control in our NZ crops.

"If the pest infestation is below the spray threshold you don't have to worry about spraying."

Mr Walker said the key to deciding what sprays to use was based on rotating chemicals over time.

"NZ has adopted the 'two window' insecticide resistance management strategy, which was developed by SA entomologists, to increase the effective life-span of the new DBM insecticides."

Mr Walker said scouting was not time consuming.

"What we've developed is a quick and easy scouting system where growers can look and see if the plant is infested or not, it's very quick and

you can sample quite a few plants — 50 to 100 in a crop," he said.

Mr Walker said the major growers were behind the program and those taking it up had reduced their sprays by more than 50 percent.

Mr Baker said he hoped to see a similar scouting and spray threshold approach adopted by SA brassica growers.

"The Horticulture Research and Development Corporation has recently provided funding to assist in training SA growers and crop scouts. Hopefully similar reductions in numbers of sprays needed to produce a quality brassica crop can be achieved in SA as has been the case in NZ."

DBM project an HRDC success

ONE OF the success stories of the HRDC vegetable research program is the Diamondback Moth (DBM) project – a national project with a major component conducted by Greg Baker of PIRSA.

The project is in its second year and ultimately aims to improve the control of DBM in brassica vegetable crops and to maintain the effectiveness of insecticides to ensure long term sustainability.

So far, the project has delivered a manual of 'best-practice' guidelines for DBM control, which contains specific articles on control methods.

The manual was widely distributed to brassica growers in SA but if you missed out contact Craig Feutrill on 0418 831 089 for a copy.

A 'two-window' resistance-management strategy has been developed for using the five new insecticides that are undergoing registration (two are through), for DBM control in Australia.

This management strategy is essential due to DBM's ability to rapidly become resistant to insecticide sprays.

Just how far the DBM flies within and between crops has not been known until recently,

and this new understanding will be used to develop improved resistance management strategies.

Generally, if the moths are in a crop they will not move far, but there is always a percentage that will fly a few hundred metres in search of greener pastures.

The major chemical companies have produced a range of new insecticide compounds of which five are being assessed for effectiveness on the DBM pest whilst being 'soft' on the predators and parasites in the crop.

Two of these have already been registered for use in Australian brassica crops.

To effectively manage pests, you have to know what pest and beneficial insects are in the crop, and this project has developed a cost-effective method of monitoring.

Mating disruption or confusion pheromones have successfully been used for other pest insects in different crops. This strategy was investigated as an alternative control method for DBM, but unfortunately the cost was too great for the required level of control.

• For further information contact Greg Baker on (08) 8303 9544 or email baker.greg@pl.sa.gov.au



Greg Baker (SARDI) and John Newman discuss Diamondback Moth (DBM) and the management handbook amongst Mr Newman's broccoli at Charleston.

To receive a copy of *The Grower*

If you know of a vegetable grower who does not receive a copy of *The Grower*, please send mailing details and a contact phone number to Craig Feutrill at PO Box 6014, Halifax Street, Adelaide 5000 or fax to (08) 8232 1311.

Name _____

Address _____

Phone _____

Diamondback Moth IPM News - February/March 2000

Current Field Situation

DBM

Following the larger-than-usual influx of diamondback moth (DBM) into brassica vegetable crops last spring, heavy infestations of DBM eggs and caterpillars (larvae) occurred in many crops during November-December. However DBM populations in most crops declined in January-February to low levels following a succession of heat waves.

It is thought that hot weather (temperatures above about 35 °C) adversely affects the development of DBM. The heavy rains that fell across much of the Adelaide Hills and Plains on February 20-22 will also have helped to suppress DBM by drowning many of the larvae and adults.

The combination of recent weather events and the renewed availability of insecticides that provide good DBM control has created an ideal opportunity to successfully manage DBM in brassica vegetable crops throughout the remainder of this summer and autumn.

A number of growers whose crops are scouted have reported being able to reduce their spraying from the usual 1-2 sprays per week to only 1 spray per 10-14 days as a result of this situation. This not only improves the bottom line, but also helps preserve insecticides from development of DBM resistance.

The twin ingredients of crop scouting and effective insecticides are allowing DBM to be managed with renewed confidence.

Other Pests

Cabbage centre grub has been found in some brassica vegetable crops on the Northern Adelaide Plains in recent weeks. Similar observations have been made in Victorian brassica crops.

These grubs have a dark head and reddish-brown longitudinal stripes along their body. They can be particularly damaging to transplants because they feed on and destroy the growing point and thereby cause multiple unmarketable heads to develop. If detected in damaging numbers they can be controlled with methamidophos (Eg. Nitofol™, Monitor™) or methomyl (Lannate™, Nudrin™, Marlin™).

Update on New Insecticides

The fourth new DBM insecticide, Novartis' Proclaim™, is now registered for use in Australian brassica vegetable crops.

As with the other new DBM insecticides (Regent™, Secure™ and Success™), Proclaim™ has been slotted into the "Two Window" Insecticide Resistance Management Strategy. Proclaim™ has been placed with Regent™ to be used for DBM control in the February to August time-window.

The updated "Two Window" Insecticide Resistance Management (IRM) Strategy is presented in the following table:

ONLY USE THESE NEW PRODUCTS IN THE TIME-WINDOW INDICATED:	
SEPTEMBER 1 ST – JANUARY 31 ST	FEBRUARY 1 ST – AUGUST 31 ST
Secure™ Success™	Regent™ Proclaim™

Insecticide Resistance Management

Why bother with the "Two Window" IRM Strategy?

"Surely if I don't use the same chemical too often resistance won't develop."

"Swapping from one chemical to another from one application to the next must be as good at combating resistance as the fancy 'Two Window' strategy".

These are commonly heard comments. However these reservations about the "Two Window" IRM Strategy are misplaced. There is in fact a very substantial benefit to brassica growers that practice the Strategy. Current scientific thinking on resistance management indicates that the number of effective sprays with each of these new insecticides will be at least **doubled** if used in accord with the "Two Window" Strategy (compared to simply swapping between different chemicals on a shorter time basis).

Despite this major benefit, some growers remain unconvinced. They query, "What does it matter if these products don't remain effective for all that long? New products will be released if these fail."

There are two flaws with this view.

FIRSTLY, it ignores the **higher cost** associated with newly released products. New pesticides are often 2-3 times more expensive than older products in the first few years following their launch. Therefore there is a **very considerable long-term cost saving** to be gained by preserving an insecticide against the development of resistance.

SECONDLY, it is unlikely that several new products for DBM control will become available in close succession again. This recent development has provided a **once-in-a-lifetime opportunity** to successfully preserve these insecticides by following the "Two Window" IRM Strategy.

Another objection is also raised. "OK, there may be good reasons for practicing the "Two Window" Strategy if everyone in the industry did so. But, why should I bother. I know of other people that aren't following the strategy, so DBM will become resistant anyway!!"

FORTUNATELY we now believe that this last objection is also untrue. As long as your brassica crops are separated from those of your brassica-growing neighbour by at least 400 to 500 metres you **WILL** benefit from following this "Two Window" Strategy, irrespective of the poor practices of your neighbour. This understanding is based on the findings of recent studies conducted by SARDI and the University of Adelaide as part of the HRDC-funded National DBM Project. (See research report below for some further details.)

In conclusion, growers are urged to adhere to the "Two Window" IRM Strategy to help preserve the effectiveness of these valuable new products for as long as possible.

Recent Research Findings of the HRDC DBM Project

DBM Dispersal

Field trials designed to measure the dispersal distance of DBM moths have revealed that under normal conditions in actively-growing crops male DBM fly for an average distance of only 30-60 metres, and 99% of them are expected to remain within 300 m of their emergence site. Fortunately the females are even more sedentary than the males. These findings are being used to design improved insecticide resistance management strategies, but strongly suggest that if a brassica vegetable property is separated by at least 400 to 500 metres from neighbouring brassica crops that it is unlikely to be invaded by DBM moths from nearby crops.

Effectiveness of New Insecticides

The effectiveness of 5 new insecticides was compared in a field trial conducted at Virginia. Two sprays of the recommended rate of each product were applied seven days apart. There was no significant difference in the larval mortality that resulted from the spraying of Regent™, Secure™, Success™, Proclaim™ and the as yet unregistered Avatar™. All 5 products provided greater than 98% reduction in larval numbers, which is significantly better than all other registered insecticides (excepting Phosdrin™).

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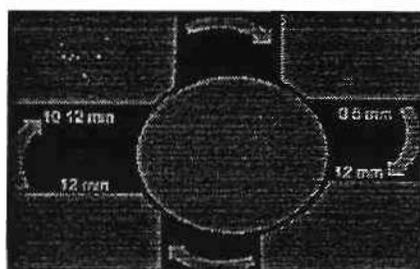
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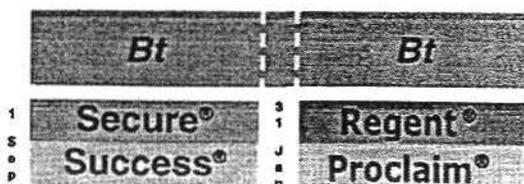
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Toward Integrated Management of Diamondback Moth

G. Baker J. Mo M. Keller and R. Roush



Diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is the most destructive insect of Brassica vegetables in many countries. It was the first crop pest to develop resistance to DDT. Today, it has evolved resistance to many insecticides that have been used for some length of time, including some toxins of the bacterium *Bacillus thuringiensis*. To address the problem in Australia, a national HRDC project* aimed at improving integrated management of the pest was launched in July 1997. Some of the project activities are outlined here.



SPs & OPs SPs & OPs

Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug

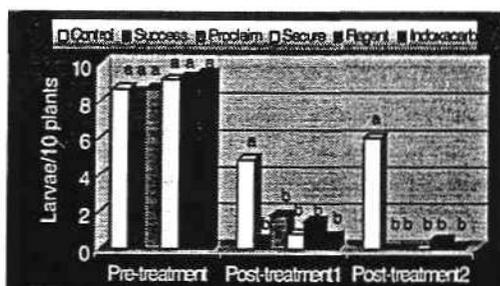
For management of resistance to newly registered insecticides (Regent®, Secure®, Success®, and Proclaim®) a "two-window" strategy was introduced in 1998. In this strategy, the use of these insecticides was restricted to either the 1st Sep.-31st Jan. period or the 1st Feb.-31st Aug. period. The use of Bt is encouraged in early stages of crop development but continuous use of Bt over a lengthy period is strongly discouraged.



Local dispersal information is needed for the designing and implementation of resistance management strategies and alternative control strategies such as crop-break, mating disruption, and trap-and-kill. Mark-recapture experiments were carried out to study the local dispersal pattern of DBM. Preliminary results suggest limited movement of the moths within healthy host patches, with 99% of the released moths likely to remain within <200m of the release point.



For efficient monitoring of DBM populations, sequential binomial sampling plans targeting 3 proportional action thresholds (15%, 25%, 35% infested plants) and 3 density action thresholds (0.2, 0.4, 0.6 larvae/plant) have been developed.



Efficacy of newly registered insecticides. Different letters within a group indicating significant difference at $P < 0.05$. Impacts of these insecticides on some parasitoid wasps have also been studied.

*Project team: Greg Baker (Chief Investigator), SARDI, SA; Peter Ridland (Chief Investigator), Agric. Vic. (Arranged alphabetically) F. Berlandier, Agric. WA; J. Duff, Qld DPI; N. Endersby, Agric. Vic; L. Hill, DPI, Tas; P. Hughes, Qld DPI; L. James, NSW Agric; M. Keller, Adelaide Uni.; J.Mo, SARDI, SA; R. Roush, Adelaide Uni.; B. Walsh, Qld DPI; R. Vickers, CSIRO entomology.

1999 Rural Report

IPM in brassicas successful

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FROM TONIA GRUNDY, DANIEL TAN and BROWNWYN HOULDING, Queensland Horticulture Institute, Gatton Research Station, Gatton DPI

THE brassica industry and consumers will continue to learn more about pest management in cabbage, broccoli and cauliflower crops in the next three years as work in this area continues in a new project being funded by ACIAR (Australian Centre for International Agriculture Research).

The environment is also set to gain from the project as farmers use more sustainable pest management practices.

After the annual general meeting of the Brassica Improvement Group on October 14, guest speaker Myron Zalucki from the University of Queensland presented an overview of the continuing ACIAR brassica pest management project in Australia and China.

Associate Professor Myron Zalucki and Dr Michael Furlong from the University of Queensland will be leading the ACIAR brassica pest management project during 1999-2003. Dr Furlong will be based at Gatton Research Station to work with growers, QDPI and visiting Chinese scientists. He is experienced in insecticide resistance, parasites and fungal diseases of Diamondback Moth (DBM).

PROJECT

The new project will continue to build on the principles of good integrated pest management (IPM) by utilising biological and cultural pest management integrated with chemical control.

The reduction in synthetic pesticide use has meant that alternative pest management practices are feasible, as natural enemies of the brassica pests are able to survive in the crop environment. Already



QDPI OFFICERS, PETER Deuter and Sue Heiszwolf, looking at parasitic wasps collected from a sustainable broccoli trial at Gatton Research Station.



DIAMONDBACK MOTH (DBM) larvae, pupae and adult — a major pest of brassica crops in Australia.

some farmers in the Lockyer Valley have been able to grow crops by relying solely on monitoring and leaving natural enemies to control the brassica pests. Another important practice of the Lockyer Valley brassica growers is the voluntary summer break in production.

This serves to reduce the incidence of the brassica pests in the following season as well as hindering the development of insecticide resistance.

FOCUS

In the next three years the work will focus on maintaining and further developing the sustainable pest management practices. The work includes:

- field assessments of current pest management practices on beneficial insects which will be done on growers' properties;
- measuring the rate of parasitism of DBM eggs by *Trybliographa* wasps;
- a field DBM insecticide resistance kit will be developed to provide a quicker turnover time between DBM collection and getting results on the effectiveness of the pesticides being used;
- continued monitoring of resistance levels for new insecticides such as Regent(R) and Securo(R) and;
- an IPM extension package will be further developed.

This work will complement other pest management issues being addressed in the national HRIH (Horticultural Research and Innovation Corporation) brassica project, which has had funding from July 1997-June 2001.

OPTIONS

In this project, innovative insect control options and dispersal of DBM are being investigated. Brassica growers will also be aware of the DB Insecticide Resistance Management Strategy as a Handbook that was developed in the project and is being widely distributed to brassica grower meetings and chemical company representatives.

The local industry and community have benefited from the brassica work that has been done over the last decade in the Lockyer Valley. This work has been possible through projects funded by HRDC as ACIAR and with significant contributions being made by local QDPI officers, Peter Deuter, John the Brownwyn Houlding, Brendan Nolan, Peter Hugh Sue Heiszwolf and visiting Chinese scientists.

The projects have developed sound, sustainable management strategies that reduce pesticide use, and are appropriate and acceptable to growers and other stakeholders. In all of these projects, strong industry participation has been a key element.

IPM, including monitoring, use of biological insecticides and an insecticide Resistance Management Strategy for DBM were introduced. Field and beneficial populations were monitored regularly checking for DBM eggs, larvae and pupae and beneficials such as *Diadegma* wasps. Yellow sticky traps and pheromone traps were used to monitor. Field days and training were provided to growers, and other service providers in brassica production and management of IPM.

(continued page 15)



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IPM in brassicas

(from page 14)

BIG GROUP

Brassica growers have taken up the challenge of IPM in brassica crops by forming the Brassica Improvement Group. The group has met monthly for the past two years and at its annual general meeting last week members committed themselves to another year.

The group discusses crop issues, including pest management, that have arisen on their own farms as well as

inviting a guest speaker each month. Guest speakers have included QDP project updates, chemical company representatives, talking about new products, crop nutritionist as well as irrigation specialists. The group has also served as a voice at project planning and review meetings.

Further information on all of the above issues can be obtained by contacting DPI, Gatton Research Station telephone (07) 5468 2222.

The Gatton, Loc

Moth influx on its way

BRASSICA growers should be prepared for an influx of cabbage moth, according to DPIF Entomologist Lionel Hill.

Mr Hill said yesterday that catches of cabbage moth in a light trap at Devonport had been twice the average levels through spring and early summer.

"This will probably result in heavy pest pressure on brassica crops, and these moths may well be resistant to chemicals," Mr Hill said.

Cabbage moth is likely to be the third abundant insect pest this season. Firstly cutworm caterpillars were abundant in November. In the Christmas-New Year period armyworm caterpillars reached plague proportions in pastures and cereal crops. Next, brassica growers are likely to face high populations of cabbage moths.

Cabbage moth is not the same as the conspicuous cabbage white butterfly. They are only 2cm long and fly at night. They are sometimes called diamond-back cabbage moths because of pale yellow markings along their backs.

Unlike the larger cabbage white butterfly caterpillars, the green cabbage moth caterpillars become very wriggly if disturbed and grow to only 1cm long. They are the major pest of commercial brassica crops and feed only on plants in the brassica family.

Cabbage moth has become a major headache in Victoria in recent seasons because it is showing increasing resistance to the insecticides. Some Tasmanian populations already have high levels of resistance to one spray.

Mr Hill said that Tasmanian brassica growers need to do two things to combat cabbage moth. One is to rotate chemicals in their spray program to minimise the build up of resistance. The other is to introduce new control tactics such as:

- Ensure transplants are clean;

- Destroy breeding sites in old brassica crop residues;

- Destroy breeding sites like wild radish and wild mustard;

- Avoid placing high value brassicas next to unsprayed brassica fodder crops;

- Monitor grubs on plants and keep regular records to improve spray programs;

- Consider using commercially available pheromone traps to monitor moth activity;

- Use best spray practice, check nozzles, calibrate and use sufficient volumes;

- Use BT biological sprays when grubs are young.

BT sprays are bacterial diseases specific to caterpillars. They can be sprayed on like chemicals. They are most effective on young caterpillars and require good spray coverage. BT offers another group to include in spray rotations and comes under trade names like Biobit, Novosol, Delfin, Thuricide, DiPel Forte and soon a new strain called Kentari.

The main groups of chemicals for rotation are synthetic pyrethroids and organophosphates each with near ten chemicals registered for each group in Tasmania. Continued sole reliance on synthetic pyrethroid sprays will lead to spray failures. However, there are also one cyclodiene group (endosulfan) and one carbamate group (methomyl) chemicals registered although the latter is only for cabbage white butterfly.

Mr Hill said that cutworm and armyworm moths invaded Tasmania every spring from winter breeding grounds on the mainland. Whether or not cabbage moth does the same is not known but Mr Hill said that it is possible significant numbers cross Bass Strait, given that similar migratory behaviour occurs in Europe.

Brassica pests under control

IN recent years diamondback cabbage moth has become resistant to some insecticides.

Mainland growers and a few Tasmanian growers have experienced difficulty in maintaining control of this pest.

Caterpillars of this pest are the main grub infesting broccoli, cauliflowers, cabbages and sprouts.

Last week, Nancy Endersby of the Victorian Institute for Horticultural Development at Knoxfield showed Tasmanian growers how to monitor their crops for this pest and the correct way to rotate insecticides so as to avoid resistance.

Using her records of brassica crops grown in Werribee market gardens, Ms Endersby illustrated a crop that received 13 sprays when three would have sufficed.

Records from her crop monitoring included counts of eggs and grubs on plants as well as counts of moths caught in pheromone traps.

Cabbage moth was not present in significant numbers in this crop for most of its existence.

Horticultural advisor with the Department of Primary Industries, Water and Environment Julia French said the cabbage moth requires six weeks for a life cycle in summer and much longer in cool weather. There were

often periods when sprays were unnecessary but these could be determined only by crop monitoring.

Ms French plans to demonstrate methods to monitor crops that are not time-consuming. The methods are being developed in Victoria and South Australia as part of a national research project funded by brassica industry levies.

Ms Endersby's visit to meetings in Devonport and Campania was funded by the same project and arranged by DPIWE and South Pacific Seeds field officers.

Ms Endersby showed that insecticide resistance was generally low in Tasmania, but a few hot spots of resistance had developed.

Tasmania was in the best position of all states to exploit existing insecticides.

Double-barrelled spray mixtures endanger this natural advantage.

No rotation of spray ingredients and false rotations, such as weekly alternations, should be avoided.

Ms Endersby said rotation periods should approximate the life cycle of the pest.

One generation of the pest should encounter only one type of insecticide and the following generation a different insecticide. In summer this indicated a monthly rotation.

Tasmanian Country, Friday 18th June 1999

Better ways of controlling brassica pests

THE moth is on the loose and some Tasmanian growers are having difficulty controlling the pest.

In past years diamondback cabbage moth has become resistant to particular insecticides.

Caterpillars of this pest are the main grub infesting broccoli, cauliflower, cabbages and sprouts.

Last week some Tasmanian growers and their farm advisers met a leading Victorian researcher to discuss research into this pest.

Nancy Enderby, of the Victorian Institute for Horticultural Development at Knerfield,

showed growers how to monitor their crops for this pest.

Ms Enderby described the correct way to rotate insecticides so as to avoid resistance.

Using her records of brassica crops grown in Warribee market gardens, Ms Enderby illustrated a crop that received 13 sprays when three would have sufficed.

Records from her crop monitoring included counts of eggs and grubs on plants, as well as counts of moths caught in pheromone traps.

Cabbage moth was not present in significant numbers in this crop for most of its existence.

Ms Julie French, a horticultural adviser with DPIWE, said that the cabbage moth required six weeks for a life cycle in summer and much longer in cool weather.

She said there were often periods when sprays were unnecessary but these could only be determined by crop monitoring.

Ms French plans to demonstrate methods to monitor crops that are not time consuming.

These methods of counting eggs, grubs and moths of diamondback cabbage moth are being developed in Victoria and South Australia as part of a national research project funded

by brassica industry levies. Ms Enderby's visit was funded by the same project.

Many other topics including prevention of moth breeding outside crops and misunderstandings about insecticide rotation were discussed at meetings in Devonport and Campbell arranged by DPIWE and South Pacific Seeds field officers.

Ms Enderby showed that insecticide resistance was generally low in Tasmania but a few hot spots of resistance had developed.

Tasmania was in the best position of all states to exploit existing insecticides.

Double-barricaded spray mixtures endangered this natural advantage.

No rotation of spray ingredients and false rotations such as weekly alternations should be avoided, she said.

Ms Enderby said rotation periods should approximate the life cycle of the pest.

One generation of the pest should encounter only one type of insecticide and the following generation a different insecticide. In summer this indicated a monthly rotation.

For more information contact Julie French 6431 7649 or Lionel Hill 6422 7631.

The Advocate, 16th June 1999

The Primary Producer 4

Cabbage moth influx

BRASSICA growers should be prepared for an influx of cabbage moth, according to DPIF entomologist Lionel Hill.

Mr Hill said last week that catches of cabbage moth in a light trap in Devonport had been twice average levels through spring and early summer.

"This will probably result in heavy pest pressure on brassica crops, and these moths may well be resistant to chemicals."

Mr Hill said cabbage moth was likely to be the third insect pest in great abundance this season, after cutworm caterpillars and armyworm caterpillars.

Cabbage moth is not the same as the conspicuous cabbage white butterfly. Cabbage moths are only 1cm long and fly at night, with pale yellow markings along their backs.

Unlike the large cabbage white butterfly caterpillars

The third insect pest in great abundance this season, after cutworm caterpillars and armyworm caterpillars.

- Lionel Hill, DPIF

the green cabbage moth caterpillars become very wriggly if disturbed and grow to only 1cm. They are the major pest of brassicas and they feed only on plants in the brassica family.

Mr Hill said cabbage moth had become a major headache in Victoria because it is showing increasing resistance to one popular spray.

Mr Hill said Tasmanian brassica growers needed to do two things - Rotate chemicals in their spray programmes to minimise the build-up of resistance, and introduce new control tactics such as ensure transplants are clean, destroy breeding sites in old brassica crop residues, destroy breeding sites

like wild radish and wild mustard, monitor grubs on plants, keep regular records to improve spray programmes, consider using commercially-available pheromone traps to monitor moth activity, use best spray practice, calibrate and use sufficient volumes, and use BT biological sprays when grubs are young.

BT sprays are bacterial diseases specific to caterpillars. They can be sprayed on like chemicals, most effective on young caterpillars and require good spray coverage. BT offers another group to include in spray rotations and comes under trade names like Biorbit, Novocel, Dalfin, Thuricide, DiPal Forte and soon Kentari.

The main groups of chemicals for rotation are synthetic pyrethroids and organophosphates.

Continued sole reliance on synthetic pyrethroid sprays will lead to spray failures. There are also one cyclodiene group (endosulfan) and one carbamate group (methomyl) chemicals registered although the last is only for cabbage white butterfly.

In theory at least, there are four groups that can be used in rotations - synthetic pyrethroid, organophosphate, cyclodiene and BT.

Mr Hill said that cutworm and armyworm moths invaded Tasmania every spring from winter breeding grounds on the mainland. Whether or not cabbage moth does the same is not known but Mr Hill said it was possible that significant numbers of cabbage moth cross Bass Strait given that similar migratory behaviour occurs in Europe.

The Advocate, 22nd January 1997

Brassica Grub Resists Insecticides

In Victoria, cabbage moth caterpillars have become resistant to many insecticides and may do so in Tasmania. In the last two seasons, Victorian brassica growers have suffered heavy losses from grub damage. Some growers have tripled spray frequencies, or moved to short lived but hazardous insecticides with only temporary success.

The cabbage moth is the main caterpillar pest of Tasmanian cabbages, cauliflowers, broccoli, brussels sprouts and related crops. It is internationally known as the diamondback moth. Don't confuse it with the larger cabbage white butterfly or the British cabbage moth. It is only about 1cm long, and is dark grey in colour with distinctive yellow diamond shaped markings along its back.

One of the most popular insecticides for its control is permethrin (Ambush®) which is a member of the synthetic pyrethroid class of chemicals. In the most recent season, Victorian entomologists measured levels of resistance to this insecticide in caterpillars on crops at 20 to 50 times that of laboratory strains of diamondback moth not exposed to chemicals.

Although reports of control problems in Tasmania last autumn are only now reaching DPIF, I have collected samples of grubs from a variety of crops during summer and autumn, including one crop with control problems. These were sent to Victoria for quantification of their susceptibility to Ambush®, and results are expected soon.

If you experience difficulties in achieving control of diamond back moth, please let me know promptly so that I can have the caterpillars checked out.

Insecticide resistance in diamondback moth has been a major problem in tropical countries for decades. Resistance in Australia was first documented in 1987 in Queensland. Similar problems have gradually revealed themselves in cooler

states where selection pressure is less because the pest has slower life cycles and encounters fewer sprays. But now it may be here in Tasmania.

Hopefully we can learn from previous experience. Simply changing to another insecticide is merely a stop gap measure. In tropical areas, diamondback moth has beaten every insecticide used against it and therefore integrated control measures are essential.

In Victoria, the biological or bacterial spray, *Bacillus thuringiensis* or B.T., is becoming a vital component in diamondback moth control. B.T. sprays are sold as Di Pel Forte®, Thuricide®, Delfin®, Novosol®, and Biobit®. However, B.T. sprays only kill young caterpillars so other measures are required as well.

In Tasmania, the essential features of diamondback moth control are:

- Begin with clean transplants;
- Keep transplants grub free from the start with B.T;
- Control wild radish and wild mustard which harbour the grubs;
- Destroy crop residues quickly;
- Monitor plants from the start;
- Use good spray technology; correct rates and high volumes especially for B.T. sprays;
- Spray at dusk to minimise ultraviolet breakdown of spray residues;
- Rotate insecticides among the biological, organophosphate, carbamate and synthetic pyrethroid groups;
- Avoid mixtures because they can increase the likelihood of resistance to both chemicals; and
- Keep records of grub counts and sprays to help advisors assess control failures and to help reduce the frequency of sprays.

More information on control strategies is being developed.

The Institute for Horticultural Development in Melbourne publishes a newsletter "The Holey Leaf" devoted to diamondback moth control, contact Nancy Endersby on phone (03) 2109222.

Lionel Hill
Entomologist, Devonport
Phone (004) 21 7636.

Diamondback Cabbage Moth

There are two species of caterpillars that attack brassica crops. They are cabbage white butterfly and diamondback cabbage moth. The second is usually known as cabbage moth locally but overseas there is a quite different species by that name.

The diamondback cabbage moth is developing serious levels of resistance to insecticides in Tasmania. Two samples of caterpillars (from Forth and Wesley Vale) were sent to the Institute for Horticultural Development at Knoxfield in Melbourne late last season. Tests showed that one Wesley Vale population had 30 fold resistance to permethrin insecticide (Ambush (R)) but one Forth population showed little resistance.

This means that growers will have to consider rotating sprays, using biological sprays and adopting nonchemical control methods. The big difference between the two samples shows that

populations with low resistance still exist. Repetitive overuse of one insecticide will soon destroy this susceptibility.

One way of slowing this process is to rotate the use of chemicals such that one generation of caterpillars is exposed to sprays from two or three groups of chemicals rather than repeated sprays of one group.

The current major groups are *synthetic pyrethroids*, *organophosphates* and *carbamates*. But there is also one old *cyclodiene* chemical and several *novel* groups just appearing on the market.

Notably there is also the *biological* spray *Bacillus thuringiensis* or simply BT that is now available under several registered trade names e.g. Biobit, Novosol, Delfin, Thuricide, Xentari and DiPel Forte. Quality control for BT sprays has improved greatly in recent years. Most of these are registered in Tasmania.

An overview of the chemical groups can be gained from the publication *Peskem*. For caterpillars on brassicas in Tasmania there are :

- 9 synthetic pyrethroid sprays (tau fluvalinate, lamdacyhalothrin, permethrin, alphacypermethrin, alpha-methrin, cypermethrin, deltamethrin, esfenvalerate, fenvalerate);

- 11 organophosphate sprays (mevinphos, parathion methyl, azinphos ethyl, methamidaphos, methidathion, chlorpyrifos, trichlorfon, nated, acephate, prothiophos and malathion);
- one cyclodiene spray (endosulfan);
- one carbamate (methomyl) and
- one biological (*Bacillus thuringiensis*).

Some of these are available under several trade names. Check the label to ensure that such products are currently registered for your particular use.

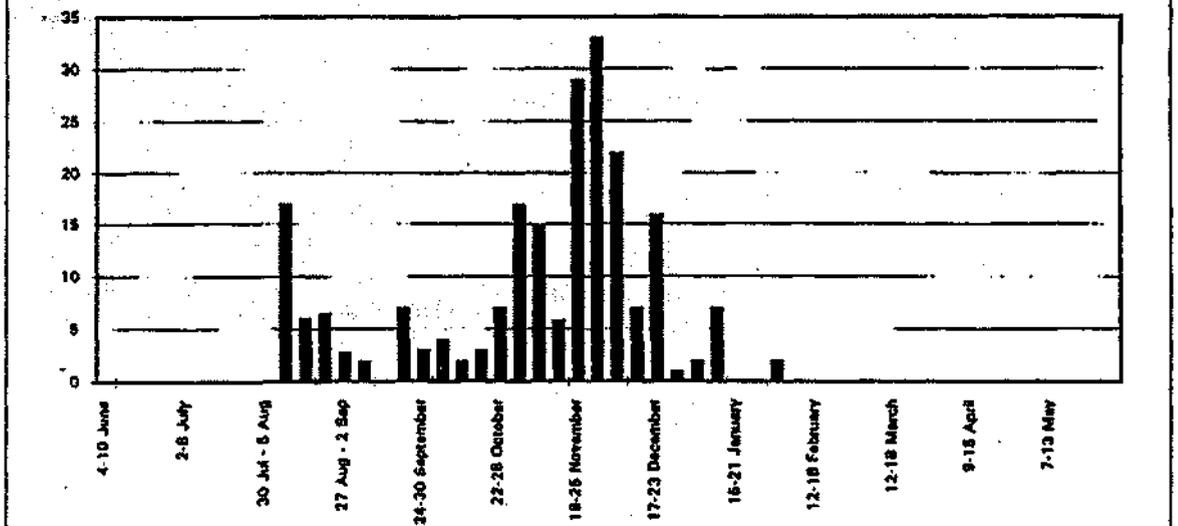
Use of BT in transplant productions will conserve other sprays for field use.

In the field a spray program should begin with BT sprays while caterpillars and plants are small. This is because BT sprays need good coverage and are less effective against older caterpillars. This preserves chemical sprays for later. Follow, if necessary, with a sequence of one spray from each of the other groups.

Besides rotating sprays revise your application methods. Check rates and volume. These are on the label. Check nozzle calibration. Minimize exposure of spray deposits to ultraviolet light by spraying late in the day.

Besides chemicals there are other control measures that will lessen pest pressure. These were mentioned in issue 5 and will be updated in a future issue.

Weekly catches of diamondback cabbage moths in a light trap, Devonport 1992-93



Cabbage moth caterpillars are getting harder to kill

In Victoria, cabbage moth caterpillars have become resistant to many insecticides and they may do the same in Tasmania.

In the last two seasons, Victorian brassica growers have suffered heavy losses from grub damage. Some growers have tripled spray frequencies, or moved to short lived but hazardous insecticides with only temporary success.

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20 Sept 95

Although reports of control problems in Tasmania last autumn are only now reaching DPIF, I have collected samples of grubs from a variety of crops during summer and autumn, including one crop with control problems. Results should be known soon.

The essential features of diamondback moth control in Tasmania are:

- Keep transplants grub free from the start with B.T.
- Control wild radish and wild mustard which harbour the grubs.
- Destroy crop residues quickly.
- Monitor plants from the start.
- Use good spray technology, correct rates and high volumes, especially for B.T. sprays; spray of dusk to minimise ultraviolet breakdown of spray residues.
- Rotate insecticides among the biological, organophosphate, carbamate and synthetic pyrethroid groups. Avoid mixtures because they can increase the likelihood of resistance to both chemicals.

● Keep records of grub counts and sprays to help advisers assess control failures and to help reduce the frequency of sprays.

More information on control strategies is being developed.
— LIONEL HILL, DPIF entomologist, Devonport (004) 21 7636.



Cauliflowers must be free of grub damage to give an economic return.

Examiner, 20th September 1995

Pest team to check crops

THE DPIWE integrated pest management team will be visiting brassica crop farmers next month as part of a new project on cabbage moth.

Cabbage moth or the diamondback moth damages brassica crops (for example: cauliflower, cabbage, broccoli) across the State and is known to become pesticide resistant.

The team, technical officers Felicity Wardlaw and Phill Gardham, entomologist Lionel Hill and agricultural officer Julia French, will be working with farmers to find ways to reduce the use of pesticides and learn more about the moth, which is sometimes confused with the cabbage white butterfly.

Miss Wardlaw, who joined DPIWE in December, said they were hoping to monitor crops and visit farmers.



Miss Wardlaw

"I'm looking forward to working with them and getting out in the crops," she said.

Miss Wardlaw said they would also be assisting farmers in identifying pests in their brassica crops.

The project is part of a three-year nationwide programme funded by Horticultural Research and Development Corporation.

The project will also determine whether diamondback moths survive during the winter.

Mr Hill, who is also part of the team, said a significant area of brassica crops were grown on the North-West Coast.

He said a third of the crops were used for frozen food, a third for fresh broccoli and a third for seed crops. He said there were also many fodder crops.

The Advocate

NEW SOUTH WALES



• Following a very successful annual vegetables conference, NSW Ag district horticulturist (vegetables) Leigh James discusses the latest findings on diamondback moth management with NSW Free Growers chair Rod Sherriff at his Castlereagh farm.

Growing unity

GROWER unity and knowledge sharing were the joint focus of the Annual Sydney Basin Field Grown Vegetables Conference on Friday, July 14 at the Richmond Club.

Event co-ordinator, local NSW Agriculture district horticulturist (vegetables) Leigh James, said more than 60 vegetable farmers from across the Sydney basin attended. Grower groups represented included the NSW Free Growers Horticultural Council, NSW Farmers and the Australian-Chinese Growers Association.

Mr James said both NSW Farmers' horticultural group chairman Graeme Sower and AusVeg Board representative Jeff McSpedden stressed the same message — the importance of unity between grower groups across NSW.

"They emphasised that unity strengthened the growers' voice for lobbying government for research and development funding which is vital to improving production and profitability," Mr James said.

The latest findings on research into pest and disease control were also shared, with farms across the Hawkesbury playing a crucial role in the research programs.

As state co-ordinator for the National Clubroot Project, Mr James said growers were pleased to hear great strides had been made in combating clubroot, a major soil borne disease affecting brassicas (broccoli, cauliflower etc.) particularly in the Hawkesbury area.

With trials carried out at the Castlereagh

property of NSW Free Growers' chair Rod Sherriff, the project team discovered using lime to raise the acidity of the soil and improving soil drainage were vital factors in fighting clubroot. Research also identified the benefits of some fungicides and fumigants.

"Clubroot is not the overwhelming problem it was five years ago," Mr James said. "Once if a grower had clubroot, the infested soil had to be abandoned for three to five years."

Findings were also shared on controlling heliothis grub in corn cobs following field trials at Mario Muscat's Pitt Town Bottoms farm and John Micallef's Agnes Banks farm. As research co-ordinator for this project, Mr James said findings were "looking very promising" for using a parasitic wasp to control the grub. "Growers soon may not have to use any synthetic pesticides on sweet corn," he said.

Trials, once again at Mr Sherriff's property, were also looking very promising for control of Diamondback Moth in crucifers such as cabbages. With its ability to lay 200 eggs per female with a 14-day complete life cycle, this moth is a major pest worldwide, as well as in the Hawkesbury.

As co-ordinator of the National Diamondback Moth Project Team, Mr James said the moth very easily developed an immunity to synthetic pesticides. "But we have now developed a management strategy based on when to use the pesticides to delay resistance," he said.

Gazette, Wednesday 26th July 2000

Moth control measures come a long way



NSW Agriculture District Horticulturist at Windsor, Leigh James, with local grower, Rod Sheriff.

ROBYN YEO
Dubbo

FOUR years ago, Hawkesbury vegetable grower, Rod Sheriff, lost ninety percent of his 48 hectare brassica crop to Diamondback moth.

He, along with brassica vegetable producers throughout Australia, felt the burgeoning economic effects of the problem of chemical resistance.

Diamondback moth, formerly known as cabbage moth, is an age-old problem for market gardeners producing cabbages, cauliflowers, and broccoli.

Traditionally the moth was controlled using organophosphates (OP) and synthetic pyrethroids (SP). But resistance to these chemicals, particularly the SP's, first appeared in the late 1980's.

Since that time, control measures for Diamondback moth

have come a long way.

NSW Agriculture District Horticulturist (Vegetables) at Windsor, Leigh James, has been working on a national project team to develop an integrated pest management (IPM) strategy for Diamondback moth.

"Researchers and entomologists are looking at various control prospects including physical control methods using light traps, mating disruption using pheromones, as well as biological and chemical control," Mr James said.

"While much of this work is ongoing, our role at NSW Agriculture has been to tackle the extension aspects of the project.

"As a result we've been able to develop a Diamondback moth handbook for growers based on integrated pest management (IPM).

"The IPM strategy involves crop monitoring, using spray

thresholds and chemical control when it's warranted, promptly working in crop residue after harvest and in serious infestation cases, co-operating with neighbours to completely spell the paddock from brassicas for two or three weeks in early to mid-summer.

"It's critical that growers rotate certain insecticide families for six months of the year and then rotate different insecticide families for the other six months." Diamondback moth (DBM) creates most havoc in warm weather when its life cycle shortens to 14 days or less.

Copies of the National Diamondback Moth Project Team's control handbook are available free of charge to levy paying brassica vegetable growers from Leigh James.

For contact: Leigh James, NSW Agriculture, Windsor (62)4877 0800.

NSW Agriculture TODAY, July 2000

VICTORIA

NEWS

Diamondback moth tackled

A new national research and development project has been designed to help brassica growers develop effective insecticide-resistance management strategies to control *Plutella*, known commonly as diamondback moth.

The project, supported by the Horticultural Research and Development Corporation, involves departments of agriculture in South Australia, Victoria, New South Wales, Western Australia, Queensland and Tasmania, as well as CSIRO.

The increasing use of insecticides in brassica crops over the past decade has not been without cost. Diamondback moth, the most destructive pest of brassica vegetables worldwide, has developed resistance to commonly used insecticides and is becoming harder to control.

According to the project's Victorian co-ordinator, Dr Peter Ridland, "there is a short term need for brassica vegetable growers to improve their control of diamondback moth and delay resistance

building up, as well as a longer term need to develop cost effective alternative methods of control."

A survey will be conducted to get a better understanding of current growing practices and growers' use of integrated pest management (IPM) strategies.

Growers will have access to advice on crop monitoring and first-hand information from scouts visiting brassica crops in Victoria.

The project will assist growers to implement an effective insecticide-resistance management strategy, involving rotation of chemical groups and improved timing of sprays.

"Extension kits providing information on the moth, its natural enemies, insecticides and spray application, will help growers in their ongoing campaign," Dr Ridland said.

Agriculture Victoria's Institute for Horticultural Development scientist, Nancy Endersby, will assist growers to follow insecticide-resistance management strategies. She will be monitoring

pest activity in crops on four properties to develop economic thresholds which will determine whether spraying is necessary.

Regular field days held on these properties will enable the grower community to witness the results.

Dr Ridland said the project scientists would work with growers to promote effective methods of spray application.

A series of regional workshops in each state will involve growers in hands-on activities for best-practice spray-application methods. The most important concepts will be demonstrated in the crop at night, where fluorescent dyes will be used to highlight how the pesticide gets to the target and equipment performance.

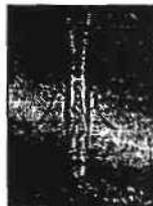
The potential to use other biological controls such as the native wasp *Trichogramma* as an alternative control method in seedling greenhouses is being investigated.

Research in Japan and the United States has demonstrated the disruption of

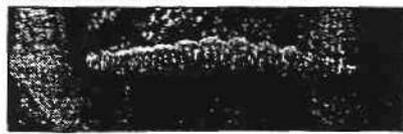
mating using a synthetic sex pheromone can sustain diamondback moth infestations at low densities.

The CSIRO Division of Entomology, Brisbane, is looking at a *Plutella* sex pheromone blend which could be successful in disrupting mating and thereby help to reduce moth populations early in the season.

Contact: Peter Ridland or Nancy Endersby at the Institute for Horticultural Development, Kewfield, Victoria, for more information about the project, phone (03) 9210 9222.



The adult diamondback moth showing the diamond mark on the back. Photo courtesy Chae-Gyung book on brassicas.



Close-up of the larvae of the diamondback moth. Photo courtesy Chae-Gyung book on brassicas.

Good Fruit & Vegetables, December 1997

National project aims to develop better management strategies

THE increasing use of insecticides in brassica crops over the past decade has not been without cost.

Diamondback Moth, the most destructive pest of brassica vegetables worldwide, has developed resistance to commonly used insecticides and is becoming harder to control.

A new national R & D project will help brassica growers to develop effective insecticide resistance management strategies to control *Plutella*, commonly known as the Diamondback Moth.

"There is a short term need for brassica vegetable growers to improve their control of Diamondback Moth and delay resistance building up, as well as a longer term need to develop cost effective alternative

methods of control," said the project's Victorian coordinator, Dr Peter Ridland.

A survey will be conducted to get a better understanding of current growing practices and growers' use of integrated pest management (IPM) strategies.

Growers will have access to advice on crop monitoring and first hand information from scouts visiting brassica crops in Victoria.

The HRDC funded project involves departments of agriculture in South Australia, Victoria, New South Wales, Western Australia, Queensland and Tasmania, as well as CSIRO.

The project will assist growers to implement an effective insecticide resistance management strategy, in-

volving rotation of chemical groups and improved timing of sprays.

"Extension kits providing information on the moth, its natural enemies, insecticides and spray application, will help growers in their ongoing campaign," Dr Ridland said.

Agriculture Victoria's Institute for Horticultural Development scientist, Nancy Endersby, will assist growers to follow insecticide resistance management (IRM) strategies.

She will be monitoring pest activity in crops on four properties to develop economic thresholds which will determine whether spraying is necessary.

Regular field days held on these properties will enable the growers community to witness the results.

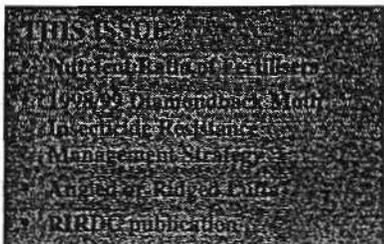
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A series of regional workshops in each State will involve growers in hands-on activities for best practice spray application methods.

The most important concepts will be demonstrated in the crop at night, where fluorescent dye will be used to highlight "getting the pesticide to the target" and equipment performance.

The potential to use other biological controls such as the native wasp *Trichogramma* as an alternative control method in seedling greenhouses is being investigated.

Gippsland Farmer, Wednesday January 14, 1998



Nutrient Ratio of Fertilisers
(Stephen Moore, Geelong State Government Offices, ☎ (03) 5226 4667)

Plants take up nutrients as they grow and nutrients are removed when the plant is harvested or lost due to leaching and erosion. Many soils do not have enough nutrients for optimum plant growth. Fertilisers are used to replace nutrients lost from the soil profile. The suitability of a fertiliser to maximise yield for a particular soil and crop combination is governed by its proportion of nutrients.

Plants contain 100 or more natural chemical elements, less than 20 of these elements are essential for plant growth. The major nutrients or chemical elements are Nitrogen (N), Phosphorus (P) and Potassium (K). Many commercial fertilisers are labelled with a N:P:K nutrient ratio. The N:P:K ratio of fertilisers describes the amount and proportion of nitrogen (N), phosphorus (P) and potassium (K). Sometimes Sulphur (S) and other nutrients are added to the nutrient ratio (eg. N:P:K:S).

Example 1: Urea has a N:P:K ratio of 46:0:0. This means 46% of the chemical fertiliser is nitrogen and no other element is provided. If a grower used 100 kg of urea per hectare they would be applying 46 kg of nitrogen to the crop.

Example 2: Superphosphate has a N:P:K:S ratio of 0:9:0:11. This means the fertiliser contains 0% N, 9% P, 0% K and 11% S. If a grower used 100 kg of superphosphate per hectare they would be applying 9 kg of phosphorus and 11 kg of sulphur to the crop.

Many growers use fowl manure to provide nutrients to their crops. If fowl manure (deep litter) is applied at a rate of 22 cubic metres per ha, the fertiliser rates can be reduced by one-third. Too much fowl manure added could lead to an excessive amount of phosphorus and potassium in the soil.

Applying fertilisers with the wrong nutrient ratio or applying the wrong amount of fertiliser will cost the grower money and sometimes damage crops. Selecting a fertiliser with the right nutrient ratio for your soil and crop is best determined from reliable soil sampling and soil analysis programs which should be carried out well before planting. Contact your local agriculture department for further information.

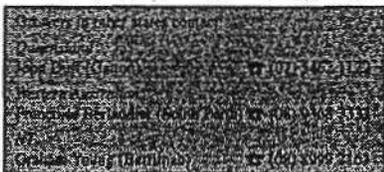
1998/99 Diamondback Moth Insecticide Resistance Management Strategy
(Nancy Endersby, IHD Knoxfield, ☎ (03) 9210 9222)

In the October 1998 issue of the newsletter (Issue 13), we indicated that a two-window strategy (four in Queensland) designed to reduce selection pressure on new chemical families for the control of diamondback moth would be available late 1998:

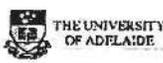
For NSW, South Australia, Tasmania and Victoria, use

Bt		Bt	
Secure®		Regent®	
SPs & OPs		SPs & OPs	
1 Sep, Oct, Nov, Dec, Jan	Jan 15	Feb, Mar, Apr, May, Jun, Jul, Aug	

- Secure® may be used from 1 September until 15 January
- Regent® may be used from 16 January until 31 August
- Labels of new products will limit use within the windows
- It is important to monitor crops regularly for DBM
- Do not use mixtures of insecticides for controlling DBM
- Use of the biological insecticide Bt, in the early stages of crop development is encouraged at all times of the year



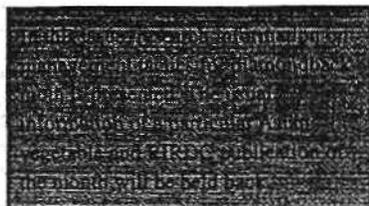
NSW Agriculture



Shaping the Future

Access to Asian vegetables

A publication of the Department of Natural Resources & Environment and Horticulture Research, Development Corporation



Diamondback moth (DBM) – What's going on in the 1998/99 season?

(Nancy Endersby and Peter Ridland, IHD Knoxfield ☎ 03 9210 9222)

Caterpillars of diamondback moth, *Plutella xylostella*, only feed on members of the family Cruciferae and are a particular problem on Asian Brassica vegetables such as Chinese cabbage, Chinese broccoli (kailaan), Chinese flowering cabbage (choy sum), Chinese chard (pak choy), Shanghai Chinese chard (Shanghai pak choy), Baby Chinese chard and Mustard green (kai choy). They also infest Brussels sprouts, cabbage, cauliflower and broccoli.

In recent years, Australian crucifer growers have struggled to control DBM with synthetic pyrethroid and organophosphate insecticides because the pest has developed high levels of resistance to these insecticide families. A National Horticultural Research and Development Corporation (HRDC) DBM project is aiming to improve control of DBM with existing insecticides, to limit development of resistance to newly-available insecticide families and to develop cost-effective alternative control strategies.

An Insecticide Resistance Management Strategy for the new chemical families has been developed with AIRAC (AVCARE Insecticide Resistance Action Committee). A central feature of the strategy is to divide the calendar year into two production windows. Growers in most states have two lists of insecticides to choose from. One for September - January and a different list for February - August. A four-window strategy has been developed for Queensland growers. Use only one type of chemical in one window. This strategy will be available in late 1998 and will be published in this newsletter. A colour-illustrated Integrated Pest Management (IPM) Manual is being prepared.

Management of DBM and most crop pests is best approached by integrating a wide range of pest management tactics to prevent pests from reaching damaging levels in crops. Regular crop monitoring and record keeping are the cornerstones of successful IPM programs.

Key IPM recommendations for management of DBM in 1998/99

- Use pheromone traps to monitor the build-up of moths, particularly early in the season (spring). An increase in moth numbers should be a prompt to monitor the crops and look for eggs and larvae. Pheromone traps can be bought from some chemical resellers or from Dunlop International Pty Ltd (02) 9983 1776.
- Use *Bacillus thuringiensis* (*Bt*) to allow DBM a break from exposure to synthetic insecticides and to protect existing natural enemies. *Bt* is a bacterium that is formulated into a biological insecticide. *Bt* products registered for use on brassica crops kill only caterpillars and are very valuable in managing DBM. Ensure good spray coverage of the plant as the pest must eat *Bt* for it to be effective. Do not expect instant results as caterpillars take 2-3 days to die but they do not feed after eating *Bt*. Apply *Bt* after irrigation, not before. Best results are obtained on small caterpillars (less than 5 mm long).
- Crop hygiene. Start off with clean, healthy transplants, choose less susceptible varieties, and plough in crop debris as soon as possible after harvest. Ask your supplier to use *Bt* on your transplants.
- A summer crop break. Plan with your neighbours (within several km) to have a break from crucifer production of 2 to 3 weeks in early to mid summer to starve out DBM.
- Use improved spray application and strategic application of insecticides according to the two-window strategy (available soon).
- Monitor the crop and spray only when necessary.

Life cycle

Eggs of DBM are very small and difficult to see. At times of high pest pressure, they are found in clumps on both sides of the leaves and on stems of the plant. They are pale yellow, oval shaped and less than 1 mm long. When the egg batches, the tiny caterpillar mines into the leaf and feeds on the internal leaf tissue.



Eggs of DBM



Subsequent growth stages of the caterpillar feed on the outside of the leaf making numerous small holes, like hail damage, or leaving the upper leaf surface intact as a characteristic opaque "feeding window". The final growth stage causes the most damage and is very difficult to control.



Caterpillars (larvae) of DBM (final growth stage)

When fully grown, the caterpillar spins a protective cocoon and pupates inside. It emerges as a moth (12 mm long, brown with a white diamond pattern along its back). The moth lays eggs and begins the cycle again.



Pupa of DBM



Diamondback moth

The life cycle of insects is dependent on temperature. Insects develop faster in warm weather than in cool weather. During winter, the pest develops slowly and causes little damage. As the temperature increases in spring and summer, the moth goes through its life cycle more quickly and pest numbers build up rapidly.

The message for growers is to be very cautious whenever there is a spell of hot weather even in spring or early autumn.

Crop monitoring

Detailed crop monitoring studies in South Australia and Victoria are leading to the development of simple, grower-friendly sampling schemes. Regular monitoring enables growers to spray only when required and to check on the success (or failure) of previous treatments. Other benefits include:

- Detecting the build-up of pests well before economic damage occurs
- Making correct decisions on whether control measures are necessary
- Optimising the timing of spraying or other control measures
- Selecting the most appropriate control measure
- Identifying problem varieties and areas within crops

How do I monitor?

Inspect randomly selected plants at least weekly. Look at the whole plant, including both sides of leaves. Look for

eggs on the stem and leaf stalks. Walk a zigzag or figure-8 pattern through the crop, starting at a different place each assessment and looking at plants at regular intervals. A 10x magnification hand lens is useful. Record pest numbers and their development stages. Use these counts to judge whether a spray or other management tactic is required and to check whether control tactics applied previously have been successful. The more plants you look at, the more accurate will be your assessment of what is happening in the crop. Record your weekly egg and caterpillar counts.

What use are insect records?

Each week's records can be compared to see whether pests are becoming more or less abundant. The records will show whether a previous spray application had the desired effect. Long-term records will reveal whether some areas of a paddock consistently harbour more insects, for example along edges. They will also indicate when pest pressure is greatest. Observations of beneficial insects may be useful in determining whether a spray is required or whether another control measure would be better. Keeping records may confirm suspicions that a particular variety always hosts a lot of pests or that stressed plants are more attractive to the pests. At times of high pest pressure it may be possible to avoid growing the more susceptible varieties.

To identify DBM, contact your local:

- Agriculture New South Wales**
Leigh James (Windsor) ☎ (02) 4577 0622
- Queensland Department of Primary Industries**
John Duff (Gatton) ☎ (07) 5462 1122
- South Australia Research and Development Industries**
Greg Baker (Adelaide) ☎ (08) 8303 9544
- Tasmania Department of Primary Industries & Fisheries**
Lionel Hill (Devonport) ☎ (03) 6421 7601
- Agriculture Western Australia**
Françoise Berlandier (South Perth) ☎ (08) 9368 3333
- NT Department of Primary Industries and Fisheries**
Graham Young (Berrimah) ☎ (08) 8999 2163
- Department of Natural Resources and Environment (Victoria) officer:**
Stephen Moore (Geelong) ☎ (03) 5226 4667
Subra (Bairnsdale) ☎ (03) 5152 0600
Mural Top (Tatura) ☎ (03) 5833 5222
Greg Hayes (Myrtleford) ☎ (03) 5731 1222

Editors: Mandy Chew and Wendy Morgan

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Institute for Horticultural Development
Private Bag 15
South Eastern Mail Centre VIC 3176
Email: chewm@knoxy.agvic.gov.au
Website: <http://www.nre.vic.gov.au/trade/asiaveg>
ISSN 1329-9174

Shaping the Future
 Access to Asian Vegetables



TIME TO START MONITORING FOR DIAMONDBACK MOTH IN ASIAN BRASSICA VEGETABLES

(Nancy Endersby & Peter Ridland, Agriculture Victoria, Knoxfield ☎ (03) 9210 9222)

It's time to watch out for caterpillars in *Brassica* vegetable crops. Caterpillars (larvae) of the diamondback moth (DBM), *Plutella xylostella*, can inflict serious damage on Asian vegetables such as Chinese cabbage during the warmer months of the year. Insects develop faster in warm weather than in cool weather. Generations start to overlap during summer and DBM numbers can build up very rapidly. From late spring to late autumn it is important to check for presence of DBM in crops in southern Australia. Regular crop monitoring and record keeping are the cornerstones of successful Integrated Pest Management (IPM) programs.



Reliance on chemicals as a control measure has resulted in the development of resistance to many insecticides by populations of DBM throughout the world. Resistance to synthetic pyrethroid insecticides has been detected in populations of diamondback moth in all Australian states. Since 1993, *Brassica* growers in Victoria have had difficulty in controlling the caterpillars of diamondback moth and some have experienced insecticide control failures.

The life cycle of diamondback moth was described in detail in Issue 13, October 1998 of this newsletter. Moths lay eggs which develop into caterpillars. Caterpillars feed

until they reach their maximum size, then spin a cocoon, pupate and emerge as a moth.

National DBM Project

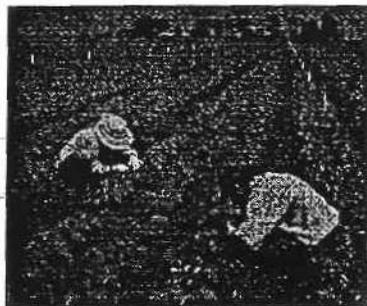
We are now into the third year of our National Horticultural Research and Development Corporation DBM project.

The project aims to improve control of DBM with existing insecticides, to limit development of resistance to new insecticide families and to develop cost-effective alternative control strategies.



Key project recommendations for management of DBM in 1999 / 2000

- Use pheromone traps to monitor the build-up of moths, particularly early in the season. An increase in moth numbers should be a prompt to monitor the crops and look for eggs and caterpillars. Traps may be purchased from Dunluce International Pty Ltd (02) 9983 1776 and some chemical resellers.
- Crop hygiene. Start off with healthy transplants which are free of caterpillars and plough in crop debris as soon as possible after harvest.
- Monitor the crop once per week by inspecting randomly selected plants



throughout the paddock. Record pest numbers and their development stages. Use these counts to judge whether a spray is required and to check whether control

Logos of partner organizations: School of Resources and Environment, Primary Production & Research, NSW Agriculture, DPI (Department of Primary Industries), The University of Adelaide, University of Tasmania, and Victoria University.

AIRAC DBM Insecticide Resistance Management Strategy for New South Wales, South Australia, Tasmania and Victoria 1999/00

September to January	February to August
<p style="text-align: center;">Bt Secure[®], Success[®] Other registered insecticides (except Regent[®])</p>	<p style="text-align: center;">Bt Regent[®] Other registered insecticides (except Secure[®] & Success[®])</p>

1. Secure[®] and Success[®] may be used throughout September to January.
2. Regent[®] may be used throughout February to August.
3. Labels of the new products limit the number of applications per crop.
4. Other insecticides registered for DBM may be used at any time of the year.
5. It is important to monitor crops regularly for DBM.
6. Do not use mixtures of insecticides for controlling DBM.
7. Use of the biological insecticide, Bt, in the early stages of crop development is encouraged at all times of the year.

Growers in other states contact:

Queensland

John Duff (Gatton) (07) 5462 2222

Western Australia

Françoise Berlandier (South Perth) (08) 9368 3249

tactics applied previously have been successful. The more plants you look at, the more accurate will be the assessment of what is happening in the crop.

- Use *Bacillus thuringiensis* (Bt) to allow DBM a break from exposure to synthetic insecticides and to protect natural enemies of pests. Bt is a bacterium that is formulated into a biological insecticide. Bt products registered for use on Brassica crops kill only caterpillars. Ensure good spray coverage of the plant, as the pest must eat Bt for it to be effective. Do not expect instant knockdown. Apply Bt after irrigation, not before. Best results are obtained on small caterpillars (less than 5 mm long).
- Follow AIRAC's insecticide resistance management strategy. Project staff around Australia have worked closely with AIRAC (AVCARE's Insecticide Resistance Action Committee) to develop an effective Insecticide Resistance Management Strategy for the new chemical families available. A central feature of this strategy is separation of the calendar year into two windows, with the use of each new chemical being restricted to one window. The strategy aims to delay the development of resistance to new insecticide groups.

Editors: Graeme Thomson and Wendy Morgan

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Website: www.nre.vic.gov.au/trade/asiaveg

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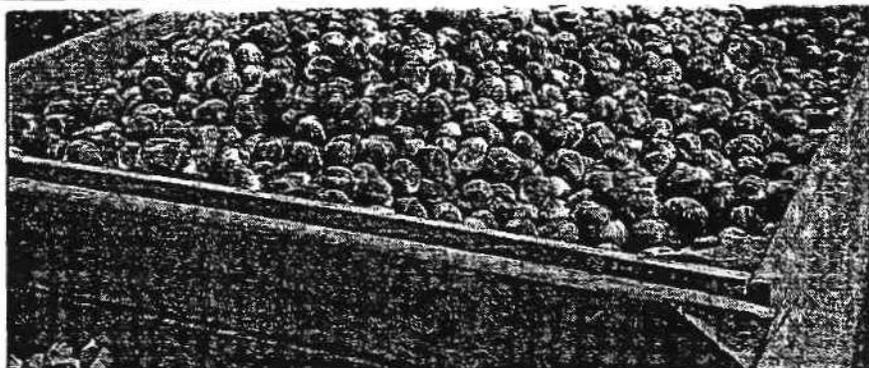
Project research – Where do the moths come from?

We are trying to answer some important questions such as:

- Do moths move into the vegetable growing areas in spring or do they emerge from old crops?
- Are the moths on canola and weeds resistant to insecticides?

This spring we have been sampling Brassica crops (vegetable, forage and canola) and weeds in key areas in the state to assess levels of DBM activity and potential sources of moths.

In Victoria there are some extensive canola crops to the north west of the vegetable growing district of Werribee South. Preliminary results suggest that insecticide susceptible moths are moving from the canola to the vegetable crops. Such movement would be most helpful for delaying development of resistance to the new insecticides. We are doing further testing in spring 1999 to assess permethrin resistance status of diamondback moth from a number of crops throughout the Werribee area and in nearby canola crops.



Diamondback moth can inflict serious damage on vegetables like Brussels sprouts

Start monitoring for diamondback moth

Nancy Endersby, Agriculture Victoria, Institute for Horticultural Development, Knoxfield

IT'S TIME to watch out for caterpillars in Brassica vegetable crops.

Larvae of the diamondback moth (DBM), *Plutella xylostella*, can inflict serious damage on vegetables like cabbage, broccoli, cauliflower and Brussels sprouts during the warmer months of the year.

Insects develop faster in warm weather than in cool weather. Generations begin to overlap during summer and DBM numbers can build up rapidly. From late spring to late autumn it is important to check for presence of DBM in crops. Regular crop monitoring and record keeping are the cornerstones of successful Integrated Pest Management (IPM) programs.

Reliance on chemicals as a control measure has resulted in populations of diamondback moth throughout the world developing resistance to many insecticides. Resistance to synthetic pyrethroid insecticides has been detected in populations of diamondback moth in all Australian states.

Since 1993, Brassica growers in Victoria have had difficulty in controlling the larvae of diamondback moth and some have experienced insecticide control failures.

National DBM Project

We are now into the third year of our national Horticultural Research and Development Corporation (HRDC) DBM project. The project aims to improve control of DBM with existing insecticides, to limit development of resistance to newly available insecticide families and to develop cost-effective alternative control strategies.



Nancy Endersby

Key project recommendations for management of DBM in 1999/2000:

Use pheromone traps to monitor the build-up of moths, particularly early in the season (spring). An increase in moth numbers should be a prompt to monitor the crops and look for eggs and larvae. Traps may be purchased from Dunluce International Pty Ltd (02) 9983 1776 and some chemical resellers.

Crop hygiene

Start with healthy transplants free of larvae, choose less-susceptible varieties and plough-in crop debris as soon as possible after harvest.

Monitor the crop by inspecting randomly selected plants weekly and spray only when necessary. Record pest numbers and their development stages. Use these counts to judge if a spray is required and to check whether control tactics previously applied

have been successful.

Examples of spray thresholds are included in the National DBM Project Handbook available from Nancy Endersby. The more plants you look at, the more accurate the assessment of what is happening in the crop.

Bt

Use *Bacillus thuringiensis* (Bt) to allow DBM a break from exposure to synthetic insecticides and to protect existing natural enemies. Bt is a bacterium formulated into a biological insecticide. Bt products registered for use on Brassica crops kill only caterpillars.

It is important to ensure good spray coverage of the plant, as the pest must eat Bt for it to be effective. Do not expect instant knockdown. Apply Bt after irrigation, not before. Best results are obtained on small caterpillars (less than 5 mm long).

Follow AVCARE's insecticide resistance management strategy. Project staff around Australia have worked closely with AVCARE to develop an effective Insecticide Resistance Management Strategy for the new chemical families available.

A central feature of this strategy is separation of the calendar year into two windows, with the use of each new chemical being restricted to one window. The strategy for 1999/00 will be sent to Brassica vegetable growers shortly. In the meantime, last year's strategy of limiting use of Secure® to the September - January window and use of Regent® to the February - August window still applies.

Please contact Nancy Endersby if you are not on the mailing list: 9210 9222.

Southern Farmer, October 1999

APPENDIX 2 to Final Report
Horticultural Research and Development Corporation
Project VG97014

Advancing the integrated management of
diamondback moth (DBM) in *Brassica*
vegetables (July 1997-June 2000)



Project Workshop,
Waite Campus, Adelaide,
21st - 23rd September 1998

Horticultural Research and Development Corporation

Project VG97014: Advancing the integrated management of diamondback moth (DBM) in *Brassica* vegetables (July 1997-June 2000).

**Project Workshop, Waite Campus, Adelaide, September 21-23, 1998.
Convened by SARDI and University of Adelaide.**

1. INTRODUCTION

The first Workshop convened as part of the national HRDC project on Diamondback Moth management was held in Adelaide from September 21-23 1998. The purpose of the meeting was to foster an exchange of ideas between the national project team, other DBM researchers and *Brassica* growers, and to provide a forum for a review of the Project's progress, a reassessment of the Project's priorities and to forward plan.

This report documents the participants, the agenda, the presentations, the planning discussions and the key recommendations that took place at the Workshop, and the comments on the Project provided by Professor Tony Shelton.

2. PARTICIPANTS

Mr Greg Baker, S. Aust. Research and Development Institute.
Ms Françoise Berlandier, WA Agriculture.
Dr Peter Cameron, Crop and Food Research, Auckland, NZ.
Mr John Cranwell, *Brassica* grower, S. Aust.
Mr John Duff, QLD Horticultural Institute.
Ms Nancy Endersby, Agriculture Victoria.
Mr Lionel Hill, DPI, Water and Environment, Tasmania.
Ms Bronwyn Houlding, QLD Horticultural Institute.
Mr Xing Geng, University of Adelaide.
Mr Leigh James, NSW Agriculture.
Dr Mike Keller, University of Adelaide.
Mr Jeff McSpedden, *Brassica* grower, NSW.
Mr Mahmood Ahmad, University of Adelaide.
Dr Jianhua Mo, S. Aust. Research and Development Institute.
Dr Peter Ridland, Agriculture Victoria.
Dr Rick Roush, University of Adelaide.
Mr Scott Samwell, *Brassica* grower, S. Aust.
Prof Tony Shelton, Cornell University, Ithaca, USA.
Dr Richard Vickers, CSIRO Division of Entomology.

3. AGENDA

Monday 21st September: Progress To Date

- 9:15 am: "House-keeping"
- 9:30 am: Welcome by Mr Barry Tugwell, Chief Scientist, Horticulture, SARDI
- 9:40 am: Prof Tony Shelton, Cornell University, Ithaca, USA.
"Current developments in US DBM research and pest management practices."
- 10:30 am: Morning Tea
- 11:00 am: Dr Peter Cameron, Crop and Food Research, Auckland, NZ.
"Current developments in NZ DBM research and pest management practices."
- 11:30 am: Mr John Duff, QLD Horticultural Institute.
"Is *Brassica* IPM in the Lockyer Valley cost-effective?"
- 12:00: Dr Jianhua Mo, SARDI
"DBM dispersal studies: progress and future directions."
- 12:20 pm: Ms Nancy Endersby, Agriculture Victoria
"Crop monitoring in Victoria: 1997-98 season."
- 12:40 pm: Dr Jianhua Mo, SARDI
"Presence-absence sampling for monitoring DBM populations."
- 1:00 pm: Lunch
- 2:00 pm: Mr Leigh James, NSW Agriculture
"Development and Distribution of a National DBM extension kit."
- 2:15 pm: Dr Peter Ridland, Agriculture Victoria
"Survey of VIC *Brassica* growers and seedling producers: spray practices and understanding of insecticide resistance."
- 2:40 pm: Ms Nancy Endersby, Agriculture Victoria
"Insecticide resistance monitoring update."
- 2:55 pm: Ms Françoise Berlandier, WA Agriculture
"Seasonality and levels of insecticidal resistance in WA populations of DBM."
- 3:20 pm: Mr Mahmood Ahmad, University of Adelaide
"Survey for resistance to *Bacillus thuringiensis* in field populations of *Plutella xylostella* L. in Australia."
- 3:40 pm: Afternoon Tea
- 4:00 pm: Mr Lionel Hill, DPI, Water and Environment, Tasmania
"Tasmanian *Brassica* pest issues."
- 4:15 pm: Dr Jianhua Mo, SARDI
"An evaluation of the effectiveness of the DARABUG model for predicting DBM development under cool-temperate conditions."
- 4:30 pm: Dr Richard Vickers, CSIRO Division of Entomology
"A QLD evaluation of pheromone mating disruption as an alternative method of DBM control."
- 5:00 pm: Lirra Lirra Café (licensed Waite café)

Tuesday 22nd September: 1998-2000: Re-focusing and fine-tuning.

- 9:00 am: Overview of the DBM ACIAR Project (Bronwyn Houlding, QLD Horticultural Institute)
- 9:15 am: Reassessment of Current Project Objectives (Their ongoing significance, suitability of current methodologies, adequacy of available resources, etc.)
Extension hand-book and wall-chart. (Including discussion of Geoff Norton's proposal of a CD Rom for *Brassica* IPM extension and education.)
Extend best-practice spray application methods.
Plan, implement and assess an IPM/IRM strategy, and assess the methods used to encourage adoption of this strategy.
- 10:30 am: Morning Tea

- 11:00 am: Reassessment of Current Project Objectives (Cont'.)
Plan, implement and assess an IPM/IRM strategy, and assess the methods used to encourage adoption of this strategy. (Cont'.)
Crop monitoring research.
DBM dispersal/movement study.
Assess performance of new insecticides.
- 1:00 pm: Lunch
- 1:45 pm: Reassessment of Current Project Objectives (Cont'.)
Effect of surfactants on DBM egg-laying behaviour.
WA insecticide resistance screening.
Assess mating disruption as a DBM control tactic.
Assess inundative releases of *Trichogramma* wasps as a non-insecticidal means of controlling DBM in seedling nurseries.
- 3:30 pm: Afternoon tea
- 3:45 pm: New or Expanded Objectives
- Evening meal at the Edinburgh Hotel.

Wednesday 23rd September: Other Issues

DYMEX: population modelling for DBM – presentation by Mark Stanaway, University of Queensland.

The dissemination of DBM pathogens by the use of disease-baited pheromone traps – presentation by Richard Vickers, CSIRO.

Hosting the 4th International DBM Workshop.

4. PRESENTATIONS

The papers presented at the Workshop are reproduced in the Appendix.

5. SUMMARY OF PLANNING DISCUSSIONS

5.1 Publication of the IPM Handbook for DBM

The primary users of the IPM handbook are likely to be re-sellers, consultants and extension personnel, and secondarily growers.

Graph paper should be included in the handbook so growers can track population trends and observe the effects of control measures.

A small pocket book with a slip-in laminated card listing current control recommendations is what is most needed by growers. The majority of growers take a simple approach to pest management and many growers will not read more detailed notes. A small, simple publication based on pest identification and pest control measures (i.e. Which pest? Which product? What time?) would reach the broadest audience.

Efforts should be made to revise and reprint the small extension handbook produced by Sue Heisswolf in Queensland. The best available photos should be used, and if possible it should be in a binder that allows replacement of pages so updates are easily made. Sponsorship for the small booklet should be sought from organisations such as IAMA, etc.

A new HRDC-funded *Brassica* pathology project at IHD, Knoxfield is to produce a pocket book on *Brassica* pests and diseases. Peter Ridland and Nancy Endersby will approach this project team to ascertain whether the National DBM Project team can become involved with production of the pest component of this publication.

The potential for Aust/NZ collaboration on the production of extension materials will be explored with Peter Cameron.

Wall charts were considered a poor investment as outdated versions may remain on display in sheds, etc.

The date should be printed on all extension materials.

Geoff Norton's proposal for the production of a CD Rom on IPM in *Brassica* Crops (with HRDC, ACIAR funding) was discussed. In the process other electronic media options were discussed.

The World Wide Web has some advantages:

- It can serve as a repository of readily updated information,
- Individuals can print out or save documents for further reference.

Disadvantages of the Web:

- Only a minority of growers currently have access at home,
- Like any extension material, it needs an ongoing commitment to maintenance and updating.

Geoff Norton will be questioned about his preference for a CD Rom over other options such as the Web.

5.2 Spray Application Roadshows

The roadshows highlighted the inadequacy of the spray coverage achievable with boom sprayers in *Brassica* vegetables.

The critical need for R&D to test new spray technologies that have the potential to markedly improve insect control and the performance of "soft" IPM-compatible insecticides in *Brassica* vegetables was endorsed, but it was considered that this should be left to a new project rather than incorporating this milestone into the existing HRDC project.

Tony Shelton showed some data on the use of *Bt* applied with electrostatic, boom and drop-nozzle sprayers. The electrostatic sprayer had the most uniform coverage on upper, middle and lower leaves; the sprayer with drop nozzles had reduced coverage on upper leaves; the boom sprayer had reduced coverage on both the upper and middle leaves. Although the electrostatic sprayer had the best results with *Bt* in these trials, it is affected by static electricity in the air and other factors. Air assisted sprayers may deliver the best results in the widest range of conditions.

5.3 IPM / IRM strategy

No cross-resistance is anticipated among the new chemistries as each has a different target site.

It was agreed that the Two Window IRM Strategy should be introduced with the long-term pattern of chemical use considered so that a consistent message can be maintained. The strategy will ultimately have at least two new chemicals in each window. This should allow the placement of at least one relatively soft chemical in each window, and will also promote competitive pricing. The strategy splits the period of high pest risk in southern Australia and should give companies similar market share.

The major chemical companies have endorsed the strategy and, through AIRAC, they "own" it. This is essential for promotion and compliance.

The introduction of the strategy will be delayed until Secure™ is available in November-December. A public launch of the strategy through the media should take place at this time. The strategy will be promoted on an ongoing basis through re-sellers.

In Queensland the original Three Valleys resistance management strategy broke down over time in the absence of reinforcement.

In 1999-2000 the strategy will be revised in concert with AIRAC to include the newly-registered chemistries and possibly to "window" the older chemistries (OPs, SPs and perhaps the *Bt*s) in an endeavour to help preserve them.

Mycogen has developed a new *Bt* product with only the Cry-1C protoxin. If this is registered in Australia, then the strategy should be adjusted so different *Bt* toxins are used in the two windows.

The loss of Phosdrin™ leaves the industry without a short withholding period "clean-up" spray near harvest. For this reason Rotam Australia Pty Ltd is seeking re-registration of the organophosphate Dibrom™, which when previously registered in *Brassic*as had a 1 day withholding period.

New Zealand does not yet have registration of any of the new chemicals. Their resistance management strategy is based on the Australian strategy, and places the SPs in one window.

5.4 Implementation of an IPM package in a Victorian *Brassica* district, and assessment of the method used to encourage adoption of this strategy

The Victorian promotion of IPM has focused on the training of commercial monitors, and adoption of efficient and effective monitoring methods.

The desire for quality assurance from wholesale buyers is driving the adoption of monitoring in Victoria.

Three new scouts, employed by the chemical reseller E. E. Muir and trained by Nancy Endersby and Peter Ridland, will monitor crops for about 5 growers in each of Werribee and Cranbourne in the 1998-99 season. The growers will pay for the scouting service. (The opportunity will be taken to collect more larval sampling data for the purpose of constructing presence-absence sampling plans.)

The seasonal variability in demand for scouting services is an economic drawback to prospective scouts.

John Cranwell expressed the view that it is highly preferable to employ trained scouts: growers rarely have the time to scout on a calendar schedule and don't have the specialist knowledge. The key is having trained scouts.

In Tasmania scouting is being offered as a service by chemical re-sellers.

5.5 Crop Monitoring Research

Most growers adhere to very low thresholds in the belief that the presence of any "grub" is unacceptable because once an infestation is established in the heart it cannot be eliminated by an insecticidal spray program. This project should endeavour to determine if this conservative view is well founded.

Jeff McSpedden noted that the banding of cauliflower heads as they develop prevents spray penetration into the head, and hence DBM must be kept at very low level leading up to and during banding.

Nancy Endersby has a large quantity of monitoring data which are being reanalysed to derive economic thresholds.

The exchange of DBM pheromone trapping data between States, collected from Aug-Oct in each State, would assist in the interpretation of early-season trap data and the provision of an early warning service to growers. (See DBM Project Communication: computer bulletin board.)

Tony Shelton commented that crop scouting is the cornerstone of *Brassica* pest management in New York. Cornell University had initially paid the scouts. After some time growers started paying 50% and finally 100%. This system has worked well now for about a decade. (A similar approach has proved highly successful in the seed-lucerne industry in the Upper South-East of South Australia.)

Tony Shelton further observed that food safety issues are driving IPM in the US. Cornell has helped develop an IPM labelling scheme with a major food retailer. It is based on a points system; produce which fails to achieve the required points is not purchased by the retailer. There is no price premium, the incentive simply market access.

5.6 DBM Localized Dispersal Study

The mark-recapture method is being used in preference to sentry plants because it provides more quantitative data on the degree of movement than does the sentry plant method.

Male DBM marked with fluorescent dye and trapped with pheromone traps are being used for this study. However information on female moth movement is required. For this purpose light traps are to be used.

Why not use between-property variation in insecticidal resistance of DBM populations to gauge gene-flow movement (dispersal) between properties within a district? This approach is expensive and the results difficult to interpret because of unknown differences in selection pressure between properties.

Peter Cameron commented that in NZ he had used mark-recapture (with both pheromone and light traps) and sentry plants, and found mark-recapture best for examining paddock to paddock dispersal. In this NZ study a steep decline in dispersing moths with distance from the release point was observed, and a small proportion of moths dispersed a longer distance.

Long-range dispersal

The extent to which DBM population exchange occurs between the vegetable cropping districts and the *Brassica* weeds and canola crops of the broad-acre districts remains unknown, as does the insecticidal resistance profile of these broad-acre DBM populations. It was agreed to screen a representative sample of DBM populations collected from canola and *Brassica* weeds during winter 1999 in WA, SA, VIC and NSW for permethrin resistance.

Bioassays of DBM collected from fodder rape crops growing 50-70 km distance from Werribee indicate that these populations are susceptible to permethrin, which anecdotally suggests that movement between these districts may be minimal.

5.7 Performance of New Insecticides and Their Impact on Beneficials

A two application replicated field plot trial is planned for the 1998-99 summer to assess the efficacy of the 5 new DBM insecticides (fipronil, chlorfenapyr, spinosad, emamectin benzoate and indoxacarb) and to assess their impact on parasitoids (VIC: *Diadegma semiclausum* and *Diadromus collaris*. SA: *Diaretiella rapae* and *Cotesia rubecula*) and on predators (the latter using pitfall traps and potted unsprayed plants which are inoculated with *Pieris rapae* eggs and placed in the trial plots). Minimum plot size: 4-6 rows of 5 m length.

It was suggested that an OP and SP should be included in this trial for comparative purposes. Peter Ridland noted some surprising results suggesting low SP impact on beneficials in Victoria.

The Impact of Predators

Tony Shelton outlined an experimental investigation of the impact of predators on DBM survival using predator exclusion cages. It was suggested that each State could use this approach to measure the predator impact in unsprayed plantings.

In addition, the identity of the predators needs to be established. (Some likely predatory groups include mites, nabid and mirid bugs, lacewings, spiders (including phalangids); the dominant predators may be nocturnal.) The minimum requirement is to establish an inventory of common predators found in *Brassica* plantings using standard sampling techniques; later, resources permitting, the relative significance of these predators will be studied.

Peter Ridland will devise and circulate to the project team for comment a proposed method for quantifying DBM egg predation in *Brassica* fields.

5.8 Effect of Surfactants on DBM Egglaying

The effect of a range of surfactants on DBM ovipositional preference on transplants will be studied in Victoria in the 1998-99 season. Peter Ridland presented some preliminary trial results.

5.9 Alternative Control of DBM in Seedling Nurseries

Inspection of a major seedling nursery in Victoria has revealed a very low incidence of DBM eggs, which calls into question the use of inundative releases of *Trichogramma pretiosum* wasps. (Tony

Shelton commented that in a Cornell study to compare 5 *Trichogramma* species, which included *T. bactrae*, *T. pretiosum* was found to be the most effective against DBM.)

An alternative suggested by Tony Shelton is the use of *Beauveria bassiana* sprays. *B. bassiana* sprays are already registered on a number of US crops. Good spray coverage is essential for effective *B. bassiana* use.

A suggested experimental approach: put seedling trays in an oviposition cage for egg-laying, and then place them in a nursery house, spray with *B. bassiana* using the nursery's spray equipment and finally assess mortality. Mike Keller suggested that given the minimal cost of investigating the *Trichogramma* option, that it should be pursued.

Tony Shelton recommended investigating *B. bassiana* in preference to *Trichogramma*.

Peter Ridland will follow up with Richard Milner (CSIRO Insect Pathologist), David Holdom (University of Queensland) and Robert Spooner-Hart (University of Western Sydney) regards current Australian *Beauveria bassiana* research, the availability of *B. bassiana* strains that may be suitable for testing against DBM, etc.

Rick Roush observed that from a resistance management perspective it would be ideal if the registration of *B. bassiana* was limited to nurseries only.

The nurseries are a critical link in the management of DBM insecticidal resistance. Being a small industry 1 on 1 contact is possible. Practices that should be promoted are installation of insect screening and host-free periods.

Given the QA path being pursued by the nursery industry they are keen to reduce reliance on toxic pesticides, but any alternatives will need to give good pest control. A potential problem with the nursery use of *B. bassiana* is the frequent fungicidal use for downy mildew control.

5.10 WA Studies

Francoise Berlandier outlined WA plans to conduct 2-3 field days, a spray application roadshow and a survey of DBM parasitoids.

In discussion the merit of the various DBM resistance assay methods was canvassed. (Edelson's, leaf-dip, etc.). Rick Roush will review the assay techniques available for DBM larvae.

The concept of a rapid resistance assay for field use by growers, consultants, etc. was considered unnecessary by the 2 grower participants. They considered that it was more practical and beneficial to put time into crop scouting rather than property assessment of DBM resistance to various insecticides.

5.11 Pheromone Mating Disruption Study

Richard Vickers reported on the 1997 Gatton trial in which the 3-component blend was no more effective than the standard 2-component blend.

Estimated cost of mating disruption in the field to provide 30 weeks protection using the 2-component blend is \$1,100 per ha. In regions where DBM is the only significant pest this may be economically feasible.

Judith Pell (Rothamsted UK) will be visiting in March, 1999 to work with Richard on auto-dissemination of fungal pathogens using 3-component blend pheromone traps (*Zoophthora radicans* is currently being investigated, but *B. bassiana* may be an alternative). J. Pell is also visiting NZ to

work with Max Suckling on *Z. radicans* strain selection. Subject to the results obtained, this method may be included in the final year of the HRDC Project.

5.12 Other Issues

Fourth International DBM Workshop, Australia, 2001

A working party of Tony Shelton, Peter Ridland, Nancy Endersby, Mike Keller, Greg Baker, M. Zalucki and A. Sivapragasam (Malaysia) was proposed.

Tony Shelton is to obtain budget and organisational details of the 3rd International DBM Workshop held in Malaysia in 1996, and send to G. Baker and P. Ridland.

It was agreed that 2.5 business days was optimal for the Workshop, and that more emphasis would need to be given to the poster sessions (and more posters accepted than in Malaysia).

Growers and crop scouts would be encouraged to participate in the 2001 Workshop.

DBM Project Communication

A computer bulletin board was recommended for facilitating communication between all Project members.

Nancy Endersby will provide a prompt for contributions prior to the production of *Plutella* Update issues.

6. KEY RECOMMENDATIONS

Extension

- A pocket book of *Brassica* pest and disease information, based on Sue Heisswolf's "Pests and Beneficials in *Brassica* Crops", to be prepared in collaboration with Knoxfield plant pathologists and QHI/ACIAR entomologists. (This is in addition to, and complementary with, the extension kit currently in production.)
- Investigate with Peter Cameron the potential for Aust/NZ collaboration on pocket book and other extension materials.

IPM/IRM Strategy

- The Two Window IRM strategy will be publicly launched in November-December 1998 to coincide with the release of Secure™.

Crop Monitoring Research

- Archival monitoring data will be reanalysed to derive economic thresholds. If necessary, the conservative view that no DBM larval presence can be tolerated (because of the inability of insecticidal spray programs to eliminate an infestation once established in the heart) will be tested.
- Each year during August-October DBM pheromone trapping data will be exchanged between States to assist in the interpretation of early-season trap data and the provision of an early warning service to growers.

DBM Long-range Dispersal

- ~2 samples each of DBM collected from canola and *Brassica* weeds during winter 1999 in WA, SA, VIC and NSW will be screened for permethrin resistance.

Performance of New Insecticides and Their Impact on Beneficials

- The 1998-99 summer insecticide trial will be expanded to include an assessment of predator impacts (using pitfall traps and potted unsprayed plants inoculated with *Pieris rapae* eggs).

Predator Survey

Peter Ridland will devise a method for quantifying DBM egg predation in *Brassica* fields.

- This will be circulated to the HRDC and ACIAR Project teams for comment.
- Resources permitting, each State will initiate a study in an unsprayed planting to identify the species composition of the predator fauna and to measure their egg-predation impact. (SA and VIC in 1998-99, other States in 1999-2000.)

Alternative Control of DBM in Seedling Nurseries

- Peter Ridland will liaise with Richard Milner (CSIRO Division of Entomology), David Holdom (University of Queensland) and Robert Spooner-Hart (University of Western Sydney) regards current Australian *Beauveria bassiana* research, the availability of *B. bassiana* strains that may be suitable for testing against DBM, etc. Subject to these discussions, samples will either be obtained from within Australia and tested in a small pilot study, or permission will be sought to import and test same from Cornell University, USA.

DBM Project Communication

- Mike Keller to set up DBM Project bulletin board (dbm-list@waite.adelaide.edu.au).

7. COMMENTS ON THE HRDC DIAMONDBACK MOTH PROJECT by PROFESSOR TONY SHELTON.

The goals of the project are outlined in the application for research funds. Comments on specific aspects follow.

Extension material

Various distribution channels for information need to be developed. An overall booklet/handbook on integrated pest management for crucifers appears needed. It is not clear to me that it should only focus on DBM since growers will also be concerned about best management practices for diseases and weeds as well. I don't know if this is out of the scope of the proposal, but with the existing information available in Australia as well as in other countries it would appear that it could be put together with little additional effort. Once it is put into print, it can also be easily put on the WWW. While it appears that growers may not use the WWW extensively at present, they will likely do so in the future, especially as the vegetable industry changes over the next decade. Once on the WWW, changes can be easily made as more knowledge is gained or as pesticide regulations and registrations change.

Besides the booklet/handbook which contains a broader range of needed information, it seems there is a need to make a smaller booklet which could be kept in a pant's pocket or glove compartment of a vehicle. This could contain pictures of pests and natural enemies, brief guidelines for control (sampling and thresholds), and a list of pesticides recommended for control. Some of this information will change more frequently (e.g. pesticide registrations) than others (e.g. pictures of natural enemies) so this publication should be amenable to adding inserts and removing outdated material.

It may be good to work with a select group of growers and people in your media services group so that information can be developed with appropriate input from the end users and the creators of the material.

Spray application

The idea of "roadshows" seems very appropriate for highlighting the need to improve spray coverage on the plant. One thing that is missing from this study, however, is a better understanding of where the insect occurs on the plant so one can assess whether one type of application is superior to another from a true biological perspective. Perhaps this could be done by including another evaluation in these trials. For example, if one is looking at three pieces of spray equipment one could spray different areas of the field (in a replicated fashion) with the same insecticide and then come back two days later and assess the number of live insects on various sections of the plant (heart leaves, lower frame leaves, etc.) compared with the number on sections of unsprayed plants. Ideally, it would be useful to do this at more than one crop stage since efficacy of the sprayer may vary depending on the size of the plant.

This project should involve someone in agricultural engineering, personnel in the private sector involved with developing and marketing spray equipment and progressive growers who can field test modified equipment. An emphasis should not only be made to develop and/or test new equipment but also to stress the proper maintenance of existing equipment (e.g. demonstrations on the value of calibration and changing nozzles regularly).

Insecticide Resistance Management Strategy

This program seems very appropriate. Prior to the widespread use of any of these newer insecticides, it would be useful to have some information on the baseline susceptibility so changes over time can be monitored and compared. There are published reports in the US, and perhaps other countries, which can be used for monitoring resistance to many of the newer materials as well as the older ones.

Although the growers at the meeting did not seem to place a high priority on monitoring for resistance, it would help them in the long run.

Crop Monitoring

The DYMEX model for predicting insect development may be important, however, at least equal effort should be placed on a developing an "in the field" scouting technique which growers or private consultants can use for decision making. A time may soon come in Australia, as it has already in many areas of America, when growers will have to provide some evidence that there was a need for a particular treatment. Emphasis should be placed on making the sampling program as time efficient as possible so growers will adopt it. Perhaps the use of pheromone traps could be used as an early warning system before in-field plant sampling is done. In many programs which I am aware of most of the reduction in the use of insecticides occurs when growers can be convinced that early season sprays are not needed. The use of pheromone traps or day-degree models could help time when more intensive plant sampling should begin. When developing the field sampling program particular attention should be given to monitoring areas in the field where insects would most likely occur such as borders areas adjacent to older host crops or crop debris for the insects.

In the Cornell IPM crucifer program field monitoring has proven to be the foundation of the program. It has allowed growers to better time their sprays, spray only when needed, and thus save costs and reduce the potential for resistance. I see the DYMEX model as primarily a useful tool for modeling the effect of specific interventions such as the effect of introducing a more efficacious insecticide or introducing a new biological agent into the system.

Trichogramma in the Nursery

As a substitute for this project, I would suggest that using a fungus could be more efficacious as a method of biological control in the greenhouse. We have tried *Trichogramma* and the fungus, *Beauveria bassiana*, and are putting our money on the latter for providing better and more reliable control (we have also spent considerable effort on baculoviruses and think that *B. bassiana* appears the most promising of the lot). Using sentinel plants, as already outlined in the proposal, would be an excellent technique for ensuring reliable test results.

Other non-chemical control such as screening the greenhouse and having a host-free period should also be investigated as tools for an overall IPM program.

Natural Enemies

As was discussed in the meeting, if time and resources permit, it would be most useful to get some measure of the effect of predators on reducing diamondback moth egg, larval and pupal populations under commercial situations, and to assess the effects of insecticides on the "guild of predators". This could be done through either exclusion cage studies or through sentinel plants with insects on them placed in the field right after a spray. In the latter method one can get a sense of the importance of overall predation by comparing the numbers of insects left on the sentinel plants with those on sentinel plants placed in unsprayed fields. Many of us are now only coming to realize the importance to predators in reducing pest populations and the need to conserve these predators.

Work on the effect of parasites and the potential role they can play in an overall IPM program for DBM should definitely continue. New parasitoids should be introduced if the existing ones have not proven to be effective enough. New work in South Africa indicates that DBM may have originated there and that this area may be the source of some more effective natural enemies. Collaboration with scientists such as Dr. Rami Kfir and Dr. Peter Cameron should be encouraged.

Mating Disruption

From the data in the literature, our own experience at Cornell and the results to date in the HRDC project this technology probably should have a lower priority in this program if the project has a completion date of 30 June 2000. However, pheromones may prove very helpful in monitoring studies (as outlined above) or in dispersal studies.

DBM Dispersal

The literature indicates that when suitable host material is available, DBM will not move any great distance unless they are moved by strong winds. Mark and recapture studies of DBM are difficult and the results need to be interpreted carefully in the context of the cropping scheme (hosts available vs. not available), the weather patterns and the experimental methodology.

As was explained to me at the meetings, the extensive land grown in canola may be a source of DBM for vegetable crucifers. A better understanding of the potential interaction that these two crops have will be important for area-wide management of DBM. The use of pheromone traps placed in the canola through the season may provide an easy measure of the DBM dynamics in this crop. Nearby land that will be planted into vegetable crucifers should also be monitored with pheromone traps before crucifers are planted as well as when they are in the field. The use of pheromone trap data in canola and nearby vegetable crucifers may provide sufficient information to assess the dispersal patterns of DBM between these two crops.

Surfactants for Egg Laying

Recent findings in North Carolina have indicated some surfactants reduce egg laying by DBM. Considerably more work needs to be done on the stability of such surfactants under field conditions as well as whether such reduced egg laying will occur when there is no choice for ovipositing females (i.e. when a whole field is sprayed and the adults have no choice on where to lay their eggs).

Verification in grower practices

In order to assess the value of this project it seems essential to document grower practices at present and to document any changes in grower practices due to the research and extension efforts generated in this project. Such data could be: the number of growers who presently use some sort of sampling of the fields before treatment and the type of sampling they do; the frequency of insecticide applications; the application methods, etc.

APPENDIX

1. The Current Status of IPM of Insect Pests of Crucifers in the United States. (Tony Shelton, Cornell University, Ithaca, USA)

Sampling and monitoring. In New York I would estimate that nearly 75% of the crucifer fields are scouted for the presence of an insect pest before any treatment is applied. This is probably pretty representative of most states, except for California where it would be even higher. This prescriptive method of managing insect pests is due to state regulations as well as the high cost of the pesticides and the needed justification for spending the money. In the past, university personnel used to recommend regular scheduled spraying, but most recommendations now focus on sampling and treating only when a threshold is exceeded. However, thresholds are usually only followed as guidelines. All states have an IPM program funded by either state or federal money and each program tries to create IPM recommendations for the major crops within that state. There is good collaboration between states when creating such IPM programs.

In the case of the diamondback moth (DBM), there are still problems in controlling this pest. Much of the problem can be traced to insecticide resistance.

Insecticide resistance. In a national DBM survey conducted in the late 1980's, high levels of resistance to pyrethroids and carbamates were found in some areas while other areas had little problems. A later survey of resistance to Bt products also showed resistance to the Bt *kurstaki* products. The development of resistance seems to be generated on a local basis, although it can spread between areas by the movement of plants. In 1997 a major outbreak of DBM occurred in California. In this case, there were some populations of DBM which had developed resistance to permethrin, but not methomyl or Bt. The outbreak seems more attributable to the mild winter and the lack of rainfall which simply allowed the populations to cycle more rapidly and not be subject to the usual environmental constraints. Recently, spinosad has received a national label and baseline susceptibility data are being obtained for populations in California, Hawaii, Florida and probably some other states as well. It is important that we develop a resistance management strategy not only for these newer insecticides but for also the older ones that are still effective. Unlike Australia where growers, industry and regulators have joined forces to create a resistance management program, such coordinated efforts don't seem to occur in the United States and this needs to change.

Biological control. Most of the biological control which occurs commercially in crucifers is through the use of Bt products. While this has been helpful in the conservation of natural enemies, there is considerable concern because of the above mentioned reports of DBM showing resistance to toxins contained in Bt products. New reports indicate that resistance to Bt *aizawai* products has occurred. How we stay ahead of such a vicious cycle appears to be more on the mind of those in research rather than those who promote, sell or buy the products.

Research has been conducted on the use of other microbial insecticides and products containing *Beauveria bassiana* have shown a decent level of control. However, compared to some of the newer products like spinosad they pale. Mass releases of parasites such as *Cotesia* sp. have been sold commercially, but the results have been ambiguous at best. Other parasitoids such as *Diadegma* have been very successful when used with softer materials which conserve them. Spinosad is one of those materials which has been shown to be very soft on beneficials yet very effective on DBM. Our challenge will be to develop a program which uses such materials without developing rapid resistance to them.

Pheromone disruption has been used in research fields, but doesn't seem to be effective at present.

The future. Regulations are dictating the future. The government has mandated that IPM will be applied on 75% of the crop land by the year 2000. No one is sure exactly what that means but it does

give an indication of things to come. More recently, the government has issued the Food Quality Protection Act which many fear will quickly lead to the cancellation of many of the organophosphate and carbamate insecticides. Such rules keep us scrambling to find alternatives, but this is especially difficult in food crops such as vegetables which have high cosmetic standards. Even the introduction of Bt transgenic crucifers, which will come into the market within 5 years, will not solve the problem alone.

Insecticides will continue to play a role in IPM, but they will no longer be the sole management strategy. Past experiences with DBM management have reinforced the belief that single-component strategies will fail. Our challenge is to work with growers, regulators and industry to come up with sustainable strategies through a better understanding of the pest's biology and ecology and the crucifer production and marketing system.

2. DBM Research and Pest Management in New Zealand. (Peter Cameron, Crop & Food Research, Auckland, New Zealand)

Over the past 2-3 years growers have recognised difficulties in controlling diamondback moth in vegetable brassicas in New Zealand. This has been demonstrated to be at least partly due to increased levels of resistance to synthetic pyrethroid and organophosphate insecticides, and growers are now beginning to use alternatives, particularly *Bacillus thuringiensis*. Prospects for the introduction of *Cotesia plutellae* are also being assessed. Recently there is increased interest in the use of crop scouting to reduce insecticide applications but there are few trained scouts. To improve management, the Brassica industry has proposed a training programme that integrates reduced-spray approaches with an insecticide rotation strategy based on the South Australian model.

Insecticide resistance

Increasing resistance of DBM to standard SPs and OPs has been reported in Cameron *et al.* (1997) and Cameron & Walker (1998a). In 1994, resistance to lambda-cyhalothrin and methamidophos reached levels associated with control failures and by 1997 resistance was recorded in several regions. The differing levels of resistance in each region appeared to be related to frequency of use of each insecticide class. Until 1997 there was very little use of *Bacillus thuringiensis* and no resistance was detected. Similarly, there was no resistance to the carbamate, methomyl.

Reduced spray programmes

From 1989 to 1993, a reduced spray programme for DBM was developed with the aim of preventing the levels of resistance reported overseas. An action threshold of 15% infested plants was determined in field experiments (Beck & Cameron 1990) and a scouting technique adapted for commercial use. Although this technique was successfully demonstrated (Beck *et al.* 1992), growers continued to rely on preventative sprays until this approach began to fail. Interest in crop scouting has subsequently increased and individual growers have used forms of crop scouting. One of the major impediments to crop scouting in New Zealand has been the lack of trained consultants.

Parasitoids

No egg parasitoids have been detected in New Zealand. Two introduced parasitoids, *Dialegma semiclausum* and *Diadromus collaris* occur commonly, but neither give adequate control of summer populations (Beck & Cameron 1992). These parasitoids are unlikely to be limited by summer temperatures as these rarely exceed 25°C. Although these observations were recorded from unsprayed sites, the impact of heavy spraying in the region examined is unknown.

The introduction of *Cotesia plutellae* has been proposed to increase parasitism over summer periods. Literature records are unclear on the specificity of this parasitoid, therefore its host range was assessed overseas and in the laboratory (Cameron & Walker 1998b). In Fiji it rarely parasitised *Helicoverpa armigera* (1 record) and *Chrysodeixis armigera* (2 records) in and around Brassica crops, and in Malaysia no hosts other than DBM were found. By contrast, in laboratory tests *C. plutellae* was capable of locating and developing in a range of species including the native species *Plutella antiphona*, *Uresiphita polygonalis*, *Nyctemera annulata*, *Graphania ustistriga* and rarely, *Bassaris itea*. Although all of these species, except *P. antiphona*, were demonstrated to be less acceptable for oviposition and development of the parasitoid, the tests demonstrated that *C. plutellae* has several laboratory hosts. In 1997/98, to obtain better estimates of field host range with species relevant to New Zealand, a preliminary field experiment was initiated in Adelaide. No parasitism was recorded in *B. itea*, *H. armigera* or *Uresiphita ornithopteralis*. More results will be required to present a case for release of *C. plutellae* in New Zealand.

Alternative host plants

A survey of alternative host plants for DBM in the Pukekohe (South Auckland) vegetable growing region (Cameron *et al.* 1997) demonstrated that total populations of DBM on white mustard crops were similar to those on vegetable brassicas. Wild radish on roadsides and crop margins provided a

smaller but stable refuge. These plants are considered to provide a significant source of susceptible DBM to dilute resistance that may occur through the use of transgenic vegetable brassicas.

Insecticide rotation strategy

In addition to the reduced spray programme, growers are also interested in implementing an insecticide rotation strategy based on the two window South Australian model. The definition of a strategy suitable for New Zealand is currently limited by the availability and registration of new insecticide classes, including spinosad, fipronil and Bt strains. However, there is strong support for defining two windows and restricting the use of synthetic pyrethroids to the second window. At present, organophosphates have not been split into different windows because cross-resistance patterns relevant to New Zealand are unknown. New insecticide classes will be added as products and information appear, but these cannot be named in grower publications until they are registered for use. Integration of the rotation strategy and reduced spray approaches for control of DBM are currently the subject of a new initiative by the NZ Vegetable and Potato Growers Federation.

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3. Is Integrated Pest Management in Brassicas in the Lockyer Valley Cost Effective?
Report prepared for Farm Walk on 13th August 1998 at the Gatton Research Station. (John D. Duff, Lynne Grbin, Vicki Hamilton, Melissa Bishop, Gerry MacManus and Bronwyn Houlding, Queensland DPI)

This research is part of the 3rd year of the ACIAR Project "Improvement of Integrated Pest Management of *Brassica* Vegetable Crops in China and Australia" and the 1st year of national HRDC Project "Advancing the Integrated Management of Diamondback Moth (DBM) in Crucifer Vegetables.

The treatments were as follows:-

- Treatment 1 Integrated Pest Management - IPM
- Treatment 2 Resistance Management Strategy - RMS
Developed with the HRDC project.
- Treatment 3 Calendar Spray Schedule - CSS
- Treatment 4 Unsprayed - no insecticides

	IPM	Resistance Strategy	Calendar Spray	Unsprayed
Decision to spray based on – 1. Pest present or absent			√	N.A.
2. Monitoring	√	√		
Release of Beneficials	√			
Monitoring tools used - 1. Pheromone traps	√	√		
2. Yellow sticky traps	√	√		
3. <i>Brassica</i> booklet	√	√		
4. Parasitism levels	√	√		
5. No. plants sampled for pests and beneficials	20	20	10	10
Level of monitoring	High	High	V. low	V. low

Treatment Results of Planting 1 at Gatton Research Station and on Grower Properties.

Chemicals used	IPM GRS	IPM 1	IPM 2	IPM 3	RMS GRS	RMS 1	RMS 2	CSS GRS	CSS1
Ambush							√		√
Hallmark						√			
Sumi-Alpha								√	
Lannate/Marlin	√			√	√	√	√	√	√
Supracide									√
Orthene							√		
Endosulfan			√			√	√		√
Tokuthion	√	√			√				
Nitofol/Monitor					√	√		√	
Regent				√		√		√	√
Delfin		√	√	√					
DiPel	√		√		√	√			
Xentari	√	√	√	√	√	√	√		√
Total No. of Sprays	6	6	9	7	6	11	12	8	13
Insecticide costs/Ha	\$318	\$336	\$420	\$305	\$318	\$572	\$643	\$387	\$820

Planting 1 GRS/on farms				
Harvest Assessments	IPMGRS	IPM1	IPM2	IPM3
% harvested	57.2	94	88	95
Insecticide applications	6	6	9	7
# synthetic insecticides	4	2	1	4
# biological insecticides	2	4	8	3
# mixtures	0	0	1F	0
Cost per hectare for insecticides	\$318.10	\$336	\$419.73	\$305
Returns per Hectare	\$4,656.17	\$10,481.50	\$12,092.40	\$12,154.06
% Pesticide Costs	6.8	3.2	3.5	2.5

	RMSGRS	RMS1	RMS2
% harvested	51.4	88.4	99
Insecticide applications	6	11	12
# synthetic insecticides	4	12	14
# biological insecticides	2	5	5
# mixtures	0	8	6
Cost per hectare for insecticides	\$318.10	\$571.99	\$643.36
Returns per Hectare	\$2,704.17	\$9,288.17	\$9,657.59
% Pesticide Costs	11.8	6.2	6.7

	CSSGRS	CSS1	UNSPR.
% harvested	37.4	80	0
Insecticide applications	8	13	0
# synthetic insecticides	9	20	0
# biological insecticides	0	4	0
# mixtures	1	11	0
Cost per hectare for insecticides	\$386.50	\$819.67	0
Returns per Hectare	\$999.77	\$5,899.29	-\$3,192.40
% Pesticide Costs	38.7	13.9	

Planting 2 GRS				
Gatton Research Station				
Harvest Assessments	IPM	RMS	CSS	UNSPR.
% harvested	78.58	83.17	80.4	2.2
Insecticide applications	6	7	10	0
# synthetic insecticides	1	3	12	0
# biological insecticides	5	4	0	0
# mixtures	0	0	2	0
Cost per hectare for insecticides	\$325.60	\$399.90	\$598.70	0
Returns per Hectare	\$8,022	\$8,253.37	\$8,590.51	-\$2,178.40
% Pesticide Costs	4.1	4.8	7.0	

Treatment Results for Planting 2 and 3 at the Gatton Research Station

Planting 2	IPM GRS	RMS GRS	CSS GRS
Chemicals used			
Pirimor		√	√
Tokuthion			√
Phosdrin			√
Nitofol/Monitor	√	√	√
Lannate			√
Regent		√	√
DiPel	√	√	
Xentari	√	√	
Total No. of Sprays	6	7	10
Insecticide costs per hectare	\$326	\$400	\$599

Planting 3	IPM GRS	RMS GRS	CSS GRS
Chemicals used			
Pirimor	√	√	√
Tokuthion			√
Phosdrin		√	√
Nitofol/Monitor			√
Regent		√	√
DiPel	√		
Xentari	√	√	
No. of Sprays to date	10	11	9
Insecticide costs per hectare	\$560	\$662	\$626

4. DBM Dispersal Studies: progress and future directions. (Jianhua Mo, SARDI)

DBM is notorious for its development of resistance against a vast array of insecticides. To reduce the rate at which DBM develops resistance against new insecticides, effective insecticide resistance management (IRM) strategies need to be formulated and alternative control methods developed. Two IRM strategies currently promoted are the window strategy, whereby the application of any insecticide is restricted to a certain period of the year, and the crop-production break. Before implementing these strategies and the alternative control method of mating disruption, we need to determine the size of the restriction zone (a *Brassica* block? a farm? a group of neighbouring farms?). The answer to this question lies in the local dispersal behaviour of the pest, and in particular, the expected distance that a given proportion of the DBM population would travel under normal conditions in the field.

Summary of 1997-98 Work

Four experiments were conducted between December 1997 and March 1998 in SA to study the local dispersal behaviour of DBM. For each experiment, 600-1200 male DBM moths marked with fluorescent powder were released in a central point in a *Brassica* field. To guard against possible influence of artificial rearing on moth behaviour, only moths reared for 3 or less generations in the lab were used in the experiments. Movements of marked males were monitored daily for about a week with sticky delta traps baited with DBM pheromone (supplied by CSIRO Entomology Division in Brisbane). Trapped moths were brought back and checked under UV light for presence of the fluorescent powder. Two trap layouts were tried: a regular grid pattern and a fan-shaped pattern. The regular grid pattern was employed for the first three experiments. The distance between 2 neighbouring traps was 25m (Figure 1). The dimensions of the grid system varied with the dimensions of the crop fields at the time of the experiments. A minimum of 100m x 100m dimension was achieved in the experiments.

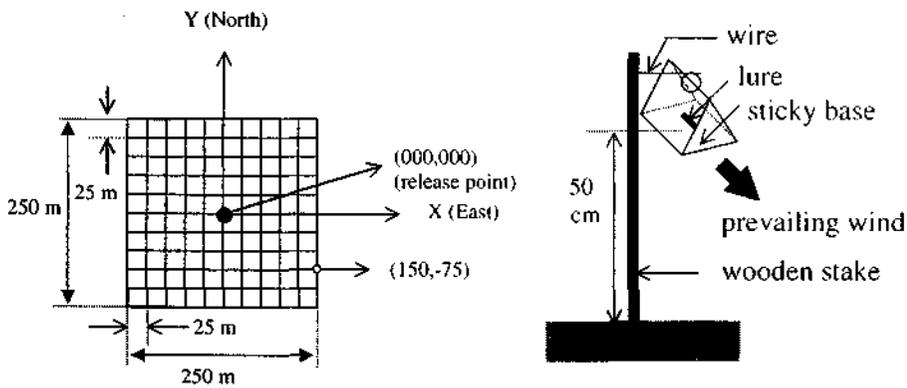


Figure 1. An illustration of the grid-pattern layout of pheromone traps. The actual size of the trap grid varied with the dimensions of the crops. One delta sticky trap (shown on the right) is placed at each grid intersection. Marked males were released at the centre grid intersection.

The fan-shaped pattern was employed in the last experiment. In this pattern, traps were laid out along 4 ordinal directions from the release point at fixed vertical distances to the release point, with the number of traps deployed increasing in proportion to the distance. The maximum distance of the traps to the release point was 112m.

Weather conditions, temperature, wind speed, and wind directions, during the experiments were monitored *in situ* with a weather data logger.

Results and Discussion

The total number of marked males caught in the four experiments ranged from 2 to 32, representing 0.3%-2.4% of all marked males released. The overall average trapping distance was 60m and the maximum 278m. Results from the Experiment-III, in which the largest number of recaptures was made, indicated that the majority of the marked males (75%) were caught within 75m from the release point. Only 12.5% were caught at distances greater than 100m.

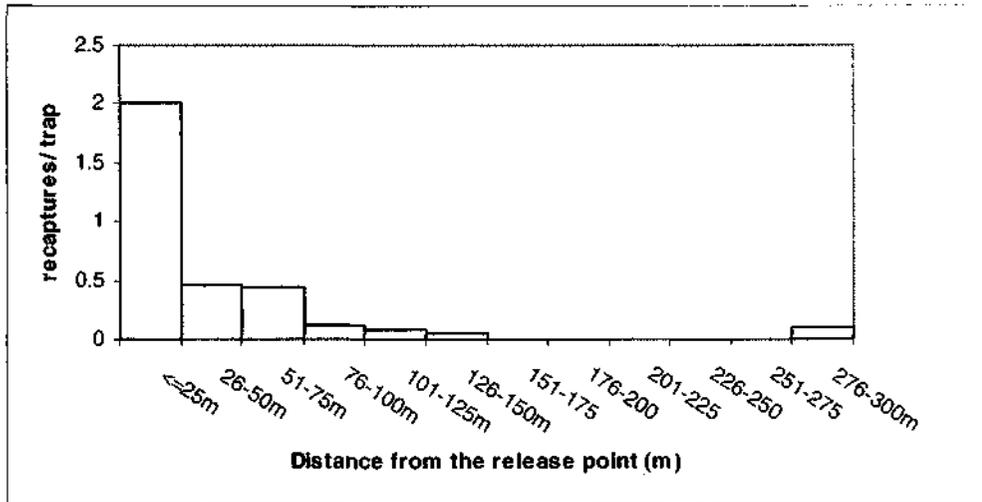


Figure 3. Number of moths caught at varying distances from to release point in mark-recapture experiment II.

Data collected so far do not allow a complete analysis of the relationship between recapture rates and distance. The total number of recaptures in a single experiment did not exceed 32 and was as low as 2. Several factors may have contributed to the low recaptures. One likely factor was weather at the time of or soon after moth release. In one experiment, the moths were released during light rain, which intensified to heavy rain soon after the release. Only two marked males were recaptured in that experiment. Insecticide applications may have also affected the recaptures. A previous study on the dispersal of DBM showed that marked males were continuously recaptured for up to 10 days after the release. In SA, farmers normally spray every week. Under this spray-frequency, the expected insecticide-free period for dispersal experiments was about 3-4 days, less than half of the normal recapture period.

While factors relating to weather and farming practices can not be manipulated by experiments, factors relating to the moths and traps can be optimised to maximise recaptures. To this end, investigations were carried on the wingspan and life span of laboratory-reared moths, and the effects of marking, mating history, pheromone concentration, and trap design on the recapture rates. Wingspan was believed to be positively related to the flight capability of DBM moths. An examination of 50 lab males and 25 field males revealed no significant differences in the wingspan ($P > 0.05$, t-test). Males lived significantly longer when fed with honey (12 d) than with no honey (6 d) ($P < 0.01$, ANOVA). Marking with the fluorescent dye did not significantly reduce the lifespan of the males ($P > 0.05$, ANOVA). Trapping tests in a wind tunnel revealed no significant effects of marking, mating status of males (unmated or mated), or pheromone concentrations (25 μg vs 100 μg) on the proportions of moth caught by the sticky traps ($P > 0.05$, Monte Carlo tests on contingency tables). However, traps with 3 stick sides caught significantly more moths than those with 1 stick side (the choice of standard delta sticky traps) in 2 of the 4 tests conducted ($P < 0.05$, Monte Carlo tests on contingency tables). More wind tunnel tests will be conducted to ascertain the effect of extra sticky sides on improving the capture rates of delta sticky traps.

Outlines of Design Modifications for Future Dispersal Experiments

The following measures will be introduced to increase the recaptures of marked males.

- ◆ Maximise the number of males released to increase the total recaptures.
- ◆ Use the 3-sticky-side trap design, if further wind tunnel tests confirm that the latter can increase the capture rates.
- ◆ Ensure that traps are placed just above the crop canopy. This practice was not strictly observed in previous experiments.
- ◆ Carefully select the time and place for the dispersal experiments to minimise competition from local females, and avoid the exposure of released moths to rain, irrigation, and spray soon after release.
- ◆ Reduce the trap spacing in the grid pattern to increase the chance of recapturing marked males.
- ◆ Explore other trap layouts, such as the cross pattern and the 8-direction linear radiating pattern.
- ◆ Whenever possible, conduct the dispersal experiments simultaneously in two or more neighbouring blocks of *Brassica* crops, so that inter-block movements of DBM can be directly investigated.
- ◆ In addition to pheromone traps, use light traps to study the inter-block and inter-property dispersal of DBM moths.
- ◆ Directly observe the movements of released moths with night-vision goggles, illuminating chemicals, or other techniques.
- ◆ Place groups of sentry plants at varying distances from an infested *Brassica* block and observe the time it takes for DBM moths from the infested block to colonize the sentry plants.

5. Brassica Crop Monitoring in Victoria: 1997/ 98 season. (Nancy Endersby and Peter Ridland, Agriculture Victoria)

Crop monitoring was conducted at four commercial properties throughout the season.

District	Property	Crop	Start	End
Werribee South	1	Cauliflower	December 1997	March 1998
Werribee South	2	Cauliflower	March 1998	June 1998
Dandenong	3	Plain cabbage	December 1997	March 1998
Dandenong	3	Savoy cabbage	March 1998	April 1998
Narre Warren	4	Plain cabbage	December 1997	March 1998

From each crop, 45 plants were sampled weekly from throughout one age planting from transplant to harvest. The only exception was the Savoy cabbage crop which was sampled for 5 weeks only. The whole plant was searched and all life stages were recorded. Moths were caught in pheromone traps (two traps per planting). Lures were changed every five weeks. After each sampling occasion the grower was informed of the pest levels present in his crop. This was followed up by a faxed summary report. For this season's trials the grower decided what insecticides he would use and when he would apply them. All growers in the study group kept spray records.

Numbers of *Plutella xylostella* were moderate in most districts this summer with the exception of two weeks in January when egg numbers on plants were very high. Most growers controlled the larvae successfully, but some had problems after the peak in eggs gave rise to a peak in larvae. Sampling results from one crop on each property are presented. Presence/ absence data from each crop sampled were sent to South Australia for analysis. The data obtained in Victoria this season will be analysed in conjunction with sampling data obtained in previous seasons to refine economic thresholds for *Brassica* pests and sampling methods.

Figure 1 shows the numbers of moths, eggs and larvae observed in a cauliflower crop in Werribee South. Note that the moth and egg peak on 6/1/98 is followed by a peak in numbers of larvae on 20/1/98. Damage to cauliflower curds by larvae of *P. xylostella* was minimal.

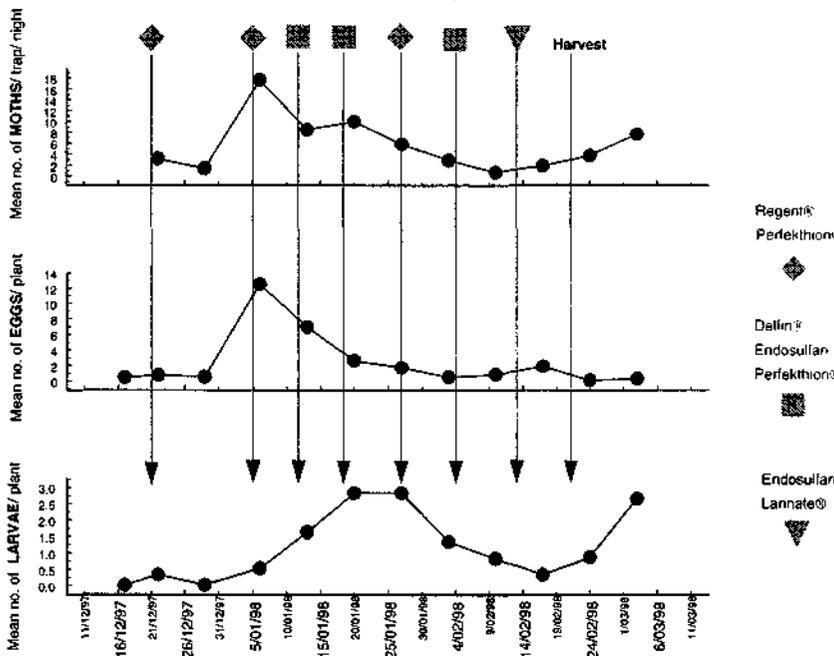


Figure 1. *P. xylostella* numbers in a cauliflower crop at Werribee South (Property 1) December 1997 to March 1998.

Figure 2 shows the numbers of moths, eggs and larvae observed in a second cauliflower crop in Werribee South later in the season. This planting received only five insecticide applications, one of which was an aphicide only. The grower stopped spraying for diamondback moth when the monitoring results showed that very low numbers were present. Information about aphid numbers assisted the grower to decide when to apply aphicides.

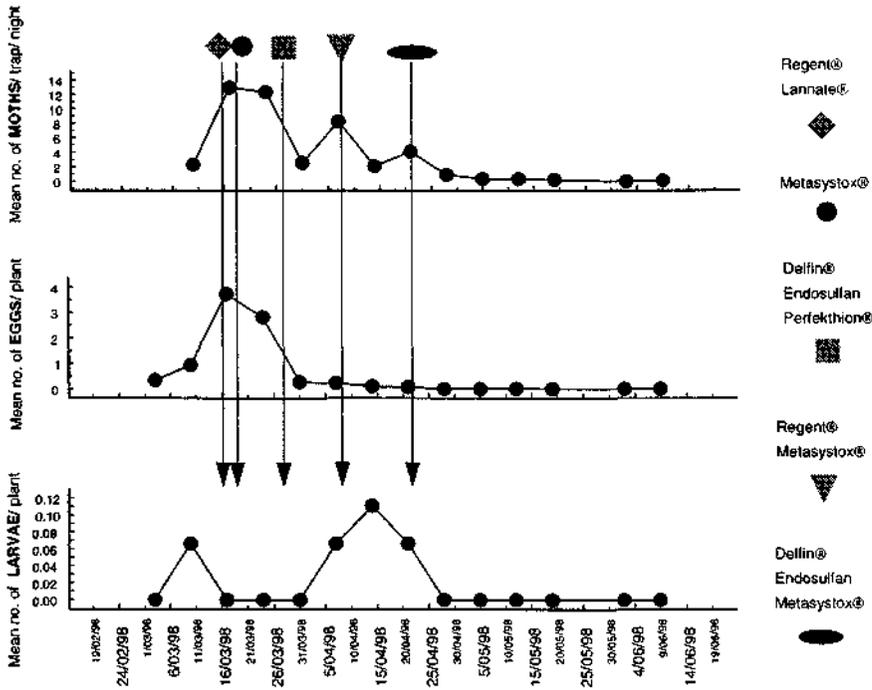


Figure 2. *P. xylostella* numbers in a cauliflower crop at Werribee South (Property 2) March 1998 to June 1998.

The cabbage crop at Dandenong (Figure 3) received 13 applications of insecticide. Larval numbers reached a peak in mid to late January, but were brought under control by an application of fipronil followed by a mixture of mevinphos and methamidophos. Some feeding damage was sustained by the crop, but the majority of heads were harvested.

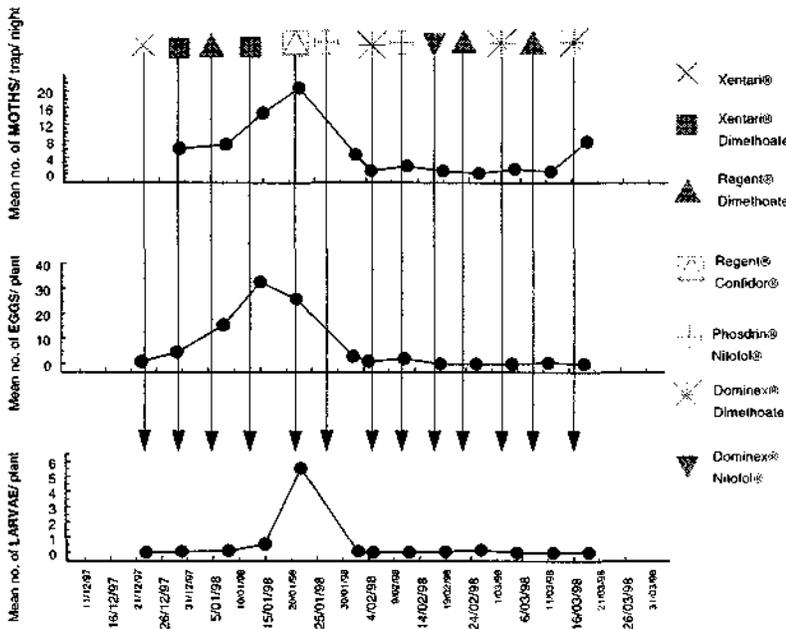


Figure 3. *P. xylostella* numbers in a cabbage crop at Dandenong (Property 3) December 1997 to March 1998.

The cabbage crop at Narre Warren received a total of 12 applications of insecticide (Figure 4). The crop was not sprayed for a 2 week period due to adverse weather conditions and sprayer breakdown. This period coincided with a peak in numbers of larvae and the crop was damaged. Feeding damage, severe aphid infestation and low cabbage prices prompted the grower to plough some of the crop back into the ground.

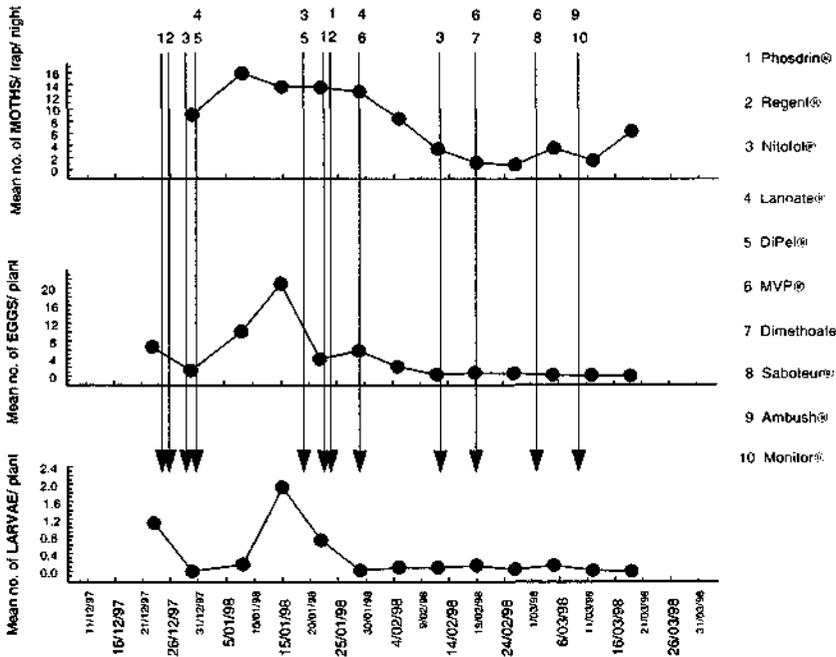


Figure 4. *P. xylostella* numbers in a cabbage crop at Narre Warren (Property 4) December 1997 to March 1998.

Numbers of eggs found on a planting of Savoy cabbage monitored throughout March and April 1998 are shown in Figure 5. Noctuid eggs (probably *Helicoverpa armigera*) were in abundance.

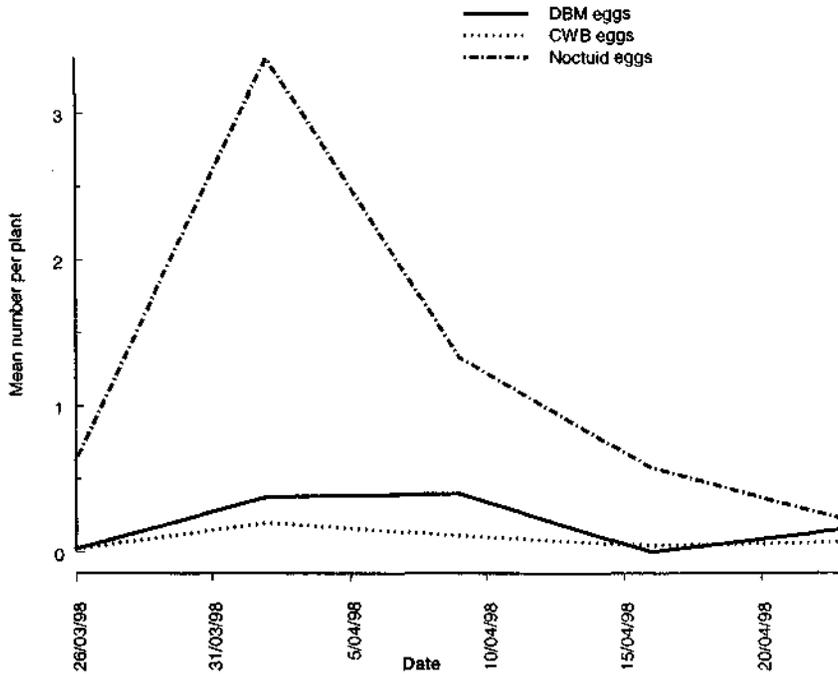


Figure 5. Numbers of Lepidoptera eggs found on a planting of Savoy cabbage at Dandenong (Property 3) in March and April 1998.

Figure 6 shows numbers of larvae found in the same planting.

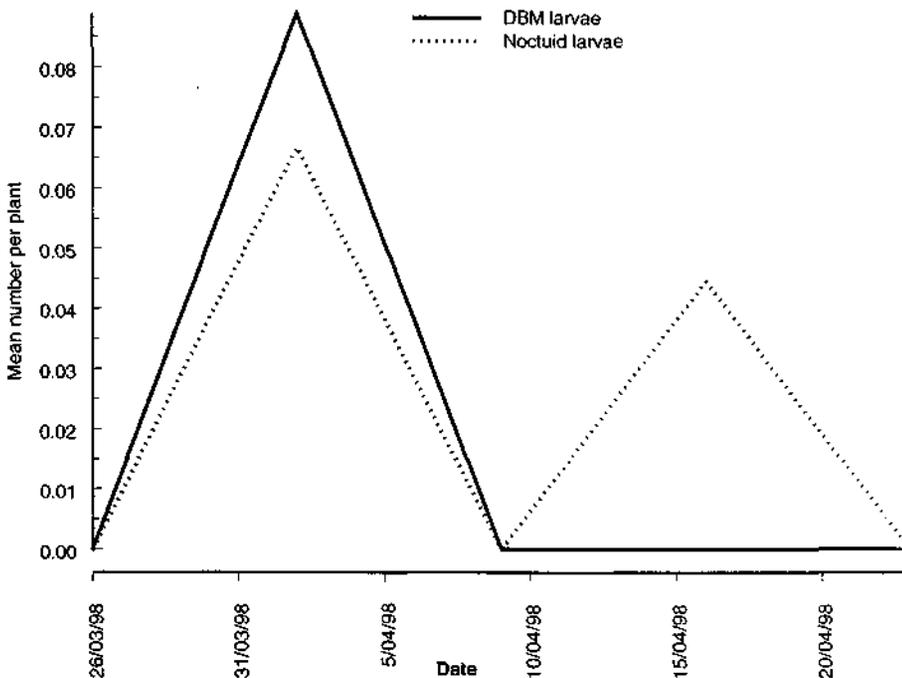


Figure 6. Numbers of Lepidoptera larvae found on a planting of Savoy cabbage at Dandenong (Property 3) in March and April 1998.

Monitoring of seedling nursery

Weekly monitoring of *Brassica* vegetable seedlings was conducted at a seedling nursery in Victoria to obtain baseline information on levels of diamondback moth infestation, distribution of eggs and spray

practices. The information will be used to design trials to assess the potential of *Trichogramma* as a biological control agent in *Brassica* seedling nurseries.

Annual production of the nursery is 93 600 000 seedlings per year (468 000 trays). The area under *Brassica* production in hot houses and shade areas is 8.5 ha. Seedlings were sampled from the edges and centre aisle of a hot house and on the perimeter of an outside shade area. The hot house sides are open and the house is not insect-proof. Seedlings are propagated in the hothouse and remain there for an average of six weeks before being moved outside.

Brassica seedlings produced are cabbage, cauliflower, broccoli, Brussels sprouts, Chinese cabbage and Chinese broccoli. Multiple batches of different varieties are grown in each hot house. Seedlings from each variety present were sampled in one hot house. Sample size varied from week to week as different batches were moved in and out of the hot house. In general, number of seedlings sampled in the hot house ranged from 800 to 1000. Approximately 150 to 500 seedlings were sampled on each occasion in the shade area.

Two pheromone traps were hung inside the hot house. Two more were set up later in the outside shade area. Moth catches in the hot house during the sampling period (December 1997 to April 1998) were low, but reached a peak in mid-January and then decreased (Figure 7).

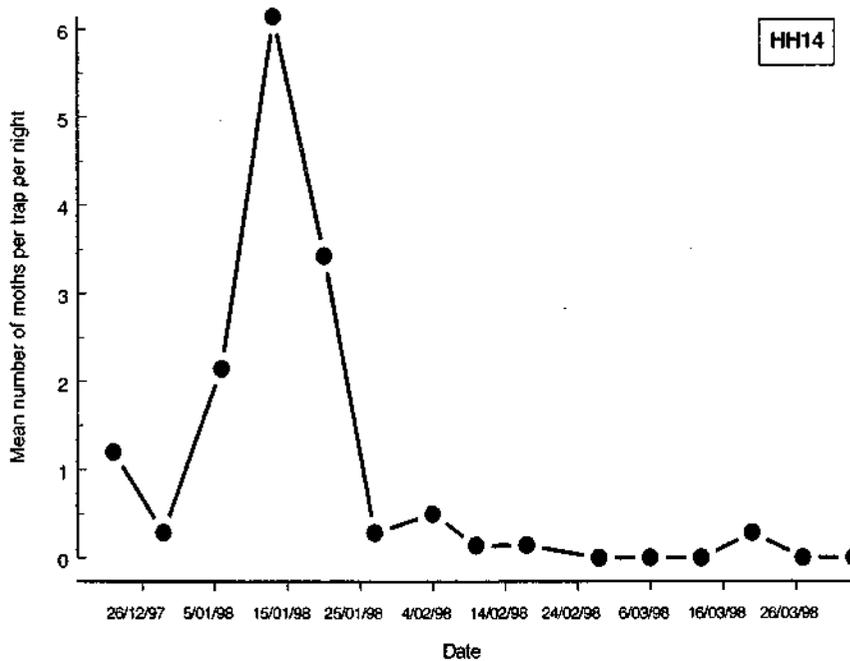


Figure 7. Diamondback moth numbers in seedling hot house (HH14).

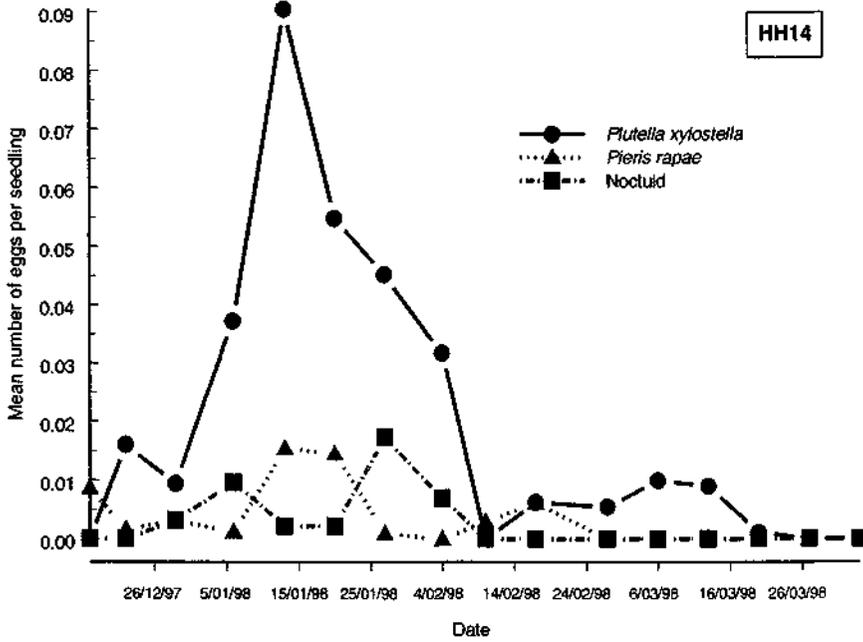


Figure 8. Numbers of eggs in seedling hot house (HH14) - December 1997 to April 1998.

Numbers of diamondback moth eggs also reached a peak in mid-January on seedlings in the hot house (Figure 8), however, numbers were always very low. Very low numbers of cabbage white butterfly and noctuid eggs were also observed.

Pheromone trapping in the outside shade area was begun later than trapping inside the hot house. Moth numbers peaked in mid to late March (Figure 9).

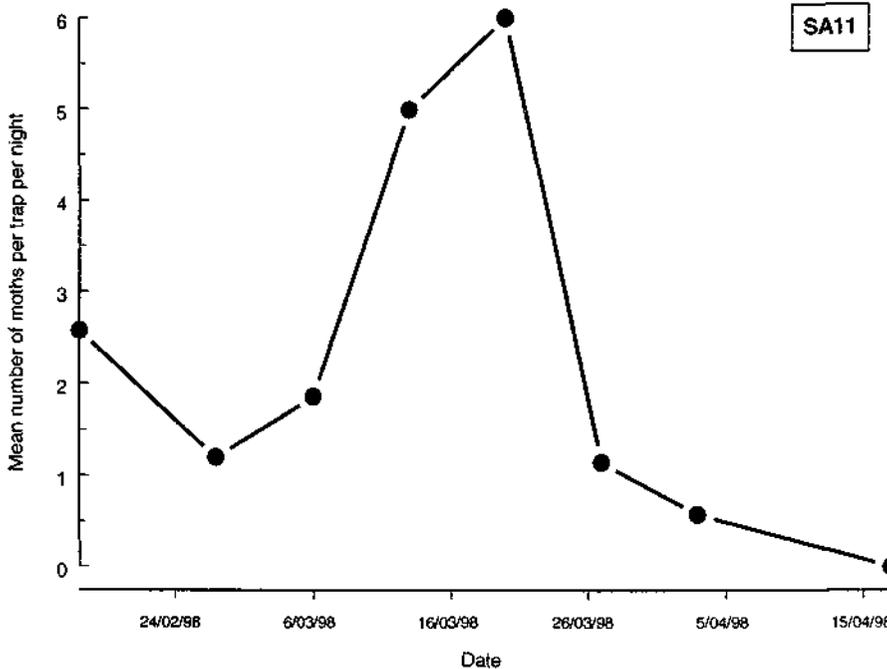


Figure 9. Diamondback moth numbers in shade area 11, February - April 1998.

There was a peak in numbers of diamondback moth and noctuid eggs in the first week of March in the outside shade area (Figure 10). Low numbers of cabbage white butterfly eggs were observed.

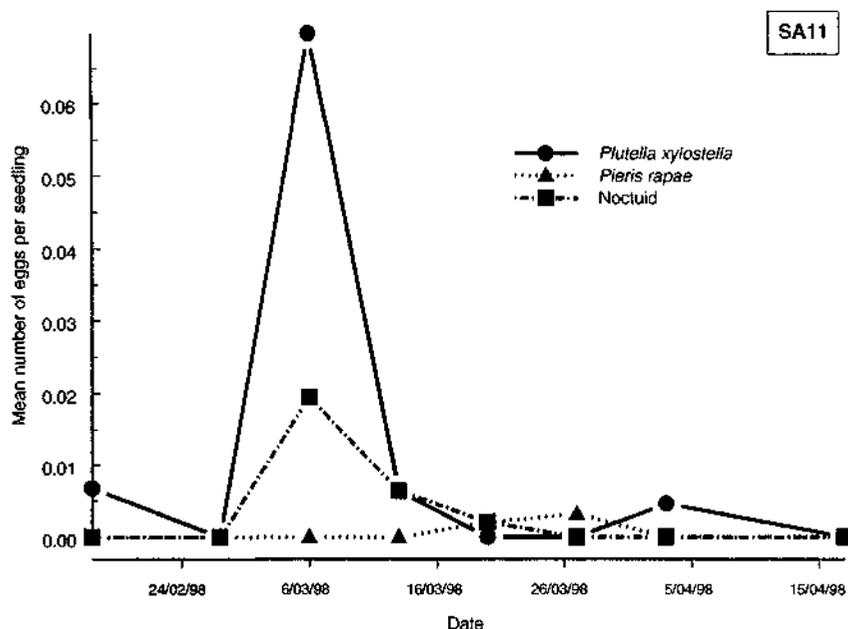


Figure 10. Number of eggs in shade area 11, February - April 1998.

Numbers of seedlings sampled and egg numbers from both the hot house and the shade area are shown in Table 1.

Table 1. Number of seedlings sampled, % infested with DBM eggs and mean number of Lepidoptera eggs per seedling in a nursery hot house and shade area in Victoria 1997/ 98.

Date	Plants	Hot house				Shade house				
		DBM eggs	% infested	CWB eggs	Noctuid eggs	Plants	DBM eggs	% infested	CWB eggs	Noctuid eggs
17/12/97	115	0.000	0.00	0.009	0.000					
22/12/97	624	0.016	1.60	0.002	0.000					
29/12/97	955	0.009	0.94	0.003	0.003					
6/01/98	833	0.037	2.16	0.001	0.010					
13/01/98	906	0.091	3.86	0.015	0.002					
20/01/98	894	0.055	2.57	0.015	0.002					
27/01/98	1038	0.045	1.64	0.001	0.017					
4/02/98	1008	0.032	2.78	0.000	0.007					
10/02/98	1014	0.000	0.00	0.003	0.000					
17/02/98	804	0.006	0.50	0.006	0.000	148	0.007	0.68	0.000	0.000
27/02/98	732	0.005	0.41	0.000	0.000	186	0.000	0.00	0.000	0.000
6/03/98	1002	0.010	0.80	0.000	0.000	258	0.070	3.10	0.000	0.019
13/03/98	1002	0.009	0.40	0.000	0.000	468	0.006	0.64	0.000	0.006
20/03/98	924	0.001	0.11	0.000	0.000	492	0.000	0.00	0.002	0.002
27/03/98	930	0.000	0.00	0.000	0.000	312	0.000	0.00	0.003	0.000
3/04/98	840	0.000	0.00	0.000	0.000	432	0.005	0.23	0.000	0.000
17/04/98						318	0.000	0.00	0.000	0.000

Spray records (insecticides and fungicides) were collected over the sample period. Table 2 shows the insecticides and number of applications used in the hot house during the first six weeks of sampling.

Table 2. Insecticides used in hot house during first 6 weeks of sampling period.

Product	Active	Chemical Family	No. of applications in 6 week period
Delfin®	<i>B. thuringiensis</i>	biological	8
Xentari®	<i>B. thuringiensis</i>	biological	4
Lorsban®	chlorpyrifos	OP - thioate	4
Chlorfos®	chlorpyrifos	OP - thioate	2
Ambush®	permethrin	SP	2
Regent®	fipronil	phenyl-pyrazole	1
Perfekthion®	dimethoate	OP - dithioate	1

B. thuringiensis was applied 12 times. On three of these occasions it was applied in a mixture with fungicides only. The other nine times it was mixed with one of each of the synthetic insecticides listed in Table 2. The use of a range of synthetic insecticides in the nursery has implications for the proposed Insecticide Resistance Management strategy and for release of *Trichogramma*.

Pheromone trapping of diamondback moth at IHD Knoxfield, Victoria, 1996 - 98

Delta traps with sticky bases have been maintained in successive crops of cabbage at IHD Knoxfield since August 1996 for pheromone trapping of diamondback moth. Traps are emptied regularly on week days. Lures (Agrisense®) are replaced every five weeks.

Figure 11 shows numbers of moths trapped per night up to September 1998.

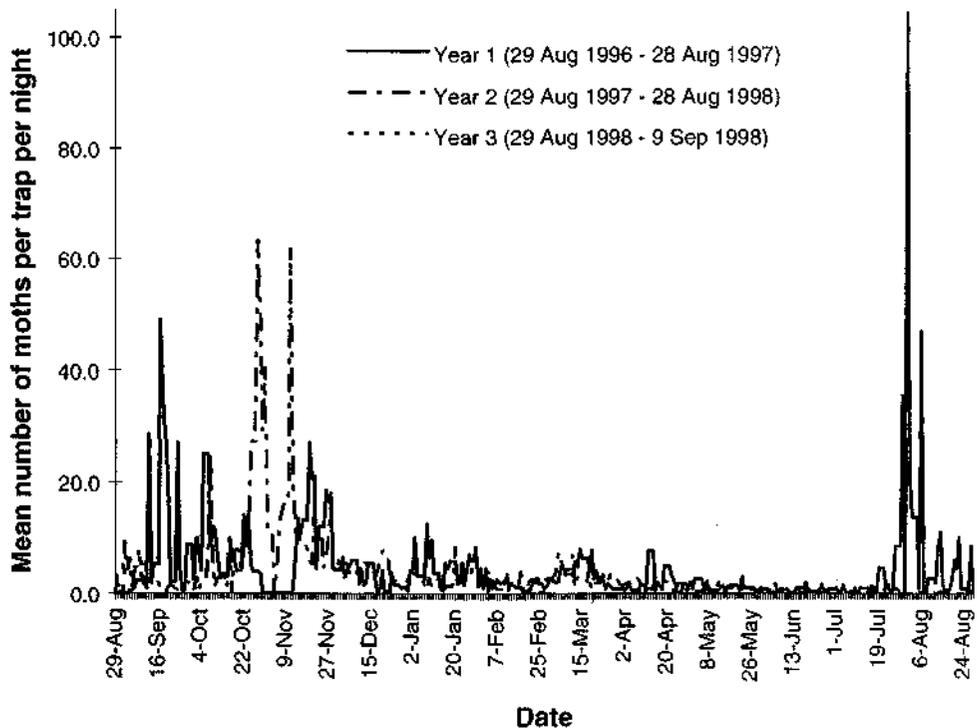


Figure 11. Numbers of diamondback moths caught in pheromone traps at IHD Knoxfield, Victoria, 1996 -98.

Figure 12 shows details of trap catches in spring, summer, autumn and winter.

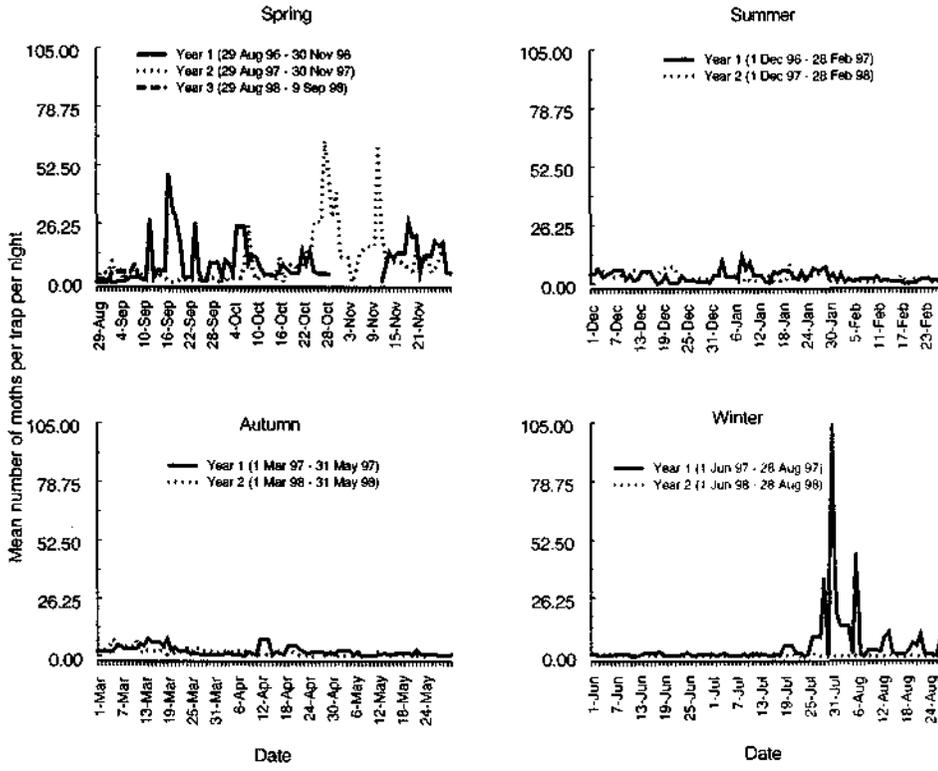


Figure 12. Numbers of diamondback moths caught in pheromone traps in spring, summer, autumn and winter at IHD Knoxfield, Victoria, 1996 - 98.

Peaks of moths occurred in spring (mid September in 1996 and early November in 1997). Moth numbers were low throughout summer and autumn in 1996 and 1997. The highest peak of moth catches occurred in winter 1997 (late July, early August). Moth numbers were very low throughout winter 1998.

Development of action thresholds for *Brassica* crops in Victoria

A sampling plan and action thresholds for larvae of *P. xylostella* and *Pieris rapae* were developed over several seasons at the Vegetable Research Station, Frankston, Victoria. The trials are described in Table 3.

Table 3. Sequence of trials for development of action thresholds 1990 - 1994.

Date	#	Trial size	Plot size	Crop	Trts	Description	Counts	Plants sampled per plot
Dec 1989	1	8 lands x 42 m	6 m x 1 land	Cabbage: Green Coronet	6 reps x 8	Threshold development: Untreated, Baker's, Increased Baker's, Critical A, Critical B, Damage, Eggs, Larvae > 1 cm	12	10
Mar 1990	2	8 lands x 42 m	42 m x 4 lands	Cabbage: Green Coronet	1 rep x 2	Grower practice vs Baker's thresholds, 2 untreated lands between the 2 treatments	15	40 (20 marked) from threshold plot only
Dec 1990	3	10 lands x 42 m	6 m x 1 land	Cabbage: Green Coronet Broccoli: Green Belt	6 reps x 10	Untreated, Regular spray, Egg, Baker's, Critical A	14	10
Nov 1991	4	20 lands x 42 m	6 m x 5 lands	Cabbage: Green Coronet Broccoli: Green Belt	6 reps x 4	Regular spray vs Critical A	13	10
Jan 1993	5	30 lands x 42 m	10 m x 3 lands, 12 m x 2 lands	Cabbage: Green Coronet	14 reps x 2	Fixed vs. sequential sampling plan	13	
Jan 1994	6	6 lands x 22 m	11 m x 6 lands	Cabbage: Savoy King	1 rep x 2	Sampling plan tested on commercial property. Thresholds vs grower practice	9	45 - 65

All threshold trials included regular insect counts and assessment of insect feeding damage at harvest. Thresholds based on *P. rapae* eggs, feeding damage and larvae > 1 cm in length gave unacceptable levels of damage at harvest. A threshold using numbers of larvae which varied with plant growth stage (Critical A) produced marketable cabbages with fewer spray applications compared with a regular program. Critical A thresholds were expressed as a maximum (a number of larvae on one m

ten plants. They were converted to a mean number of larvae per plant by looking at the relationship between mean and maximum numbers of larvae per plant by regression analysis. The mean for each maximum varied and numbers were taken from the line of best fit. The thresholds expressed as means are shown in Table 4.

Table 4. Action thresholds developed over several seasons on cabbage (cv. Green Coronet) at Frankston, Victoria for larvae of *Plutella xylostella* and *Pieris rapae*.

Growth Stage of cabbage plant	Threshold (Mean no. larvae/plant)	Sample size (no. of plants)	Precision level
1. Seedling - 5.0 cm head	1.5	45	0.15
2. 5.1 cm head - 10.0 cm head	0.9	40	0.20
3. 10.1 cm head - harvest	0.3	65	0.25

The minimum sample size required to obtain an estimate of the mean density for three different levels of precision was determined by looking at the mean-variance relationship of numbers of larvae per plant in previous action threshold experiments using Taylor's power law (Taylor 1961) and the formula of Smith and Hepworth (1992): $n_{min} = S^2/C^2m^2$, where n_{min} is the minimum number of sampling units needed to obtain an estimate (m) of the mean density, S^2 is the variance calculated from Taylor's power law and C is the level of precision required.

SAMPLING PLAN:

1. Sample unit: whole plant sample - both sides of all outer leaves, head wrapper leaves and as much of the head as can be observed without destruction.
2. Action threshold and sample size: as described above.
3. Sampling interval: once per week.
4. The starting plant is chosen at random and subsequent plants are taken at regular intervals.

Detailed measurements of sampling times were made throughout Action threshold trial #5. Figure 13 shows the average time taken for one person to inspect one cabbage plant throughout the life of the crop. Sample time for one plant ranged from 48.3 s (a seedling 2 weeks after transplant) to 97.1 s at the start of the second growth stage.

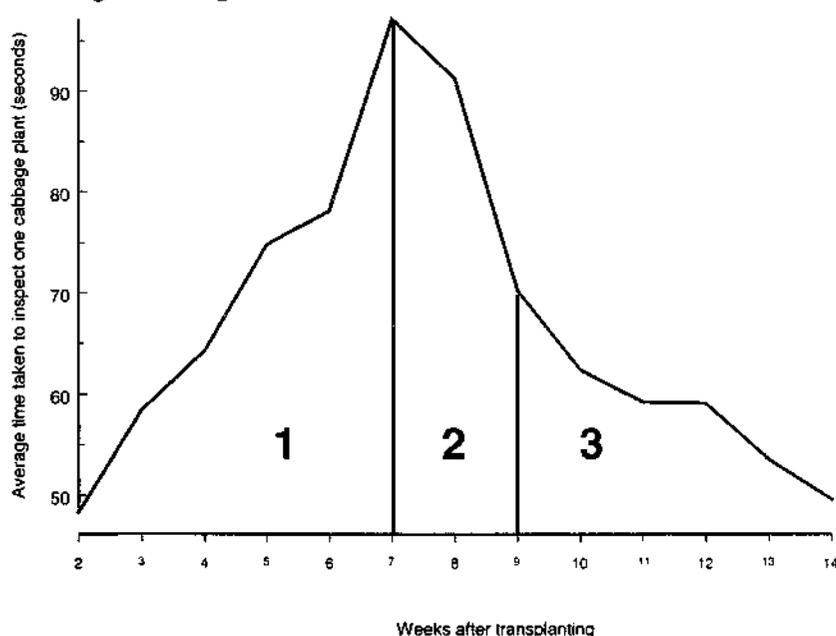


Figure 13. Average time taken for one person to inspect one cabbage plant from 2 to 14 weeks after transplanting (1 = seedling to 5.0 cm head, 2 = 5.1 cm head to 10 cm head, 3 = 10.1 cm head to harvest).

A comparison of a fixed sample size and a sequential sampling plan has been made and analysis of data is in progress. The fixed sample size sampling plan has been piloted in commercial crops over the last few seasons. Next season we hope to train and work with a commercial crop scout who will be employed by a chemical reseller. The sampling plan and thresholds developed here will form the basis of the commercial scouting program.

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- Smith, A. M. and Hepworth, G. (1992). Sampling statistics and a sampling plan for eggs of pea weevil (Coleoptera: Bruchidae). *Journal of Economic Entomology* 85: 1791 - 1796.
- Taylor, L. R. (1961). Aggregation, variance and the mean. *Nature* 189: 732 - 735.

6. The Development of a Presence-Absence Sampling Method for Monitoring DBM Larval Populations. (*Jianhua Mo*, SARDI)

Evaluation of sampling methods

In an effort to develop simple and efficient sampling methods for the monitoring of DBM, sequential sampling plans based on presence-absence data were evaluated. Compared with other sampling methods, these sampling plans are simple to use (only counting the number of plants infested) and require minimal sample sizes (and therefore sampling cost). The sampling plans were evaluated at the action thresholds of 10%, 15% and 20% of plants with heart leaves infested, and 0.1, 0.2 and 0.3 larvae in the heart/plant. These action thresholds were chosen based on an informal survey of local farmers, which indicated a very low tolerance level to DBM infestation.

Thirty-five sampling data sets were collected during November 1997 – February 1998 from a Brussels Sprouts farm in the Adelaide Hills. For each data set, 50-100 plants were randomly selected from a Brussels Sprouts block (ca. 25 m x 100 m) and the number of larvae in the heart of each plant was recorded. To estimate the percentages of larvae in the heart leaves, the number of larvae in wrapper leaves was also recorded in some data sets.

Re-sampling analyses of the 35 data sets showed that the sampling plans yielded an average correct classification rate of 97%, 92%, and 97% for the action threshold of 10%, 15%, and 20%, respectively. The respective average sample sizes were 27 (range 10-58), 37 (range 10-89), and 39 (range 10-120). Evaluation of the sampling plans under density-based action thresholds requires the establishment of the numerical relationship between proportions of infested plants (p) and infestation density (m). This was achieved with a regression model. The resulting model was highly significant ($P < 0.0001$, $r^2 = 0.97$), achieving an average relative error rate of 10% when using m to predict p , and an average relative error rate of 13% when using p to predict m . With this model, re-sampling analyses of 5 independent data sets indicated a correct classification rate of 100% for the 3 density-based action thresholds. Correct decisions were achieved at the average sample size of 19 plants.

In conclusion, sequential sampling plans based on presence-absence data can be used in classifying DBM populations levels with respect to the action thresholds currently employed by farmers. Both the density- and proportion-based approach can be expected to yield satisfactory precision at reasonable sample sizes.

Sampling distributions

Sampling plans usually vary with the spatial distributions of the sampling target, which, in turn, may vary with geographical locations and crop varieties. In sequential sampling based on presence-absence data, the variations are reflected in the relationship between the proportions of infested plants (p) and infestation density (m). To investigate the variations, sampling data collected in Victoria and in South Australia from three *Brassica* crops, cabbage, cauliflower, and Brussels sprouts were subject to analyses of differences of regression parameters. It was found that p - m regression lines obtained from these drastically different data sources were remarkably similar (Figure 1), suggesting the existence of common regression parameters. If confirmed with further data, this feature greatly enhances the prospect of implementing a nation-wide DBM monitoring program.

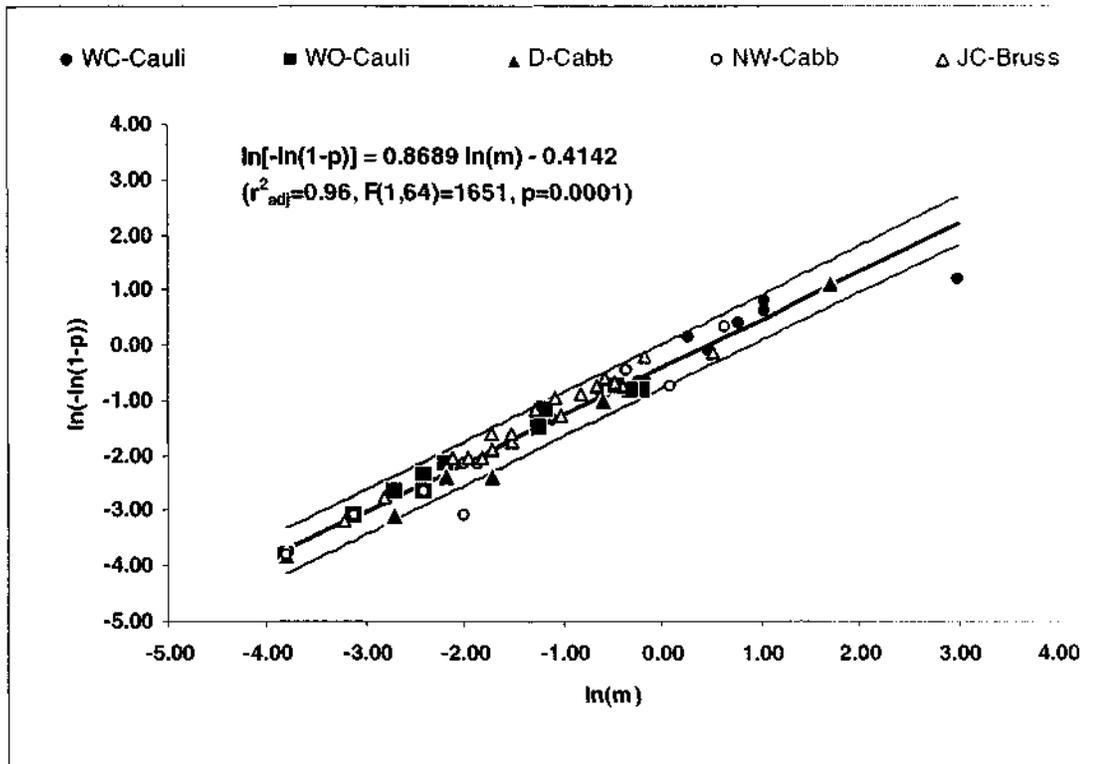


Figure 1. Scatter plots of $\ln[-\ln(1-p)]$ against $\ln(m)$ of sample data from different sites, where p is the proportion of plants infested with DBM larvae and m the number of larvae plant. The straight line in the middle is the regression line calculated from the pooled data, and the two parallel lines around it represent the upper and lower bounds at the confidence level of 95%. Site codes: WC-Cauli = cauliflower plot at Werribee (Crawfords Rd), Victoria; WO-Cauli= cauliflower plot at Werribee (O'Connor's Rd), Victoria; D-Cabb= Cabbage plot at Dandenong, Victoria; JC-Bruss= Brussels Sprouts plots at John Cranwell's, Nairne, South Australia. Sampling methods: whole-plant checking of 45 random plants in each sample in WC-Cauli, WO-Cauli, D-Cabb, and NW-Cabb, heart-checking of 50-100 random plants in JC-Bruss. Significance in slopes and intercepts between any two sites were compared with t-tests.

Proportion of larvae in the heart leaves

Some farmers or crop monitors search only the heart leaves in their monitoring of DBM. To assess the representativeness of larval counts in the heart leaves as an estimate of the total number of larvae in the plant, 9 sample data sets from Brussels Sprouts plants in which numbers of larvae in both the heart and wrapper leaves were recorded were analysed. The results showed that the proportion of larvae in the heart leaves ranged from 56.3% to 100%, averaging 83.2%. The proportions appeared to be changing in a non-linear fashion with respect to larval age, peaking between 2nd and 3rd instar (Figure 2). This pattern suggests that young DBM larvae tend to move toward the heart leaves and mature DBM larvae tend to move away from the heart leaves.

Several factors advantage a restrictive sampling approach. First, the majority of larvae were found in the heart leaves. Second, feeding in the heart leaves is more destructive to the host plant than feeding on the wrapper leaves. Third, whole-plant searching of DBM can be time-consuming and inaccurate, especially with mature plants.

In conclusion, although larval counts in the heart leaves do not seem to be a stable estimate of the total number of larvae on the plant, restrictive sampling of heart leaves can be an effective means of monitoring for DBM.

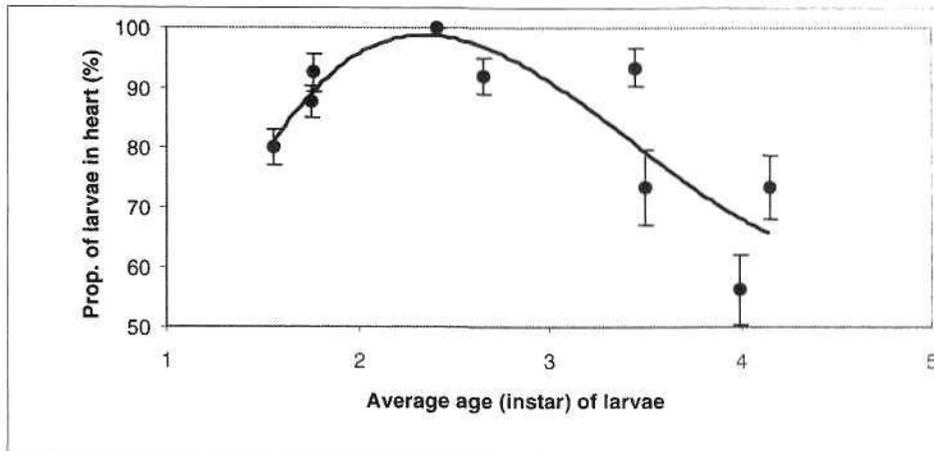


Figure 2. Relationship between the larval age (instar) and the proportions of larvae in the heart leaves. Data from a Brussels Sprouts farm.

Sampling software

A simple and easy-to-use computer program for sequential sampling based on presence-absence data has been developed to enable farmers to implement sequential sampling plans based on presence-absence data. The farmer only need specify the action threshold to get the sampling plan in both tabular and graphic form (Figure 3), along with detailed instructions. This program is being trialled by a South Australian Brussels Sprouts grower.

Pheromone trap monitoring

To monitor the seasonal patterns of DBM populations and, in particular, the timing of the post-winter invasion of DBM from their wild hosts, pheromone traps were set out in four *Brassica* farms (two in Virginia and two in the Adelaide Hills) in SA this winter. These traps will be checked weekly for number of moths caught.

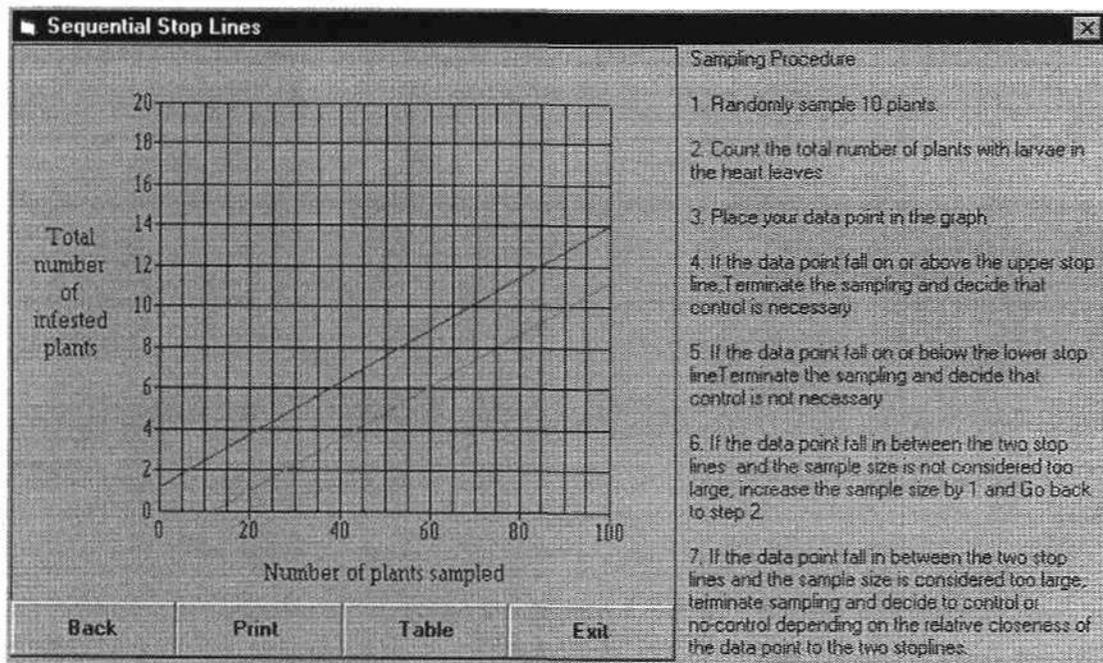


Figure 3. One output from the sampling software 'Binstop', showing the stop lines and sampling procedures.

7. Development and Distribution of a National Diamondback Moth Extension Kit. (Leigh James, NSW Agriculture and Nancy Endersby, Agriculture Victoria)

Project Synopsis:

“- to prepare and distribute a colour-illustrated extension kit to growers which outlines the identification and biology of the major pests and beneficials, and provides practical guidelines for the integrated control of these pests based on sound resistance management principles.”

“- to extend best-practice spray application methods in all major crucifer-vegetable growing districts of Qld, NSW, Vic, Tas, SA and WA.”

“- to devise, implement and assess a practical, robust IPM/IRM (insecticide resistance management) strategy for use in cabbage, cauliflower, broccoli and Brussels sprouts based on crop monitoring, economic thresholds and rotation of insecticides on a DBM generational time-frame.”

Extension Kit Progress:

* October '97; five priority topics for individual chapters established. These being; an overview of IPM and it's application to crucifers and DBM, principles of IRM plus a new 2 window IRM strategy for DBM, crop monitoring for informed decision making, identification of key and secondary pests of crucifers plus beneficials, and, what's required for effective spray coverage.

* October '97; requested copies of relevant existing DBM extension material from all other project members.

* By April '98; four individual chapters written, referred by project team members and professionally edited. These topics being; **Integrated Pest Management-what does it really mean?**, **Crop Monitoring-the key to informed decision-making**, **Insecticide Resistance Management-getting the best from your sprays while getting the better of DBM** + the latest version of the new 2 window strategy for Southern Australia, and, **The role of *Bacillus thuringiensis* in managing diamondback moth**. Articles on, How to Ensure Good Spray Coverage, plus, Enemies of DBM, drafted and submitted for referring.

* June '98; mock-up version of the extension kit folder circulated to project team members for feedback. The presentation of the inaugural 2 window strategy generated input from a wide range of sources, which gave rise to a number revisions.

* September '98; presented second mock-up version of the extension kit @ National DBM Project Workshop, Waite Campus, for comment. This version included a new, edited article, **How fast does diamondback moth develop?** A further simplified 2 window strategy was included in the IRM section by the editor.

8. Pest Management Survey of Victorian *Brassica* Growers, 1998. (Martina Bernard, Peter Ridland and Nancy Endersby, Agriculture Victoria)

INTRODUCTION

A telephone survey of vegetable *Brassica* producers in Victoria was undertaken between April and June 1998. Our aims were to assess the current status of pest management practices of Victorian growers, and to investigate their attitudes to and understanding of insecticide resistance and integrated pest management (IPM). We plan to repeat the survey in 2000 to assess changes in pest management practices and attitudes during the course of the HRDC project.

METHODOLOGY

We chose to undertake a telephone survey of 50 growers, selected at random from 3 regional lists of *Brassica* growers (approx 300 growers in all) compiled and held at IHD. We weighted the sample with respect to region (2 Western: 2 South-Eastern: 1 East Gippsland) to reflect the numbers of growers in each region. This task also highlighted the current inadequacies of vegetable industry statistics in Australia.

Each selected grower was interviewed in a standardised, 45 minute, telephone interview about pest management, insecticide resistance and Integrated Pest Management (IPM). Management of diamondback moth (DBM), *Plutella xylostella*, was the focus of the questions. All information collected applied to the 12 month period leading up to the June 1998 interviews.

Instrumentation error was minimised through questionnaire design. Interviewing, interviewer and response errors were minimised by taking care to ask questions in their exact wording, including a standardised way of stressing key words, explaining scales and checking scale understanding before recording answers. The questionnaire was adapted to the 'audible only' telephone mode. A standard definition of IPM was given before asking IPM questions to ensure that the same concept was known to all respondents before answering IPM questions. The IPM concept was not introduced until all other pest management questions were answered.

Key areas covered in the survey were:

- crop statistics
- pest problems
- chemical usage
- deployment of *Bacillus thuringiensis* (Bt)
- rotations and mixtures
- spray application issues
- understanding of insecticide resistance issues
- pest monitoring
- non-chemical control practices
- attitude to IPM implementation

RESULTS

Crops

Table 1. Area (ha) of crops in the ground on average at any one time, over the last 12 months.

Crops	West (n=21)	South-East (n=20)	Gippsland (n=10)	Total (n=51)
Brassica growers				
Number of growers	12	6	5	23
Total area (ha)	124.5	138.1	93.2	355.8
Average area (ha)	10.4	23.0	18.6	15.5
Cabbage growers				
Number of growers	7	12	4	23
Total area (ha)	49.0	118.2	49.3	216.5
Average area (ha)	7.0	9.9	12.3	9.4
Other Brassica growers				
Number of growers	17	2	5	24
Total area (ha)	162.9	3.2	25.4	191.5
Average area (ha)	9.6	1.6	5.1	8.0
Non-Brassica growers				
Number of growers	0	3	1	4
Total area (ha)	0	18.2	4.0	22.2
Average area (ha)	0	6.1	4.0	5.6
Other growers				
Number of growers	0	3	2	5
Total area (ha)		3.6	14.5	18.1
Average area (ha)		1.2	7.25	3.62
Other growers	0	2	0	2
Other growers	0	6	1	7
Other growers	0	2	0	2

A most notable regional difference was that cauliflowers were predominant (85%) in Western region. Cropping patterns were less diverse in the Western area (Table 2).

Table 2. Principal non-*Brassica* crops grown varied between regions (crops grown by $\geq 20\%$ of growers and listed in decreasing frequency).

West	South-Eastern	East Gippsland
Lettuce	Parsnip	Capsicum
Onions	Lettuce	Beans
Fennel	Onions	Sweet corn
Capsicum	Carrot	Peas
	Celery	Lettuce
	Leek	
	Parsley	
	Silver beet	
	Beetroot	

B. Pest Problems

From a list of potential pests, growers were asked to identify those pests that they sprayed last year (Table 3). They then identified those insects that caused the most damage over the last 12 months (Table 4). Diamondback moth (DBM), aphids and cabbage white butterfly (CWB) were most common pests and clearly DBM was identified as the most serious pest in each region.

Table 3. Insects controlled in last 12 months in each region.

Pest	West	South-East	Gippsland	Total	%
Diamondback moth	21	20	9	50	98
Aphids	21	20	9	50	98
Cabbage white butterfly	18	18	9	45	88
Thrips	13	7	3	23	45
Cutworm	15	5	2	22	43
<i>Helicoverpa</i>	8	5	5	18	35
Cabbage centre grub	8	9	1	18	35
Looper caterpillar	4	4	1	9	18
Sample size (n)	21	20	10	51	

Table 4. Pest types reported as the most damage causing over the last 12 months.

Pest	West	South-East	Gippsland	Total	%
Diamondback moth	20	20	9	49	96
Aphids	7	5	2	14	27
Cabbage white butterfly	1	2	1	4	8
Cutworm	1	0	2	3	6
<i>Helicoverpa</i>	1	0	0	1	2
Thrips	0	1	0	1	2
Looper caterpillars	1	0	0	1	2
Cabbage centre grub	0	0	0	0	0
Sample size (n)	21	20	10	51	

C. Insecticide Usage

Some 84% of growers used Bt as part of their spray program. Of these growers, 59% used Bt only (always or often) when the crop is young, while 31% always or often used Bt throughout the crop. The remaining 10% used Bt sporadically.

Growers tended to use several different Bt products:

Delfin (67%), DiPel Forté (60%), MVP (40%), Xentari (35%) and Biobit (2%).

Growers frequently mixed Bt with other insecticides:

[ALWAYS 25%, OFTEN 23%; SOMETIMES 16%; RARELY 14%; NEVER 23%]

Their reasons for using mixtures included:

Aphid control 71%; contact kill 51%; residual kill backup 31%; Bt used as a backup for synthetic insecticide 14%; kill DBM moths 11%; Bt was old 3%; saving labour 3%.

The mean number of sprays per crop is given in Table 5 and the most common spray interval used by growers during summer was 7-10 days.

Table 5. Mean number of sprays (Bt and synthetic insecticides) per crop during the year (Spring - Christmas, Christmas -Autumn, Winter).

Time of Year	mean number of sprays per crop	
	Bt	Other insecticides
Before Christmas	4.0	5.3
After Christmas	4.9	6.6
Winter	0.9	2.3

The main synthetic insecticides used by growers in the last twelve months are listed in Table 6. Mevinphos and methamidophos were the most commonly used OPs, while permethrin and cypermethrin were the most commonly used SPs. It was noteworthy that many growers (56%) have used fipronil in its first season of availability. The major regional differences concerned endosulfan (12 of 14 users were from Western region) and methomyl (7 of 9 users from South-East region). Note that methomyl is not registered in Victoria for DBM. Both these compounds were frequently mixed with Bt. We have not accessed spray records directly so we have not been able to estimate amounts of each product used.

D. Insecticide rotation

Growers were asked: "In the last 12 months, how often have you used insecticides in rotation on your Brassica crops? Please answer using the words: 'always', 'often', 'sometimes', 'rarely', or 'never'."

Their responses were as follows:

ALWAYS 52%; OFTEN 24%; SOMETIMES 14%; RARELY 8%; NEVER 2%

Details of their often esoteric rotation strategies are still being processed. The task of promoting a rational rotation strategy remains high priority.

Table 6. Percentage of growers using synthetic insecticides for control of Lepidoptera in the last 12 months. (Organophosphates=OP; Synthetic pyrethroids=SP, organochlorines=OC; Carbamates=Car; Phenyl pyrazole=PP)

OP	SP	OC	Car	PP
mevinphos (58%)	permethrin (44%)	Endosulfan (28%)	methomyl (18%)	fipronil (56%)
methamidophos ^T (48%)	alpha- cypermethrin (26%)			
chlorpyrifos ^T (30%)	deltamethrin (18%)			
parathion-methyl ^T (20%)	cyfluthrin (18%)			
diazinon ^T (2%)	lambda- cyhalothrin (16%)			
methidathion ^D (8%)	esfenvalerate (12%)			
prothiofos ^D (2%)	tau-fluvalinate (8%)			

^T = Thioate OP; ^D = Dithioate OP

E. Spray Application

Apart from 1 grower who used a Silvan Turbomiser, all growers used boom sprays. A minority (26%) of the booms were air assisted. Hardie and Goldacres were the dominant manufacturers (81%) in the Western region while Silvan was dominant in the South-East (50%). Overall, these 3 manufacturers had 90% of the market.

Cone nozzles were used by 58% of growers, while 36% used flat-fan nozzles and 6% used both types. Most (70%) growers used plastic nozzles (on average, 20.0 months between changes) while 17% used ceramic nozzles (on average, 28.5 months between changes) and 13% still used brass nozzles (on average, 28.5 months between changes).

Standard calibration of spray rigs was done by 64% of growers, with 12.1 months between calibrations, on average.

Spray records were always kept by 64% of growers (although quality of records could not be assessed). Only 20% of growers either rarely or never kept records.

F. Crop Monitoring

Growers were asked how they decide when to spray their crops. While 84% used some form of monitoring, 90% had a regular spray program that suggested that their monitoring had little influence on their actual decision to spray. Some growers (12%) relied on monitoring only in the low-pressure part of the season. Some 38% used the weather forecast as a guide. This is most likely related to the fine-tuning of timing, e.g. whether to spray today or tomorrow if rain, wind, etc. is forecast.

While most growers [ALWAYS 38%; OFTEN 26%] monitored for pest presence before spraying insecticide, they employed a considerable variety of methods.

Only 29% of growers counted larvae while the remaining 79% only looked for presence or absence of larvae as well as damage. The sampling strategy varied greatly. The median number of plants looked at was 20 (range 100 plants to 1 plant) and the median number of sites inspected was 4 (range from 15 locations to 1).

G. Sources of Information

Growers were asked about their sources of information about pest management (Table 7), their most important sources of information (Table 8) and those issues they considered when deciding which insecticide spray to use (Table 9). The clear message is that the chemical resellers play a vital role in information transfer. This reinforces the need for the project team to work very closely with the resellers in disseminating pest management information arising from the project.

Table 7. Sources of pest management information used by growers.

Information source	no. of growers	%
Chemical reseller	50	100
Own knowledge & experience	43	86
Other growers	35	70
Trade journals & newsletters	29	58
Department of Agriculture	28	56
Spray contractor	2	4
Private consultant	1	2
Sample size (n)	50	

Table 8. Source of pest management information nominated by growers as their most important source.

Information Source	no. of growers	%
Chemical resellers	37	74
Chemical resellers & other growers	1	2
Chemical resellers & own knowledge	2	4
All sources equally important	1	2
Department of Agriculture	1	2
Other growers	2	4
Private consultant	1	2
Own knowledge	2	4
Own knowledge & other growers	1	2
Trade journals and newsletters	2	4
Sample size (n)	50	

Table 9. The percentage of growers which considered the following issues when deciding what insecticide spray to use.

Decision aids	no. of growers	%
Chemical reseller	39	78
Past experience	35	70
Pest type	32	64
Crop stage	23	46
Pest pressure	20	40
Other growers	10	20
Label information	8	16
Withholding period/toxicity	4	8
Department of Agriculture	3	6
Journals and newsletters	2	4
Spray contractor	2	4
Monitoring contractor	1	2
Sample size (n)	50	

H. Non-chemical Pest Management Practices

Growers were asked a series of questions about cultural control methods they may be employing on their properties. Weed control, management of crop residues and rotation with non-*Brassica* crops were all practised commonly (Table 10). However, there is no information on the quality of their implementation of these practices. Nearly all growers are also using transplants from specialist nurseries. More specific practices such as planting seedlings away from old crops and employing a summer break from brassicas were used much less frequently. Protection of beneficials appeared to be only from using Bt, rather than providing refugia.

Table 10. Cultural control / non-chemical pest management practices employed by growers.

Cultural Control	Total	%
Controlling weeds in/around the crop fields	49	98
Ploughing in crop residues after harvest	48	96
Rotating Brassicas with non- <i>Brassica</i> crops	45	90
Using seedlings from specialist nurseries	42	84
Nursery seedlings grown on premises	7	14
Seed used only (radish grower)	1	2
New seedlings away from older crops - sometimes	11	22
New seedlings away from older crops - always	8	16
Summer production reduced/(break) because of DBM	9	18
Summer production break - other reason	6	12
Encouraging naturally present insect predators	6	12
Sample size n	50	

I. Attitudes to Insecticide Resistance

A list of statements about insecticide resistance was read to each grower. They were asked to choose a point on a 1-5 point scale depending on how much they agreed or disagreed with each statement. Their responses are given in Table 11.

Table 11. Grower understanding of insecticide resistance issues.

Statement	Absolutely disagree	←	Uncertain	→	Absolutely agree
1. Resistance means that pests 3 survive spraying		3	7	9	27
2. Resistance is caused mainly by 7 excessive spraying		0	11	11	20
3. Resistance may be slowed down 1 by rotation of insecticides		0	4	10	34
4. Resistance can be slowed down 9 by spraying less often		11	11	5	13
5. Resistance can be slowed down 5 by non-chemical controls		6	9	15	14
6. Pests could develop a resistance 2 to Bt		1	27	8	11

They generally agreed with statements 1, 2, 3 and 5. Many (40%) disagreed with the fourth proposition that resistance can be slowed down by spraying less often, while most were uncertain about whether pests could develop resistance to Bt.

J. Attitudes to IPM

After being read a series of statements about IPM, growers were read a list of reasons some growers have for not using IPM. They were asked to think about their own reasons for not using IPM, and then to choose a point on a 1-5 point scale depending on how much they agreed or disagreed with each statement.

Their responses (Table 12) indicated a great desire for more information (both printed and from growers' nights) and hands-on training, some uncertainties about value of IPM programs and some polarisation between growers keen to pursue IPM programs and growers still relying on full pesticide programs. Certainly there are clear signals for our continued emphasis on improving information flow and training to growers.

Table 12. Grower attitudes to issues relating to IPM adoption.

Statement	Absolutely disagree	←	Uncertain	→	Absolutely agree
1. I don't know about IPM	7	5	15	7	14
2. I don't have hands on training in IPM	5	6	8	6	23
3. I don't have time to spare for IPM	6	9	19	9	5
4. I think it is too risky to use less chemicals	10	6	15	8	9
5. I am happy with existing controls, so why change?	13	6	10	9	10
6. I have lack of advice available to me to set up an IPM program	9	4	10	6	19
7. I want to wait & see other people in the industry use IPM first	14	7	13	6	8
8. I don't want to spend any extra money on pest control	11	4	7	6	20
9. I would like printed information about IPM	0	1	4	6	27
10. I would like to go to an IPM grower night in my area	0	1	6	11	20

9. Insecticide Resistance Monitoring Update. (Nancy Endersby, Peter Ridland and Jingye Zhang, Agriculture Victoria)

A. Screening for permethrin resistance in Tasmanian and Victorian populations of DBM.

Crop 1: Brussels sprouts
 Location: Near Devonport, Tasmania
 Collection date: March, 1998
 Spray history: Crop treated with Ambush® (permethrin)
 Generation tested: F2

Crop 2: Cauliflower
 Location: O'Connors Rd, Werribee South, Victoria
 Collection date: May 1998
 Spray history: Refer to spray records (Sampling property 2)
 Generation tested: F1

METHODS

A leaf dip bioassay after Tabashnik and Cushing (1987) was adopted. Cabbage (*Brassica oleracea* var. *capitata* cv. Green Coronet) leaf discs of 4.5 cm diameter were dipped for 5 s in distilled water solutions of formulated insecticide and hung vertically to dry in a fume hood for 2 h.

The following concentrations of permethrin were used for the susceptible laboratory population (Waite): 3.16, 10, 17.78, 31.62, 56.23, 100, 177.7 ppm and the field collected populations (Devonport and Werribee): 10, 31.62, 56.23, 100, 177.8, 316.2, 1000 ppm. The following concentrations of chlorpyrifos were used for both the susceptible laboratory population (Waite) and the field collected population (Devonport): 31.62, 100, 316.2, 562.3, 1000, 1778, 3162 ppm. Control discs were dipped in distilled water only. Four replicates of each concentration were made.

Discs were placed in 5 cm diameter plastic Petri dishes (Gelman®). Ten third instar *P. xylostella* larvae were placed on to each disc and allowed to feed at 28°C. Mortality was assessed at 48 h. Dead larvae were those which did not move when touched with a paintbrush.

Probit analysis (POLO-PC, LeOra Software) was used to estimate LC₅₀ and slope for each population. The fit of the data to the probit analysis model was measured by χ^2 . Heterogeneity factor (χ^2/df) was used to account for any lack of fit. The index of significance for potency estimation (g) was used to calculate 95% confidence intervals for potency.

RESULTS

<i>Bioassay 1:</i>		Ambush® (permethrin)			Test date:		27 May 1998	
Population	Subjects	Controls	Slope ± s.e.	Heterogeneity	g	χ^2	df	
Waite	280	42	2.30 ± 0.24	2.25	0.10	58.4	26	
Devonport	279	39	1.64 ± 0.20	1.48	0.09	38.4	26	
Population	LC ₅₀	95% confidence intervals		LC ₉₅	95% confidence intervals			
Waite	33.2	24.2 - 44.7		172.1	109.2 - 382.6			
Devonport	75.6	50.3 - 107.6		760.4	433.7 - 1978.2			

Probit analysis of the data showed that parallel slopes could not be fitted for the Waite and the Devonport populations in Bioassay 1. The toxicity (or resistance) ratio for the Devonport population was calculated at LC_{50} (LC_{50} [Devonport]/ LC_{50} [Waite]) (the ratio is different at LC_{95} due to different slopes). Confidence intervals in this non-parallel situation were calculated as described by Robertson and Preisler (1992). Using this method, if the 95% confidence intervals include 1, then the LC_{50} of the Devonport population is considered not significantly different from the LC_{50} of the Waite population ($P=0.05$).

Resistance ratio for permethrin: 2.3 95% C. I.: 1.6 - 3.2

Bioassay 2: Lorsban® (chlorpyrifos) Test date: 3 June 1998

Population	Subjects	Controls	Slope \pm s.e.	Heterogeneity	G	χ^2	df
Waite	280	40	3.60 \pm 0.58	1.46	0.16	38.1	26
Devonport	278	41	2.95 \pm 0.48	1.43	0.16	37.2	26

Population	LC_{50}	95% confidence intervals	LC_{95}	95% confidence intervals
Waite	652.7	464.0 - 825.0	1870.3	1383.9 - 3405.7
Devonport	804.8	546.2 - 1051.0	2908.9	2022.8 - 6118.1

Probit analysis of the data showed that parallel slopes could be fitted for the Waite and the Devonport populations in Bioassay 2. The toxicity (or resistance) ratio and 95% confidence intervals for Devonport is calculated as the reciprocal of the relative potency and confidence intervals provided by the POLO analysis (derived from the parallel slope).

Resistance ratio for chlorpyrifos: 1.3 95% C. I.: 0.9 - 1.8

Bioassay 3: Ambush® (permethrin) Test date: 16 June 1998

Population	Subjects	Controls	Slope \pm s.e.	Heterogeneity	g	χ^2	df
Waite	278	40	2.02 \pm 0.21	1.44	0.07	37.3	26
Werribee	277	40	1.70 \pm 0.19	1.37	0.07	35.8	26

Population	LC_{50}	95% confidence intervals	LC_{95}	95% confidence intervals
Waite	25.3	19.2 - 32.8	165.4	108.2 - 322.3
Werribee	156.5	116.8 - 218.5	1459.7	807.1 - 3925.9

Probit analysis of the data showed that parallel slopes could be fitted for the Waite and the Werribee populations. The toxicity (or resistance) ratio and 95% confidence intervals for Werribee is calculated as the reciprocal of the relative potency and confidence intervals provided by the POLO analysis (derived from the parallel slope).

Resistance ratio for permethrin: 6.1 95% C. I.: 4.2 - 9.2

CONCLUSIONS

1. The Devonport population has a low level of resistance to the synthetic pyrethroid, permethrin, compared with the susceptible Waite population in a leaf dip bioassay.
2. The Devonport population is not resistant to the organophosphate, chlorpyrifos, compared with the susceptible Waite population in a leaf dip bioassay.
3. The Werribee population has a low level of resistance to the synthetic pyrethroid, permethrin, compared with the susceptible Waite population in a leaf dip bioassay.

B. Bioassays of piperonyl butoxide to synergise synthetic pyrethroids for control of SP resistant populations of DBM.

METHOD

(Experiment 1)

A leaf dip bioassay after Tabashnik and Cushing (1987) was adopted. Cabbage (*Brassica oleracea* var. *capitata* cv. Green Coronet) leaf discs of 4.5 cm diameter were dipped for 5 s in distilled water solutions of formulated insecticide and piperonyl butoxide and hung vertically to dry in a fume hood for 2 h.

Field concentrations of five synthetic pyrethroids were tested on a pyrethroid-resistant field-collected population from Queensland (Niemeyer 98). Each pyrethroid was tested alone and in combination with piperonyl butoxide in a ratio of 1:5, SP: Pbo. The concentrations used are shown in Table 1.

Table 1. Concentrations of synthetic pyrethroid insecticides and piperonyl butoxide tested on a diamondback moth population from Queensland 1998.

Insecticide	Product name	Field concentration (ppm)	Piperonyl butoxide (ppm)
Permethrin	Ambush [®]	50.00	250
Esfenvalerate	Hallmark [®]	12.50	62.5
Alpha-cypermethrin	Dominex [®]	50.00	250 & 500
Beta-cyfluthrin	Bulldock [®]	20.00	100 & 200
Deltamethrin	Decis [®] forte	13.75	68.75

Control discs were dipped in distilled water only. Four replicates of each concentration were made.

Discs were placed in 5 cm diameter plastic Petri dishes (Gelman[®]). Ten third instar *P. xylostella* larvae were placed on to each disc and allowed to feed at 28°C. Mortality was assessed at 48 h. Dead larvae were those which did not move when touched with a paintbrush.

(Experiment 2)

A dose-response bioassay with esfenvalerate and piperonyl butoxide was conducted using the leaf disc method described above on a pyrethroid-resistant field-collected population of diamondback moth from Queensland (Niemeyer 98).

The following concentrations of esfenvalerate were used: 56.23, 100, 177.8, 316.2, 562.3 and 1000 ppm. Concentrations of piperonyl butoxide used were five times those used for esfenvalerate. Piperonyl butoxide was tested alone and in combination with esfenvalerate. Control discs were dipped in distilled water only. Four replicates of each concentration were made.

Probit analysis (POLO-PC, LeOra Software) was used to estimate LC₅₀ and slope for each population. The fit of the data to the probit analysis model was measured by χ^2 . Heterogeneity factor (χ^2/df) was used to account for any lack of fit. The index of significance for potency estimation (g) was used to calculate 95% confidence intervals for potency.

RESULTS

(Experiment 1)

Each of the synthetic pyrethroids tested caused low mortality of diamondback moth from the Queensland population (2.5 to 5%) (Table 2). Mortality increased slightly with addition of piperonyl butoxide for three of the pyrethroids, permethrin, alpha-cypermethrin and deltamethrin.

Table 2. % mortality of diamondback moth larvae exposed for 48 h to a range of synthetic pyrethroid insecticides with and without piperonyl butoxide.

Insecticide	Concentration (ppm)	% Mortality		
		-Pbo	+Pbo 5x	+Pbo 10x
Permethrin	50.00	2.5	15	*
Esfenvalerate	12.50	5	5	*
Alpha-cypermethrin	50.00	2.5	15	17.5
Beta-cyfluthrin	20.00	2.5	0	0
Deltamethrin	13.75	2.5	5	*

(Experiment 2)

Piperonyl butoxide alone caused no mortality of diamondback moth larvae at the concentrations tested. The addition of piperonyl butoxide to esfenvalerate reduced the LC₅₀ and LC₉₅ (Table 3), but these concentrations were still many times higher than the field concentration of 12.5 ppm. In an earlier bioassay of the resistant population and a susceptible laboratory population, the LC₅₀ of the susceptible population was 5.2 (3.8 - 6.85) for esfenvalerate. Addition of piperonyl butoxide did not make the resistant population become equivalent to the laboratory population with respect to esfenvalerate susceptibility.

Table 3. LC₅₀ and LC₉₅ of esfenvalerate for a pyrethroid-resistant population of diamondback moth, with and without piperonyl butoxide.

	esfenvalerate	esfenvalerate + Pbo
LC ₅₀ (95% c. i.)	399.9 (294.7 - 593.9)	116.5 (61.7 - 175.7)
LC ₉₅ (95% c. i.)	2292.2 (1257.8 - 7523.8)	903.8 (474.5 - 4721.5)
Slope ± s.e.	2.17 ± 0.26*	1.85 ± 0.25*
Heterogeneity	2.09	2.90
Subjects	240	239
Controls	40	40
G	0.13	0.23
χ ²	37.3	35.8
Df	26	26

*Slopes were parallel.

REFERENCES

- Robertson, J. L. and Preisler, H. K. (1992). Pesticide bioassays with arthropods. CRC Press, Inc., Boca Raton, Florida, USA.
- Tabashnik, B. E. and Cushing, N. L. (1987). Leaf residue vs. topical bioassays for assessing insecticide resistance in the diamondback moth, *Plutella xylostella* L. *FAO Plant Protection Bulletin* 35: 11-14.

10. Summary of Diamondback Moth Project Activities in the Perth Region. (Françoise Berlandier, Agriculture WA)

1. SEASONALITY OF LOCAL POPULATIONS

INTRODUCTION

Prior to this work being done, little quantitative data existed on the activity of WA populations of DBM. The two main areas of *Brassica* production in SW WA are in the Perth Metropolitan area, and in Manjimup, where the focus is on cauliflower production. Field surveys were conducted in these two areas in 1997/98.

In addition, levels of insecticide resistance in local DBM populations has not been monitored except for a few populations sent to Nancy Endersby in 1997. We attempted to test resistance levels to methamidophos and permethrin of five local DBM populations.

MATERIALS AND METHODS

DBM larvae and adults were sampled in *Brassica* crops on 5 horticultural properties within the metropolitan area of Perth on a weekly basis. Properties were surveyed for three cycles (two properties/cycle) between late spring and autumn (Table 1).

Table 1. Details of sites surveyed for DBM in metropolitan region of Perth.

Cycle	Grower	Location	Observation Dates	Crop
I	Anderson	Baldivis (south)	23/10/97 – 24/12/97	Cauliflower
	Tedesco	Wanneroo	23/10/97 – 23/12/97	Chinese Cabbage
II	Trandos (I)	Wanneroo	5/1/98 – 25/2/98	Broccoli
	Calameri	Baldivis	5/1/98 – 10/2/98	Cauliflower
III	Trandos (II)	Wanneroo	25/2/98 – 28/4/98	Broccoli
	White	Mandogalup (south)	25/2/98 – 28/4/98	Cabbage

Moth sampling

Sticky traps were changed weekly. The traps consisted of a piece of card covered with Tactel® and baited with a pheromone lure and sheltered by a cardboard roof suspended from a wooden stake.

Larvae sampling

Every week the crop at each trapping site were inspected and the number and size of DBM larvae were recorded. For the first 4 weeks 50 plants were inspected, then 30 for the next 4 weeks and 20 for the remaining visits. This reduction in numbers of plants counted corresponded with increases in the size of the plants over time.

RESULTS

Moths numbers peaked in late November, decreased over the hotter summer months of December and January, and rose again in February and remained high (up to 400/trap) until sampling ended in April (Fig. 1).

Generally, numbers of larvae in crops peaked in early December, mid-January and again in late March. Most growers sprayed their crops with a range of chemicals and some used cocktails of up to three active ingredients in a spray.

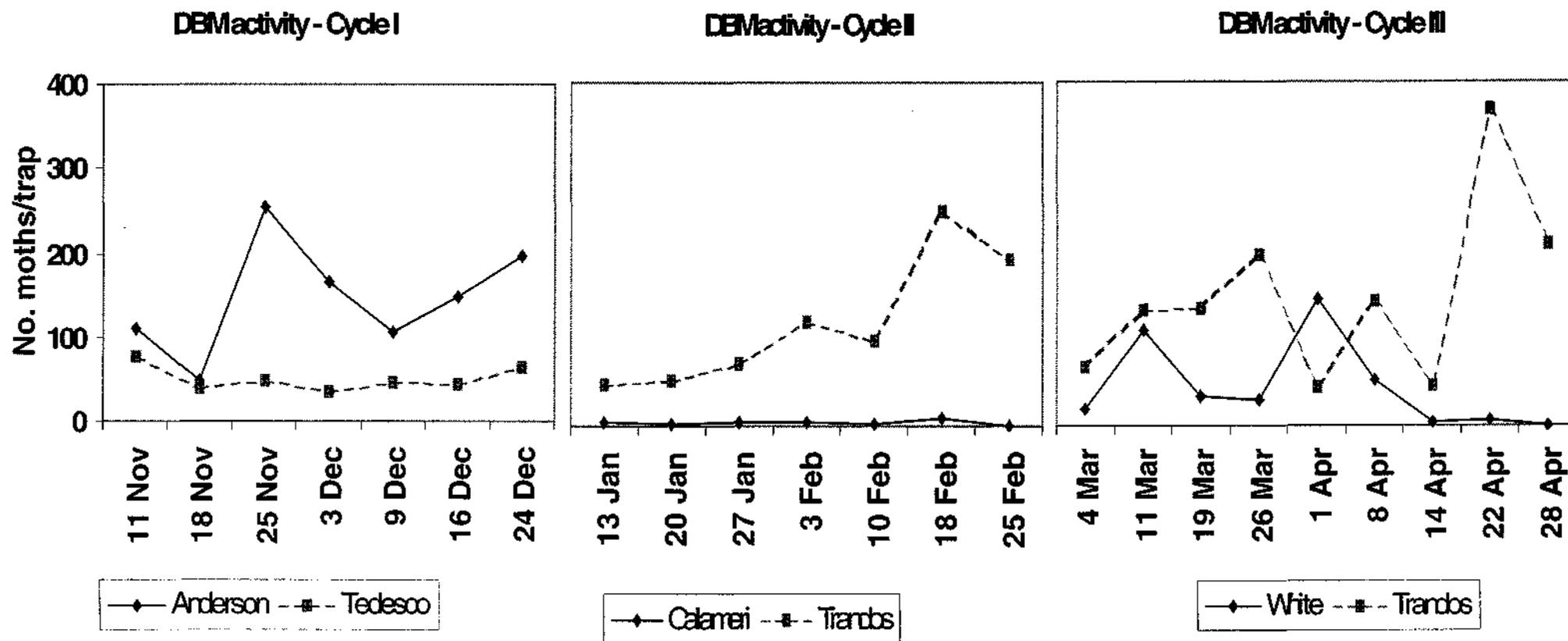


Figure 1. Numbers of DBM moths caught per pheromone sticky trap in *Brassica* crops in metropolitan Perth, November 1997 to April 1998.

2. RESISTANCE BIOASSAYS

Bioassays were conducted to determine levels of resistance in field collected colonies of DBM from WA to two commonly used pesticides, permethrin (Ambush) and methamidophos (Nitofol). These chemicals were chosen to enable comparisons with similar bioassays conducted in Victoria by Nancy Endersby. Bioassays were carried out on colonies collected from Perth Metropolitan area (Anderson,

White, Mariotti, Trandos) and from Manjimup (Phillips), located some 260 kms South of Perth. Larvae at the late 2nd instar stage were used in the bioassays. DBM colonies were raised in controlled environment cabinets on canola plants. Each test included a susceptible population obtained from Nancy Endersby (originally WAITE colony from SA).

Bioassay Method

Each bioassay was completed for the susceptible colony and for one or more of the field (experimental) colonies. The selected chemical (commercial formulation) was mixed to a concentration of 100,000 PPM, diluted to 1000 PPM and then diluted again to make a range of concentrations. Solutions were freshly made each time a bioassay was done. Cabbage leaves were cut into 7.5 cm discs and dipped into the chemical for five seconds. Each concentration was replicated five times. After the leaves were dipped they were hung in a fume hood or in the open air next to an exhaust fan (permethrin only) to dry for 2 h. Leaf discs were then placed in individual Petri dishes and 8-12 larvae from the DBM colonies tested were placed with the cabbage leaf. Petri dishes were labelled and sealed with Parafilm to prevent larvae from escaping. The Petri dishes were then incubated for 48 hours at 28 ° C. After 48 hours the number of survivors from each Petri dish was counted and recorded. If resistance was determined the bioassay was repeated with higher levels of the pesticide to determine the level of resistance.

Results

A total of 17 bioassays were conducted, and reliable results were obtained for methamidophos to all five colonies, and for three colonies for permethrin (Table 2).

Resistance to methamidophos was low in four populations and ranged from 2.2 to 3.4 times greater than the susceptible laboratory-reared population. The fifth population (White) was not found to be resistant to methamidophos.

For resistance to permethrin, reliable bioassay results were obtained for 3 of the populations, and resistance ranged from 1.2 to 6.4 times greater than the susceptible laboratory-reared population.

Table 2. Summary of resistance levels found in five populations of DBM in Western Australia to methamidophos and permethrin.

Colony	Methamidophos		Permethrin	
	LD50 (PPM)	RR*	LD50 (PPM)	RR
Susceptible (Waite)	56.45		13.28	
Anderson	138.65	2.5	results unreliable	
Mariotti	189.34	3.4	16.33	1.2
White	42.52	susc	85.51	6.4
Phillips	124.94	2.2	55.20	4.2
Trandos	157.86	2.8	results unreliable	

*LD50 for population/ LD50 for Waite population.

Acknowledgment

Anita Lyons, Linnet Cartwright, Rebecca Whittemore provided technical assistance (Perth Metro) This study was funded by Agriculture WA (\$35,000) and by HRDC (\$5,800).

11. Survey for resistance to *Bacillus thuringiensis* in field populations of *Plutella xylostella* L. in Australia. (Mahmood Ahmed and Rick Roush, University of Adelaide and J.D. Tang and Tony Shelton, Cornell University, USA)

(The study reported in this paper forms part of a PhD study by Mr Mahmood Ahmed and is not part of the HRDC National DBM Project.)

Diamondback moth (DBM), *Plutella xylostella* (L.) populations were surveyed for their responses to *Bacillus thuringiensis* (Bt) subsp. *kurstaki*. Leaf-dip bioassays were employed to test twelve field populations from *Brassica* growing areas around Australia (Table 1). The LC₅₀s of Bt subsp. *kurstaki* on the field populations from South Australia, Victoria, Western Australia and Queensland ranged from 1-3-, 3-5-, 2-3-, and 31-110-fold higher respectively, than the LC₅₀ of a lab susceptible population (Table 2). The populations detected as resistant from Queensland were further selected with Bt endotoxins repeatedly. This lab selected population did not survive when bioassayed on transgenic broccoli compared to a standard lab resistant population (87% survival) at Cornell University. Results from these bioassays suggest that DBM populations in three out of four states are still susceptible, but that in at least some areas of Queensland, resistance may already be affecting control and the potential may be high for further evolution of resistance against Bt toxins. These results are highly relevant to devising improved resistance management strategies for Bt endotoxins against DBM as well as providing base line data to detect any change in the susceptibility of DBM in future monitoring programs.

Table 1. Collection sites of DBM populations in Australia.

Collection Site	Host Plant	Collection Time
<i>South Australia</i>		
Two Wells	Cabbage, <i>Brassica oleracea</i> var. <i>capitata</i>	1996
Naime	Brussels Sprouts, <i>B. oleracea</i>	1997
Piccadilly	Wild Radish, <i>Rhaphanus raphanistrum</i>	
	Wild Mustards, <i>Sinapis alba</i>	1997
Virginia	Cabbage, <i>B. oleracea</i> var. <i>capitata</i>	
	Radish, <i>Rhaphanus raphanistrum</i> var. <i>gemmifera</i>	1997
<i>Victoria</i>		
Knoxfield	Cabbage, <i>Brassica oleracea</i> var. <i>capitata</i>	1996
Myrtleford	Cabbage, <i>Brassica oleracea</i> var. <i>capitata</i>	1996
<i>Western Australia</i>		
Manjimup	Canola, <i>Brassica juncea</i>	1998
Wanneroo	Broccoli, <i>Brassica oleracea</i> var. <i>italica</i>	1998
Mandogalup	Cabbage, <i>Brassica oleracea</i> var. <i>capitata</i>	1998
<i>Queensland</i>		
Gatton-1	Cauliflower, <i>Brassica oleracea</i> , var. <i>botrytis</i>	1996
Gatton-2	Cauliflower, <i>Brassica oleracea</i> , var. <i>botrytis</i>	1996
Gatton-3	Cauliflower, <i>Brassica oleracea</i> , var. <i>botrytis</i>	1996
<i>Lab Population</i>		
Two Wells	Cauliflower, <i>Brassica oleracea</i> , var. <i>botrytis</i>	1995

Table 2. Concentration-mortality responses of DBM populations to Btk.

Population	n ^a	Slope ± SE (95 % CL)	LC ₅₀ mg (AI/litre) (95 % CL)	LC ₉₀ mg (AI/litre)	RR ^b
S. Australia					
Two Wells	360	0.87 ± 0.14	0.03(0.01 - 0.07)	1.01 (0.60 - 2.14)	3
Nairne	300	0.64 ± 0.22	0.02 (0 - 0.16)	1.49 (0.12 - 3.86)	2
Virginia	318	0.47 ± 0.08	0.01 (0 - 0.03)	4.79 (1.60 - 32.68)	1
Piccadilly	401	0.417 ± 0.07	0.01 (0 - 0.02)	9.68 (3.01 - 70.43)	1
Victoria					
Knoxfield	120	1.31 ± 0.44	0.03 (0-0.07)	0.29 (0.15 - 1.39)	3
Myrtleford	120	0.61 ± 0.19	0.05 (0-0.17)	5.51 (1.60 - 233.63)	5
W. Australia					
Manjimup	168	0.95 ± 0.24	0.03 (0 - 0.07)	0.62 (0.32 - 2)	3
Wanneroo	96	0.57 ± 0.21	0.03 (0 - 0.14)	4.9 (1.23 - 1284)	3
Mandogalup	264	0.62 ± 0.14	0.02 (0 - 0.55)	1.96 (0.90 - 7.89)	2
Queensland					
Gatton-1	300	0.81 ± 0.12	0.31 (0.14 - 0.53)	12.03 (5.98 - 38.81)	31
Gatton-2	294	0.81 ± 0.11	1.10 (0.62 - 1.87)	41.88 (17.75 - 17.46)	110
Gatton-3	220	0.67 ± 0.13	0.57 (0.24 - 1.09)	47.26 (14.03 - 625)	57
Lab Population	260	0.81 ± 0.15	0.01 (0 - 0.01)	0.90 (0.42 - 2.43)	1

^a number of larvae tested^b Ratio is LC₅₀ divided by the lab susceptible population

12. Tasmanian Brassica Pest Issues. (Lionel Hill, DPI, Water and Environment, Tasmania)

1. Tasmania produces about 5% of Australian major brassicas (but 50% of swedes and turnips).
2. Production is primarily for processing by freezing for the Australian market e.g. Fresh market cabbage is a very minor crop whereas broccoli, cauliflower and sprouts for freezing are important. Each has its unique pest tolerance derived from processing methods. Tolerances are very low.
3. Extension is relatively simple because the industry is highly organised through the processing factories complemented by a highly centralised private advisory sector. Once a few key advisors are persuaded major changes can be rapidly implemented as was recently done with a cessation of spraying for potato moth. Expensive baseline and monitoring surveys of grower practices are not necessary.
4. One of two processing companies was to circulate the QDPI pest booklet to all its growers.
5. Crop monitoring is done mostly by a handful of commercial agronomists employed by the growers or the processing factory. Again this makes extension simple once these people are persuaded. Their cooperation will be facilitated by local demonstration.
6. The relative importance of local over-wintering versus immigration from the mainland is not understood. The date and size of spring immigrations may be a major determinant of annual pest pressure e.g. by greatly reinforcing local populations in certain years. Immigration may also reduce biological control and change resistance levels.
7. Dispersal from fodder to food crops is of interest especially in the southern growing area.
8. High SP resistance levels have been recorded in autumn populations from frequently sprayed crops.
9. Parasitoids recorded since 1940 are *Diadegma semiclausum*, *D. rapi*, *Diadromus collaris*, *Cotesia plutellae*, *Apanteles ippeus*, an indeterminate pteromalid and an eulophid wasp, the latter two probably being native hyperparasites. *Brachymeria phya* not recorded. Their current distribution and impact has not been quantified.
10. The prime growing district has an unusual maritime cool temperate climate in which maxima and minima are strongly restricted. For perhaps 100 days per annum maximum temperatures do not exceed the developmental thresholds of 13 and 11.5 C assumed in the DARABUG growth simulation model for second and third instar *Plutella* larvae. Nevertheless some good correlations for a spring generation have been obtained between DARABUG and light trap data.
11. Generation times are not known but may be longer than anticipated from mainland experience e.g. potato moth parallel.
12. For potato moth the dense shaded irrigated structure of Tasmanian crops greatly influences local dispersal in a way not apparent on the mainland. Perhaps Tasmanian Brassica crops have unique features influencing dispersal. Edge effects may be significant.

13. An Evaluation of the Darabug Model in Predicting the Development of DBM in Cool Temperate Conditions. (Jianhua Mo and Greg Baker, SARDI)

INTRODUCTION

Prediction of the timing of pest development in the field can assist with pest management. At the request of Lionel Hill (DPIF, Tasmania) a study was undertaken in Adelaide during the winter of 1998 (26 June to 14 September) to assess the ability of the DARABUG model to accurately predict the developmental times of the life-stages of DBM under cool-temperate conditions. The temperature profile of the Adelaide region during winter closely resembles that of the *Brassica* vegetable growing region of northern Tasmania during spring and autumn (Table 1).

Table 1. The time interval (dd/mm) for the best five day-degree (DD) matches of four Tasmanian *Brassica* growing districts (based) to that at Waite Institute, Adelaide during 26 June and 14 September, 1998 (521.35 DD). (The Tasmanian DD estimates are calculated using on >10 years composite temperature records for each site. The percentage difference between the DD for the Tasmanian data-set and the Waite is given in parentheses.)

B u s h y		C r e s s y	
9 / 0 3 ~ 2 8 / 0 5	(0 . 1 %)	2 2 / 0 9 ~ 1 1 / 1 2	(0 . 0 %)
1 4 / 0 9 ~ 3 / 1 2	(0 . 3 %)	6 / 0 3 ~ 2 5 / 0 5	(0 . 5 %)
1 3 / 0 9 ~ 2 / 1 2	(0 . 7 %)	7 / 0 3 ~ 2 6 / 0 5	(0 . 9 %)
1 0 / 0 3 ~ 2 9 / 0 5	(1 . 1 %)	2 3 / 0 9 ~ 1 2 / 1 2	(1 . 1 %)
1 5 / 0 9 ~ 4 / 1 2	(1 . 3 %)	2 1 / 0 9 ~ 1 0 / 1 2	(1 . 3 %)
F o r t h		G r o v e	
2 3 / 0 9 ~ 1 2 / 1 2	(0 . 5 %)	6 / 0 3 ~ 2 5 / 0 5	(0 . 1 %)
2 2 / 0 9 ~ 1 1 / 1 2	(0 . 6 %)	2 0 / 0 9 ~ 9 / 1 2	(0 . 2 %)
1 6 / 0 3 ~ 4 / 0 6	(0 . 7 %)	1 9 / 0 9 ~ 8 / 1 2	(0 . 7 %)
1 7 / 0 3 ~ 5 / 0 6	(0 . 7 %)	7 / 0 3 ~ 2 6 / 0 5	(1 . 1 %)
2 1 / 0 9 ~ 1 0 / 1 2	(1 . 6 %)	2 1 / 0 9 ~ 1 0 / 1 2	(1 . 2 %)

METHODS

Six potted cabbage plants, with a cohort of approximately 1,000 newly-laid eggs (± 6 hours), were placed outdoors at the Waite Institute on 26 June 1998. An open cover of clear plastic was suspended approximately 1 m above the plants to protect them from the rain. A UNIDATA data logger fitted with 2 thermistor probes was used to record the temperature on the lower surface of one of the cabbage leaves and in a Stevenson screen.

The stage of development of a representative sample of the DBM population was regularly assessed. The daily temperature maxima and minima recorded for each sensor were entered into the DARABUG model to obtain the predicted times to each successive life-stage.

RESULTS

The daily maxima and minima temperature profiles for the Stevenson screen and lower-leaf surface are presented in Figure 1.

The observed time of development of the DBM generation (and of egg to 3rd instar, 4th instar and pupa) in this study was reasonably well predicted by the DARABUG model (Figure 2). The model under-estimated the development time when the lower-leaf temperature records were used and over-estimated this time when the Stevenson screen records were used. However the model's prediction of

the developmental time of the individual life-stages was generally poor, and the worst fit usually occurred with the Stevenson screen temperature records (Figure 3). Because these individual life-stage errors tended to counter each other, the overall agreement with the observed generation time was achieved. It appears that the model's parameter estimates for the developmental rate of the individual life-stages may require some revision.

CONCLUSIONS

With lower-leaf temperature data, the model predicted well the development time from egg to 3rd instar, 4th instar, pupa and moth stage (error <10%). Ambient (Stevenson screen) temperature data generally resulted in an overestimation of the development time.

The model predictions of stage-specific time were not satisfactory, with relative errors up to 114%. The discrepancies were more severe with the ambient temperature data.

The results may apply to spring and autumn situations in Tasmania.

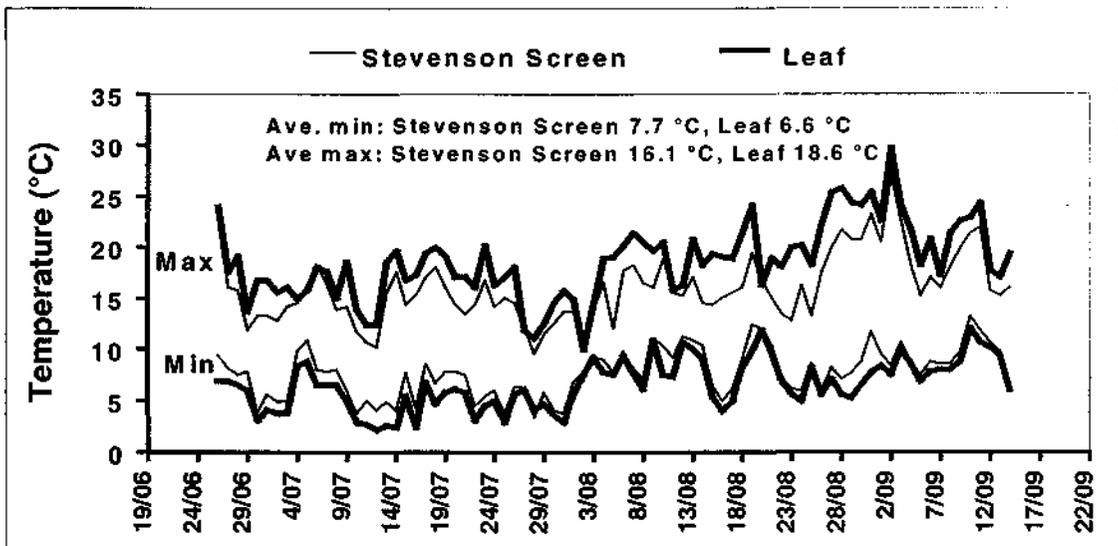


Figure 1. Daily maximum and minimum temperatures recorded by the Stevenson screen and lower-leaf surface thermistor probes during the 26 June to 14 September 1998 experiment.

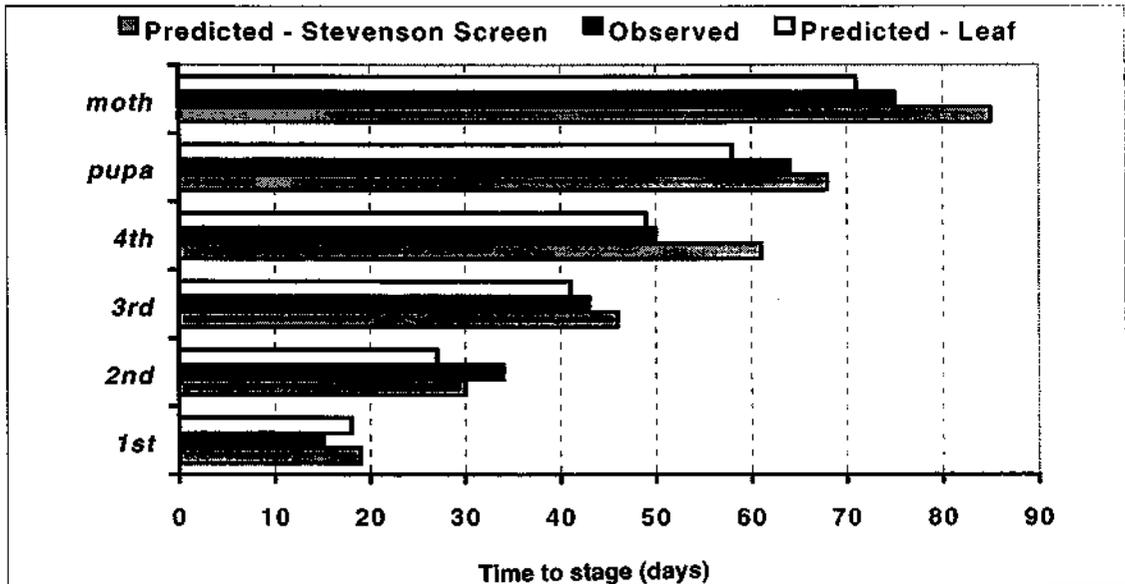


Figure 2. Development time (days) from egg to successive stages of DBM developing from 26 June to 14 September, 1998 on outdoor potted cabbage plants, Waite Institute, Adelaide.

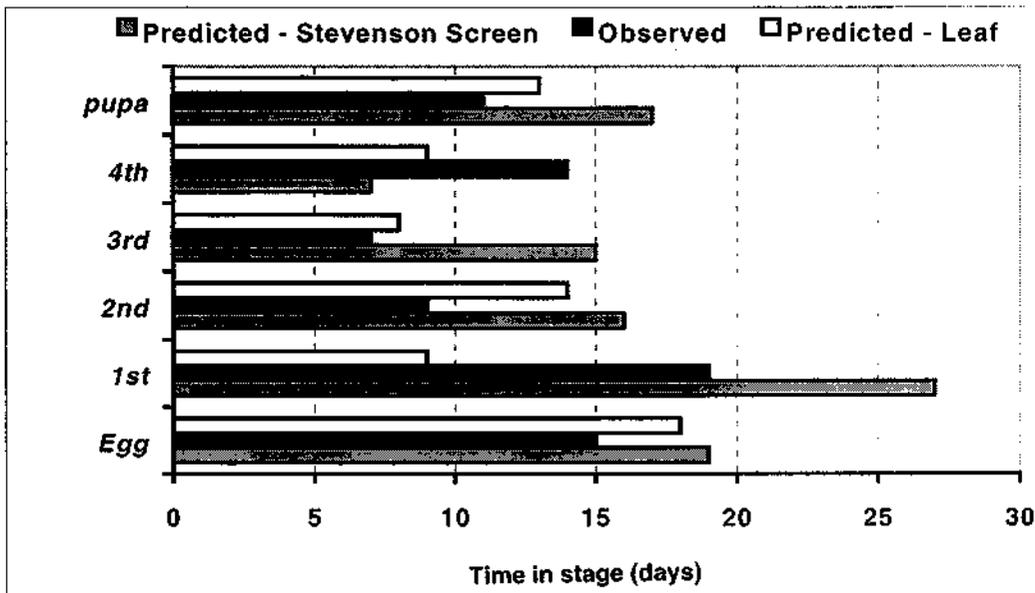


Figure 3. Development time (days) of successive stages of DBM developing from 26 June to 14 September, 1998 on outdoor potted cabbage plants, Waite Institute, Adelaide.

14. Evaluation of a New Pheromone Blend as a Mating Disruptant for Control of the Diamondback Moth *Plutella xylostella*. (Richard Vickers, CSIRO Entomology)

Introduction. Mating disruption using a ca 1:1 ratio of Z11-16 OAc: Z11-16 ALD dispensed from polyethylene tubing has been shown in several trials to be effective as a technique for controlling diamondback moth (DBM) (e.g. Ohno *et al.*, 1992; McLaughlin *et al.*, 1994, Mitchell *et al.* 1997). However the amount of pheromone needed for effective disruption has ranged from 250g to 1000 g of active ingredient/ha. and the technique is thus considered uneconomic for many growers.

The need for such large quantities of pheromone gave rise to suspicion that the pheromone blend was incomplete. Gas chromatograph analyses of DBM pheromone glands (Rumbo, unpublished) showed that there was an additional component which, when added to the two component blend, significantly improved trap catch. This 3-component blend was then evaluated in a trial to assess its efficacy as a mating disruptant in comparison with a commercially-available 2-component disruptant.

Materials and methods. Trial plots. Five plots, each measuring 30 m x 30 m and at least 150 m apart, were planted to broccoli on 22-23.9.97 at the Queensland Department of Primary Industry's Gatton Research Station. The plots were separated either by fallow ground or non-cruciferous crops (Fig. 1).

Pheromone treatments

1. CSIRO blend dispensed at rate equivalent to 125 g/ha (1 replicate);
2. Commercial blend dispensed at rate equivalent to 250 g/ha (1 replicate);
3. Commercial blend dispensed at rate equivalent to 125 g/ha (1 replicate);
4. Control (2 replicates)

The component identified by CSIRO was dispensed from 2.5 m-long 'strings' of polyethylene tubing, placed immediately adjacent to 2.5 m-long strings of the commercial 2-component blend (Shin-Etsu, Japan). Together these two strings constituted the CSIRO blend. The commercial blend was released from either 5 m or 2.5 m-long strings depending upon the amount of pheromone to be dispensed. In all pheromone-treated plots there were 18 dispensing stations, distributed as shown in Fig 2, at which the strings were attached at crop height to wooden stakes.

Pheromone traps (a) Pre treatment period: (30.9.97-26.11.97; 58 days). Before the pheromone treatments were put in place, all plots were monitored with pheromone traps (5/plot) baited with the 3-component blend to provide a measure of population levels. Catches were recorded and removed weekly, liners and baits were replaced every 4 weeks and the traps every 8 weeks.

(b) Treatment period. (27.11.97 - 8.1.98; 44 days). Maintained as previously described.

Incidence of mating at mating tables Once each week one or two (depending upon numbers available) 3 d-old virgin females were placed on each mating table (4/plot) late in the afternoon, collected the following morning and dissected to determine mating status. The presence of a spermatophore was taken to indicate that mating had taken place.

Crop damage Not assessed. For reasons associated with late failure to have the CSIRO blend formulated in a commercial dispenser and the subsequent need to load the dispensers ourselves, the treatments were applied some 6 weeks later than scheduled. By this time substantial populations of DBM had developed in all blocks and differences between treatments would have been difficult to demonstrate.

Data analyses. *Pheromone trap catch:* Separate analyses were carried out for the pre-treatment and treatment periods. Following an analysis of variance on a reciprocal transformation of the data, Duncan's Multiple Range test (DMR) was used to determine the significance of differences between means. Trap catch suppression was determined according to the following formula:

$$\% \text{ mating disruption} = \frac{\text{mean catch in control traps}^* - \text{mean catch in treated traps}}{\text{mean catch in control traps}} \times 100$$

* The value for the control plot with the lowest catch was used in these calculations, thus providing a conservative estimate of suppression.

Incidence of mating: The proportion of females mating was determined as a simple % of the total number of females placed on the tables for each treatment.

Results Pheromone traps (a) Pre-treatment period. Significantly more moths were caught in the plot later designated Control 2 than were caught in the other plots (DMR test, $P < 0.05$; Table 1). Mean catches in the other blocks were not significantly different from one another.

(b) Treatment period. Traps in the block treated with 250 g/ha of the 2-component blend caught significantly fewer moths than all other treatments. There was no significant difference between mean catch in the 2-component and 3-component blends applied at 125 g/ha, but both treatments caught significantly fewer moths than either of the control blocks (Table 1).

Table 1. Mean pheromone trap catch during the pre-treatment and treatment periods. Means within a column followed by the same letter are not significantly different ($P < 0.05$; DMR test).

Treatment	Mean catch/trap/day		% suppression
	Pre-treatment	Treatment	
2 component - 250 g/ha	0.88 a	0.06 a	94.2
2 component - 125 g/ha	0.92 a	0.22 b	78.8
3 component - 125 g/ha	0.86 a	0.28 b	73.1
Control 1	0.98 a	1.04 c	
Control 2	1.56 b	2.14 c	

Incidence of mating at mating tables. A clipped wing male was recovered from one table on 27 November and from two tables on 2 December. This raises doubts about the validity of the data on those dates because of the possibility that males could have mated with any of the females kept in the holding cage prior to their placement on the tables and/or with the female placed on the same table as the male. All data from these dates has been omitted.

Table 2. Incidence of mating of clipped-wing females placed on mating tables.

Treatment	No. fem. out	No. fem. recov.	No. fem. mated	% mated
2 component - 250 g/ha	27	6	0	0.0
2 component - 125 g/ha	27	4	1	25.0
3 component - 125 g/ha	27	10	3	30.0
Control 1	27	9	3	33.3
Control 2	27	9	4	44.4

Discussion/recommendations. On the evidence provided by the pheromone trap catches, there is little point in pursuing the 3-component blend as a mating disruptant. The efficacy of the blend was not significantly different from the 2-component blend when both were applied at 125g/ha (i.e. half the 'normal' rate) and it was significantly inferior to the 2-component blend when the latter was applied at 250g/ha. Suppression of trap catch when the 2-component blend was applied at the full rate was substantial (94% and 97% compared with Controls 1 and 2 respectively). This latter result warrants further evaluation in trials that monitor crop damage and levels of mating as well as trap

catch suppression. (Note that in the present trials so few females provided useable data that little weight should be given to the mating table studies.)

In general terms, crops planted in open fields are likely to be more windswept than, for example, orchards, where the trees provide a buffer against wind and introduce turbulence within the orchard boundaries. All other factors being equal, the distribution of atmospheric pheromone within field crops is thus likely to be less homogenous than it would be within orchards. Clearly dispenser distribution patterns will influence homogeneity and it is possible that the pattern used in these pilot studies provided better pheromone coverage than would have been obtained had dispensers been placed, as recommended, in rows 10 m apart. If further mating disruption studies are envisaged, the effects of dispenser distribution should be assessed.

Although no advantage in using the 3-component blend for mating disruption could be demonstrated, the blend has proved superior to the 2-component blend as a bait within traps. This superiority should be exploited in any evaluation of techniques to disseminate pathogens via pheromone traps for DBM control, where clearly the more males that are attracted to the traps, the greater the prospects for successful dissemination of the pathogen.

References

Ohno, T., T. Asayama & K. Ichikawa, 1992. Evaluation of communication disruption method using synthetic sex pheromone to suppress diamondback moth infestations. In: Talekar, N.S. (ed) Diamondback moth and other crucifer pests: proceedings of the second international workshop, Tainan, Taiwan, 10-14 Dec 1990. AVRDC Publication No. 92-368. 603 pp.

McLaughlin, J.R., E.R. Mitchell & P. Kirsch, 1994. Mating disruption of diamondback moth (Lepidoptera: Plutellidae) in cabbage: reduction of mating and suppression of larval populations. *J. Econ. Entomol.* 87: 1198-1204.

Mitchell, E.R., G.Y. Hu, J. Okine & J.R. McLaughlin, 1997. Mating disruption of diamondback moth (Lepidoptera: Plutellidae) and cabbage looper (Lepidoptera: Noctuidae) in cabbage using a blend of pheromones emitted from the same dispenser. *J. Entomol. Sci.* 32 (2): 120-137.

APPENDIX 3 to Final Report
Horticultural Research and Development Corporation
Project VG97014

**Advancing the integrated management of
diamondback moth (DBM) in *Brassica*
vegetables (July 1997-June 2000)**



Project Workshop,
Waite Campus, Adelaide,
28th - 29th July 1999

Horticultural Research and Development Corporation

Project VG97014: Advancing the integrated management of diamondback moth (DBM) in *Brassica* vegetables (July 1997-June 2000).

Project Workshop, Waite Campus, Adelaide, July 28-29, 1999.

1. INTRODUCTION

The second Workshop convened as part of the national HRDC project on Diamondback Moth management was held in Adelaide from July 28-29 1999. The purpose of the meeting was to foster an exchange of ideas between the national project team, other DBM researchers and vegetable *Brassica* growers and to provide a forum for a review of the Project's progress, a reassessment of the Project's priorities and to plan a submission for a second project.

This report documents the participants, the agenda, the presentations, the planning discussions and the key recommendations that took place at the Workshop.

2. PARTICIPANTS

Mr Michael Badcock, HRDC *Brassica* grower representative, Forth, Tasmania
Mr Greg Baker, South Australian Research and Development Institute
Ms Françoise Berlandier, Agriculture Western Australia
Ms Anita Chennell, Agriculture Victoria, Knoxfield
Mr John Cranwell, HRDC *Brassica* grower representative, Nairne, South Australia
Mr John Duff, QLD Horticultural Institute
Mr David East, HRDC *Brassica* grower representative, Manjimup, WA
Ms Nancy Endersby, Agriculture Victoria, Knoxfield
Mr Craig Feutrill, SA Vegetable Industry Technology Transfer Coordinator
Ms Julia French, DPIWE Tasmania
Dr Mike Keller, University of Adelaide
Mr Kon Koroneos, HRDC *Brassica* grower representative, Werribee South, Victoria
Mr Jeff McSpedden, HRDC *Brassica* grower representative, NSW
Dr Jianhua Mo, South Australian Research and Development Institute
Dr Peter Ridland, Agriculture Victoria, Knoxfield
Dr Rick Roush, University of Adelaide
Ms Emily Tee, Agriculture Victoria, Knoxfield
Dr Richard Vickers, CSIRO Division of Entomology
Assoc. Prof. Myron Zalucki, University of Queensland

3. FACILITATOR

Ms Pam Wood

4. APOLOGIES

Mr Leigh James, NSW Agriculture

5. AGENDA

Wednesday 28th July Progress To Date	
09:15 am:	Welcome and Introduction Project reports and Discussion
09:30 a.m.	Nancy Endersby & Peter Ridland - Crop Scouting in Victoria 1998/99
09:50 a.m.	Jianhua Mo - Sampling
10:10 a.m.	Françoise Berlandier - DBM & parasitoid activity in crucifer crops in Western Australia
10:30 a.m.	Jianhua Mo - Local dispersal of diamondback moth
10:50 a.m.	Morning Tea
11:10 a.m.	Leigh James - <i>Brassica</i> IPM Handbook
11:30 a.m.	Julia French - Promoting <i>Plutella</i> IPM in Tasmania
11:50 a.m.	Peter Ridland & Nancy Endersby - Insecticide resistance update
12:10 p.m.	Jianhua Mo - Testing of 5 new insecticides for their efficacy against diamondback moth and their impact on some beneficials
12:30 p.m.	Lunch
1:30 p.m.	Nancy Endersby & Peter Ridland - Oviposition trials
1:50 p.m.	Richard Vickers - 1. 'Proof of concept' trials to evaluate the use of <i>Zoophthora radicans</i> for DBM control. 2. A lure and kill system for DBM.
2:10 p.m.	John Duff - Achievements of previous ACIAR project
2:30 p.m.	Myron Zalucki - New ACIAR project
2:50 p.m.	Geoff Furness - Improving the cost-efficiency of spraying for pest and disease control
3:10 p.m.	IPM Research to Practice for Brassicas - Anita Chennell & Emily Tee
3:30 p.m.	Afternoon Tea
3:50 p.m.	Examination of Key Issues in DBM management in Australia (all participants). This will establish key areas of discussion for Day 2. Facilitator: Pam Wood
5:30 p.m.	Close Workshop Dinner: Edinburgh Hotel

Thursday 29th July 1999: Diamondback moth in Australia - the challenges	
09:00 a.m.	Session 1 Key Issues
10:45 a.m.	Morning Tea
11:00 a.m.	Session 2 Key Issues
12:30 p.m.	Lunch
1:30 p.m.	Session 3 Action plans
3:30 p.m.	Afternoon Tea
4:00 p.m.	Concluding Session - The Way Forward
4:30 p.m.	CLOSE

6. PRESENTATIONS

The papers presented at the Workshop are reproduced in Appendix 1.

7. DISCUSSION & RATING OF KEY ISSUES IN DBM MANAGEMENT BY GROWERS (G) AND RESEARCHERS (#) (each participant was given 5 votes) Possible Project Options for July 2000 - June 2003

I. DISPERSAL

- Short range
- Male and female
- Long range (canola, etc.) (#)
- Chemical markers for DBM (#)
- Sort distance dispersal studies to be completed...lead on to long distance migration (GGG#####)

II. IRM

- Resistance Monitoring (AIRAC) (G)
- Maintain and promote IRM strategy (G)
- Resistance levels should be continually monitored (GG#####)

III. PROMOTING CROP SCOUTING

- Pest ID courses for growers and crop scouts (G#####)
- Refine an egg sampling method (##)
- Monitoring: Refining of existing models (#####)

IV. EXTENSION

- Resellers (G#####)
- Grower education (GG#####)
- Chemical use

V. NATURAL ENEMIES

- On-farm assessment of natural enemy impact (G#####)

VI. ADULT INSECTICIDES

- Screening registered chemicals for adulticidal DBM activity (G####)

VII. SPEEDLINGS

- Use of speedlings to spread fungus and parasitoid agents (GGGGGG##)

VIII. CULTIVAR SUSCEPTIBILITY

- (G####)

SUGGESTIONS NOT TAKEN UP, ALREADY BEING DONE BY SOMEONE ELSE OR PUT ON HOLD

- Surfactants - increase efficacy
- Monitoring of moth numbers - value to industry? (G)
- Better spray systems (funding for new project?)
- Behaviour modifiers - pheromones, oviposition deterrents (review)
- Host plant resistance

All *Plutella* research must consider other pests.
Relevance to QA?

8. ACTION PLANS

OPTION: PROMOTION OF CROP SCOUTING (Nancy & Mo)

STRATEGY: CURRENT & FUTURE PROJECT AND RtP

OBJECTIVE: COMMERCIAL ADOPTION OF IPM

ACTIVITY	WHAT?	WHO?	WHERE?	WHEN?	FUNDS
Pest ID courses	Component of RtP workshop	RtP	All states	Now 1999-2001	HRDC & workshop fees
Crop Scout Training	i) Training of growers/ employees, advisers	NE, KK	VIC	Now →	HRDC & workshop fees
	ii) Training of commercial crop scouts	?	All states	Now →	HRDC & workshop fees
Gather scouting data to refine data collection method	Receive and compile data from trained scouts	NE, KK	VIC	Now →	HRDC & workshop fees
		?	All states		

OPTION: INSECTICIDE RESISTANCE MANAGEMENT (Peter & Nancy)

STRATEGY: Develop and promote an effective insecticide resistance management strategy

OBJECTIVE: Utilise all known methods of insect control to develop measures to minimise the build-up of insect resistance to any one insecticide product

ACTIVITY	WHO?	WHERE?	FUNDS
1. Monitoring resistance levels in a population from each state	AgVIC	National	AIRAC - HRDC
2. Regular consultation with all interested parties to update regional strategies in line with availability of new chemistries and field performance	Growers, resellers, AIRAC, researchers	Each state - coordinated by AgVIC	HRDC

OPTION: DISPERSAL

Short-distance dispersal

- To assess female movement patterns
 Method: Light trapping/ rubidium experiment (SA)

- To assess dispersal patterns in disrupted environment (harvest crops) (SA)

Long-distance dispersal

- To assess contribution of alternative host sources to DBM hort. populations in spring
- Intensive spring sampling of vegetable crops to age-structure DBM population (adult trapping) (SA)
- Chemical markers (SA? VIC?)
- Insecticide resistance profile (SA, VIC)
- Females - mated or virgin? (SA)
- (?? Queensland autumn migration?)

OPTION: ADOPTION (rather than EXTENSION)

OBJECTIVE: Increase adoption of IPM strategies that are developed by this project

STRATEGY: To use a variety of communication strategies to promote awareness and adoption of IPM strategies. The effect of these strategies will be measured.

- ACTIVITIES:**
1. Develop links and participation in the 'Research to Practice' project
 2. Publication - commercial sponsors
 - Posters
 - Video
 - Manual
 - Newspapers/magazines "Good Fruit and vegetables"
 - Area specific
 3. Field days (mornings) - bring in the experts
 4. Road shows - bring in the experts
 5. Growers' groups
 6. Coordinate, develop and review strategy

SUGGESTION: Apply for funding to appoint Industry Development Manager

OPTION: SPEEDLINGS

STRATEGY: To use speedlings as a carrier to disseminate insect pathogens and parasitoids

OBJECTIVE: Develop and monitor ways and means to maximise methods of infecting or coating speedlings with either insect pathogens or parasitoids to disrupt pest populations

ACTIVITIES:

1. To investigate/ create ways to infect or develop media so as to utilise brassica speedlings at transplant stage to disseminate insect diseases and parasitoids.
2. In the short term, conduct trials on a small scale to see if it is possible to use speedlings as a carrier of insect diseases and parasitoids and the length of period of infection that they can carry.
3. If this is successful, broaden out into limited field trials
4. If successful, re-apply for funding to develop on a national scale

WHO?: Appropriate authority
WHERE?: Localised in first application
WHEN?: For next 12 months
FUNDS?: HRDC

APPENDIX 1 - DBM WORKSHOP PRESENTATIONS

CROP SCOUTING IN VICTORIA 1998/ 99

Nancy Endersby and Peter Ridland

Institute for Horticultural Development, Knoxfield, Private Bag 15, South Eastern Mail Centre VIC 3176

Key results

- Training of commercial scouts
 - Three scouts were employed by E. E. Muir & Sons from December to February. Training consisted of one day in the laboratory at IHD Knoxfield and one day per week in the field throughout the season. At the training day we gave the scouts detailed information about DBM, insecticide resistance, crop monitoring, insect identification and Integrated Pest Management. The scouts operated in Cranbourne and Werribee districts 3-4 days per week (one scout per district with the third as emergency). Their training was continued in the field on one day per week in each district as they scouted crops for particular growers.
 - The scouts worked for three *Brassica* growers in Werribee South and five growers in Cranbourne. Scouts also assisted with monitoring of insecticide trials for some chemical companies. Scouts undertook sap testing of lettuce for some growers. Scouts generated reports for each grower after each monitoring session. The reports were shown to N. Endersby for feedback. The reports were faxed to some growers and hand-delivered to others by E. E. Muir & Sons representatives who interpreted the results and gave advice.
 - Generally one planting was followed through from transplanting to harvest and additional plantings were looked at when the grower wanted extra information. Pheromone traps were used. Scouts had no difficulty in finding eggs in the field. At a crop age of six weeks after transplanting the scouts changed from full insect counts on 40 plants to presence/ absence of larvae on 40 plants. A sample score sheet used by the crop scouts is shown in Figure 1. Figure 2 is a sample grower report.

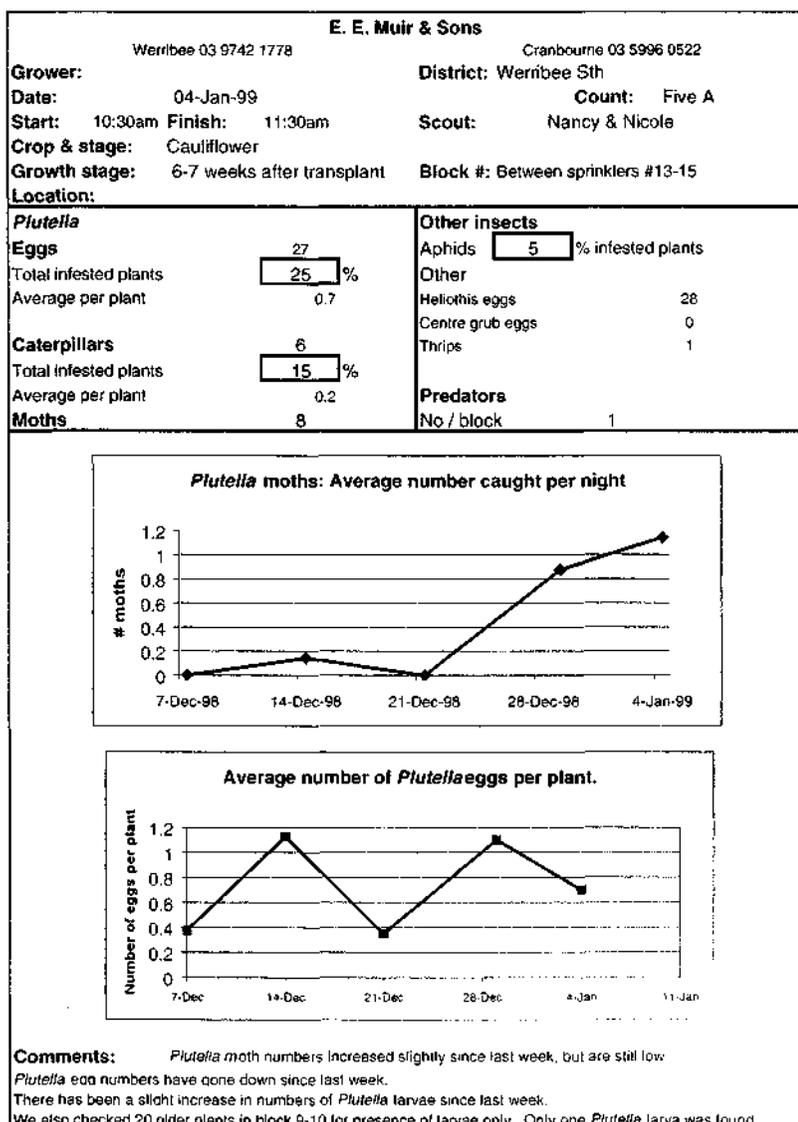


Figure 2. Sample of a grower report prepared by *Brassica* crop scouts in Victoria 1998/ 99

End of season reports and graphs of numbers of DBM throughout the life of the crop (Figures 3 to 5) were prepared for growers who submitted their spray application records. Graphs include moth numbers and percentage of plants infested with eggs and larvae. Presence or absence of occupied leaf mines (i.e. first instar DBM larvae) were graphed separately. Information about leaf mining was of interest in the early stages of the crop and was used to identify and inform the growers of the first major egg hatch.

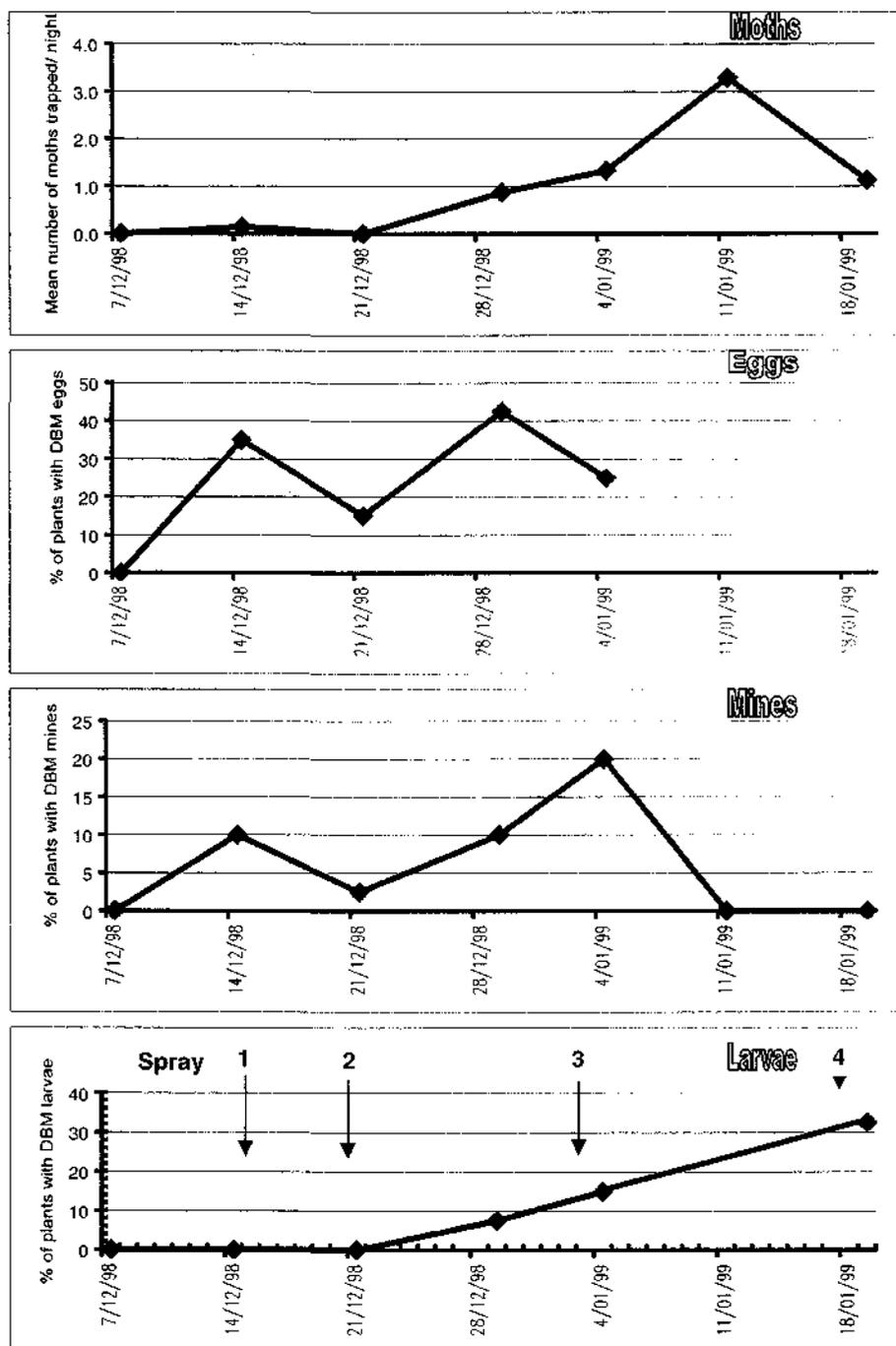


Figure 3. Infestation levels of DBM identified by crop scouts in a cauliflower crop in Werribee South, Victoria, December 1998 - January 1999. The graph of larvae does not include first instars inside leaf mines. [CROP 1 - Report on page 12]

END OF SEASON REPORT [CROP 1]

Dates	Activity	DBM Insecticide	Aphicide
30-Nov-98	Transplanted cauliflower		
07-Dec-98	Monitoring		
14-Dec-98	Monitoring		
15-Dec-98	Spray 1	Secure®	Saboteur®
21-Dec-98	Monitoring & Spray 2	Secure®	Saboteur®
29-Dec-98	Monitoring		
03-Jan-99	Spray 3	MVP® & Thiodan®	Saboteur®
04-Jan-99	Monitoring		
11-Jan-99	Monitoring		
18-Jan-99	Spray 4	Delfin® & Nitofol®	Saboteur®
19-Jan-99	Monitoring		
23-Jan-99	Spray 5	Secure®	Saboteur®
06-Feb-99	First harvest		
07-Feb-99	Spray 6	Secure®	Saboteur®
11-Feb-99	Spray 7	MVP®	
13-Feb-99	Second harvest		

- This season, moth numbers started to build up after the 21st December 1998 and reached a minor peak in the second week of January. Remember that only male moths are caught in the traps.
- The percentage of plants infested with eggs was relatively high during the second and last week of December. At this time the plants would have been 2 – 4 weeks after transplanting.
- Egg numbers were not monitored from 6 weeks after transplanting. Percentage of plants infested with larvae was monitored from this time onwards.
- A lot of leaf mines were observed during the first week of January. The larvae in these mines (first growth stage) came from the eggs laid in the last week of December. Numbers of larger larvae began to build up after the third week in December.

Spray applications

- Seven spray applications from transplant to second harvest: a fairly low number for this time of year
- The first spray (Secure® & Saboteur®) was timed well and applied after numbers of leaf mines were building up. It may have been better to use MVP® for the first sprays and use Secure® in the first two weeks of January. It would have been preferable to use Regent® in place of the two final Secure® applications.
- Aphid numbers were low throughout the sampling period. The inclusion of Saboteur® with each spray application was probably not necessary.

Resistance management

The AIRAC resistance management strategy recommends that Secure® be used from September 1 until January 14 and Regent® from January 15 until 30 August.

For better resistance management and interpretation of spray efficacy, mixtures of insecticides are not recommended e.g., MVP® plus Thiodan®; Delfin® plus Nitofol®.

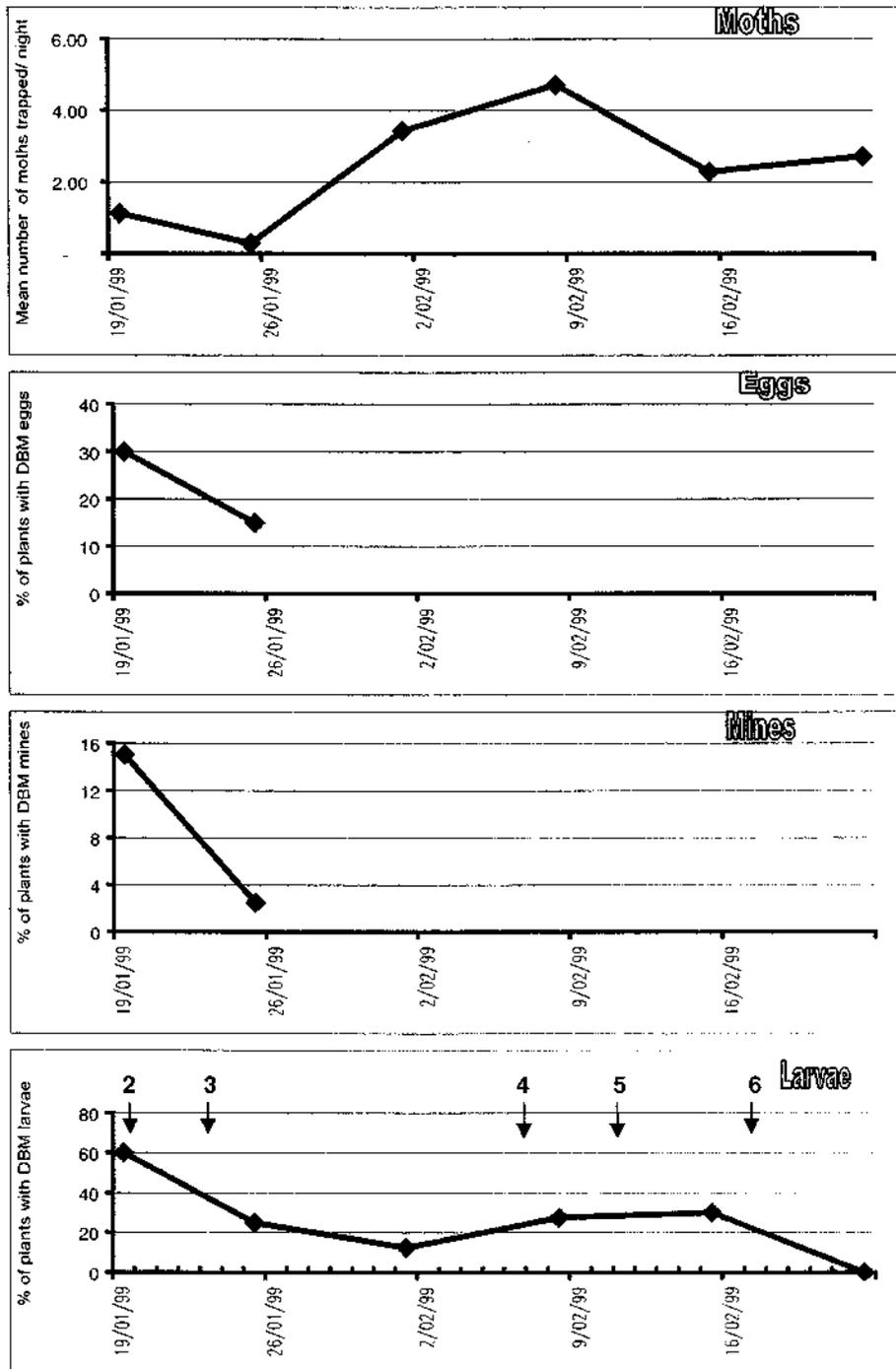


Figure 4. Infestation levels of DBM identified by crop scouts in a cauliflower crop in Werribee South, Victoria, January 1999 - February 1999. The graph of larvae does not include first instars inside leaf mines. [CROP 2 - Report on page 14]

END OF SEASON REPORT [CROP 2]

Date	Activity	DBM Insecticide	Aphicide
15-Dec-98	Transplanted cauliflower		
03-Jan-99	Spray 1	MVP® & Thiodan®	Saboteur®
18-Jan-99	Spray 2	Delfin® & Nitofol®	Saboteur®
19-Jan-99	Monitoring		
23-Jan-99	Spray 3	Secure®	Saboteur®
25-Jan-99	Monitoring		
01-Feb-99	Monitoring		
07-Feb-99	Spray 4	Secure®	Saboteur®
08-Feb-99	Monitoring		
11-Feb-99	Spray 5	MVP®	
15-Feb-99	Monitoring		
17-Feb-99	Spray 6	MVP®	
22-Feb-99	Monitoring		

- Moth numbers were low from the second week of January, but began to rise in the first week of February.
- Percentage of plants with DBM eggs and leaf mines was high in the second week of January, but had decreased by the next week.
- Egg numbers were not monitored from 7 weeks after transplanting. Percentage of plants infested with larvae was monitored from this time onwards.

Spray applications

- Six spray applications from transplant to harvest
- Percentage of plants infested with DBM larvae was high at 5 weeks after transplanting, but decreased after one application of MVP® + Thiodan® and a second application of Delfin® + Nitofol® two weeks later.
- Number of infested plants then remained low for one week, but had risen slightly by 8th February.
- Spray 4 (Secure® + Saboteur®) and Spray 5 (MVP®) kept numbers from increasing further and no infested plants were observed on 22nd February, the final monitoring occasion, after an application of MVP®.
- There was slightly more aphid activity in this planting than in Block 6 (Bays 13-15), but overall numbers were low and some applications of Saboteur® may have been unnecessary.

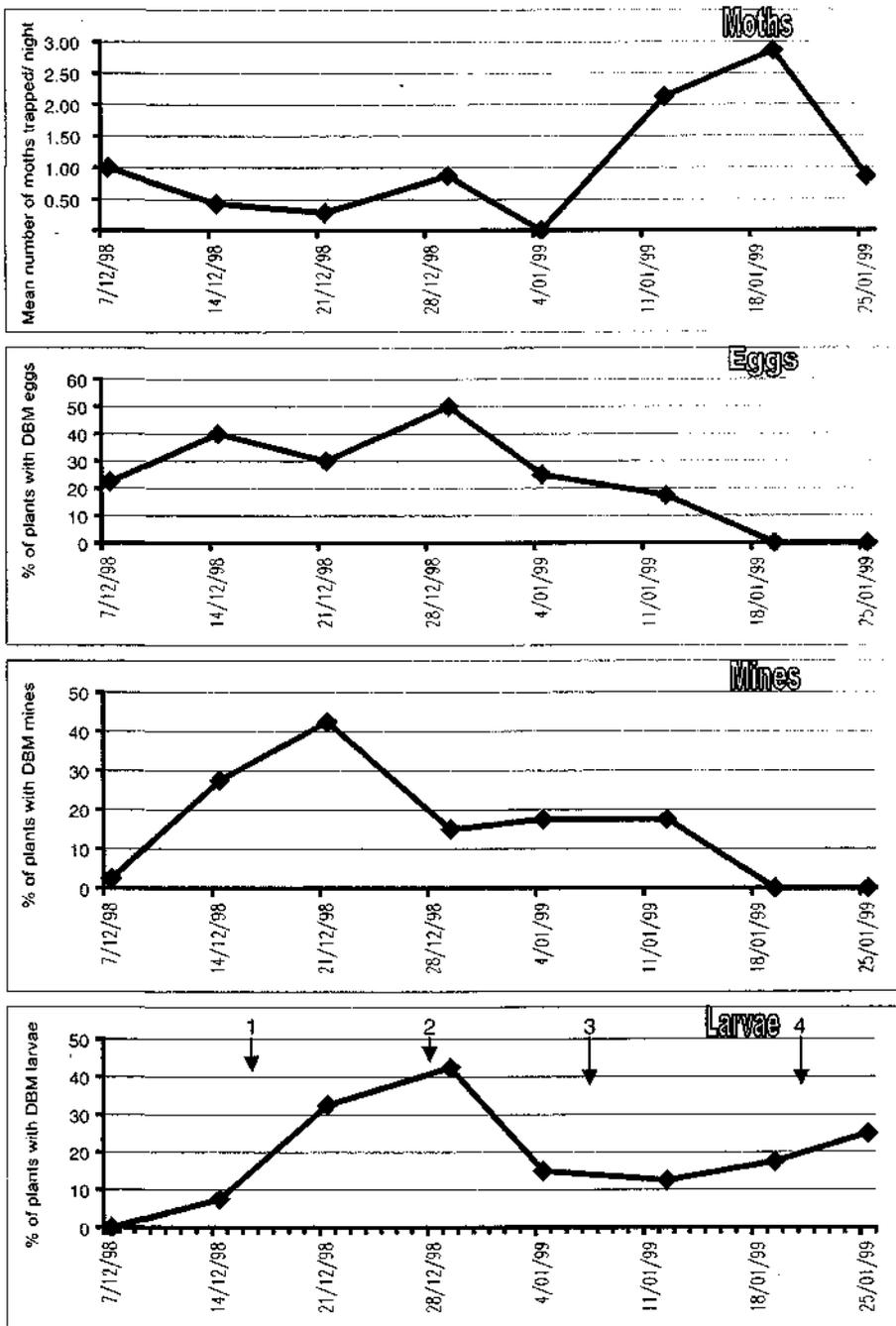


Figure 5. Infestation levels of DBM identified by crop scouts in a broccoli crop in Werribee South, Victoria, December 1998 - January 1999. The graph of larvae does not include first instars inside leaf mines. [CROP 3 - Report on page 16]

END OF SEASON REPORT [CROP 3]

Date	Activity	Insecticide
End of Nov 1998	Transplanted broccoli	
07-Dec-98	Monitoring	
14-Dec-98	Monitoring	
16-Dec-98	1	MVP®
21-Dec-98	Monitoring	
28-Dec-98	2	Regent®
29-Dec-98	Monitoring	
04-Jan-99	Monitoring	
08-Jan-99	3	Regent® & Nitofol
12-Jan-99	Monitoring	
19-Jan-99	Monitoring	
21-Jan-99	4	Delfin®
25-Jan-99	Monitoring	
29-Jan-99	Monitoring & first harvest	
2-Feb-99	Third harvest	
4-Feb-99	Fourth harvest	
6-Feb-99	Fifth harvest	

- This season, diamondback moth (DBM) numbers started to build up in the second week of January. Remember that only male moths are caught in the traps.
- The percentage of plants infested with eggs was relatively high during the second and last week of December. In December the plants would have been 2 – 4 weeks after transplanting.
- A lot of leaf mines were observed during the first week of January. The larvae in these mines (first growth stage) came from the eggs laid in the last week of December. Numbers of larger larvae began to build up after the third week in December.

Spray applications

- Four spray applications from transplant to harvest: a fairly low number for this time of year
- The first spray (MVP®) was timed well and applied after numbers of larvae were building up. Numbers continued to rise, however, possibly due to small larvae coming out of the leaf mines.
- The second spray application (Regent®) was very effective and percentage of plants infested with DBM larvae was greatly reduced
- Low numbers were maintained by the third spray application (Regent® and Nitofol®)
- Numbers of plants infested with DBM larvae were increasing slightly before harvest

Resistance management

The AIRAC resistance management strategy recommends that Secure® be used from September 1 until January 14 and Regent® from January 15 until 30 August.

For better resistance management and interpretation of spray efficacy, mixtures of insecticides are not recommended e.g. Regent® plus Nitofol®.

The crop monitoring studies identified a marked difference in DBM pressure between Cranbourne and Werribee this season (Figure 6). Port Phillip Bay separates the two districts.

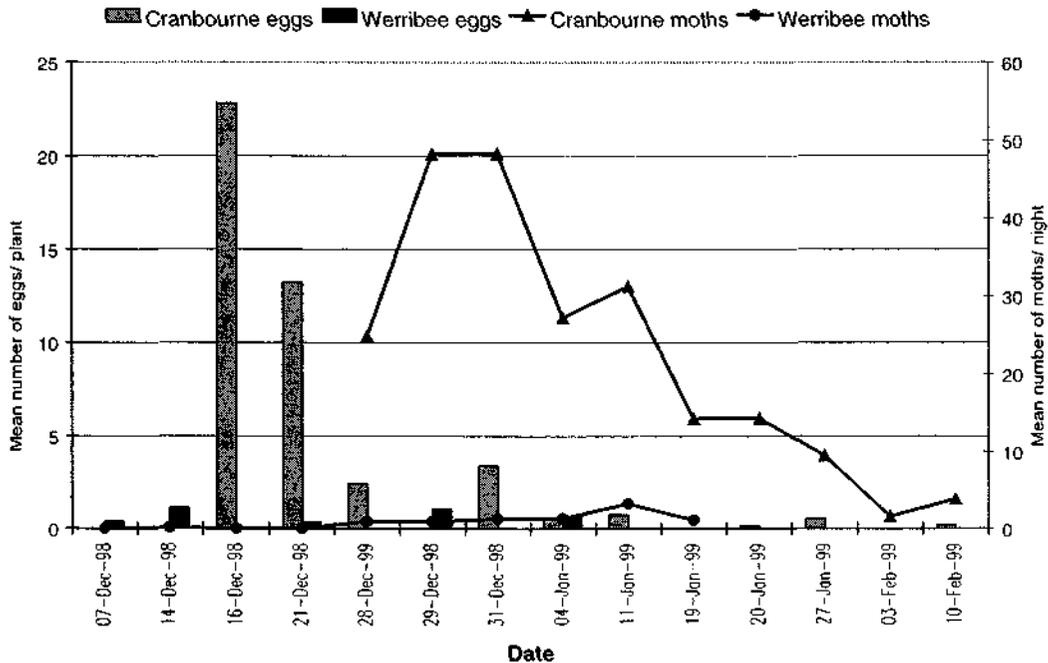


Figure 6. Comparison of DBM egg numbers and moth catches at Werribee (cauliflower) and Cranbourne (Brussels sprouts), Victoria, 1998-99

Who benefits now and in the future?

- Growers who participated in the program benefited this season. Results from this season will also be used to refine our crop scouting system which will eventually benefit all growers.

Werribee growers had an informal end of season feedback session on the scouting program. All found the information provided by the scouts valuable. Those who had the reports explained to them early in the season or who had experienced crop scouting before (by NE) had a better understanding of the results than those who only received them by fax. Some growers were prepared to spray less when pest pressure was low. One grower whom we have worked with for several seasons has now trained his brother to scout for larvae and found his results similar to those of the scouts. There were requests for more scouting next season and for further scouting of lettuce, as heliothis was a problem this season.

Next steps

a) 1999/2000

- E. E. Muir & Sons are prepared to repeat the crop scouting exercise this season. New scouts will have to be trained.
- We also intend to train more scouts for Costa's and employees of other individual growers who are interested in having a scout trained.
- We may run a scouting afternoon in Werribee and Cranbourne similar to one we ran in Lindenow in 1996.
- Second pest management survey to be conducted after Easter 2000

b) Future funding

Training of crop scouts is a fundamental part of the National DBM Project and will continue to be so in the proposed second-phase project. Growers need to employ scouts or be trained in crop scouting to have an impact on the management of DBM.

Monitoring of DBM Populations -Binomial Sampling under Sequential Rule

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Introduction

A key component of IPM is monitoring-based spraying programs. Under these programs, a crop is not sprayed unless the population level has exceeded the economic threshold or action threshold. Despite the potential benefit of reduced insecticide usage and consequently reduced control cost and the risk of insecticide resistance, a lot of brassica vegetable growers today still spray their crops on a calendar basis. To encourage more growers to adopt monitoring-based control programs, we present here a simple and efficient sampling program based on the theory of binomial sampling and sequential sampling. The performance of the sampling program is evaluated with independent data from various states in Australia.

Description of the Sampling Program

The sampling program is designed to classify DBM population levels relative to the action thresholds, ie. to decide if the population level is above or below an action threshold. Two sets of sampling plans were developed, one for the classification of the proportions of infested plants and the other for the classification of population density (number of larvae per plant). The action thresholds considered were 10%, 15% and 20% for the classification of proportions of infested plants, and 0.1, 0.2 and 0.3 larvae/plant for the classification of population density. These action thresholds were selected after consultation with brassica vegetable growers in South Australia.

Implementation of the sampling program is simple and the procedure is shown in Figure 1. First, a small number of plants (...10) is randomly selected and checked individually for the presence/absence of the larva. The number of plants infested at this sample size is compared with the upper and lower stop lines. If it is above the upper stop line then it is decided that the population level is above the action threshold and needs to be sprayed. If it is below the lower stop line then it is decided that the population level is below the action threshold and needs not to be sprayed. If it falls in between the two stop lines, then sample more plants and compare the updated sample point (accumulated number of infested plant at the new sample size) with the two stop lines again. The process is continued until a decision can be made regarding the population level relative to the action threshold, ie. until the updated sample point crosses either of the stop lines. In practice, a maximum sample size of 50 plants is recommended. If the sample point is still in between the two stop lines at that sample size, the sampling process is terminated and a spray action is recommended.

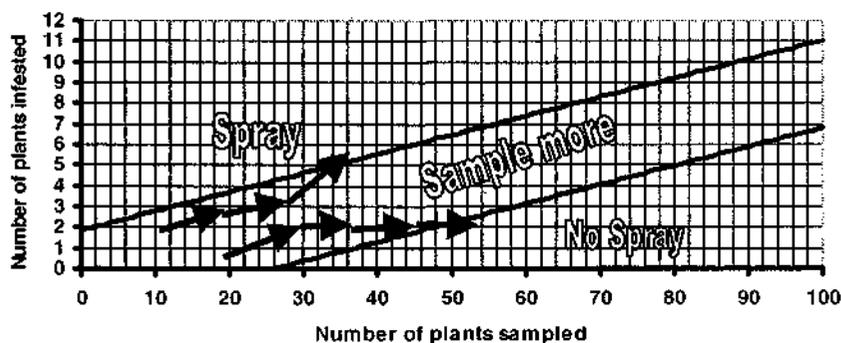


Figure 1. An illustration of the sampling procedure under the proposed sequential sampling program based on presence-absence data.

Stop lines for the classification of the proportions of infested plants relative to the action thresholds of 10%, 15%, and 20% , and that for the classification of larval density relative to the action thresholds of 0.1, 0.2, and 0.3 larvae/plant were listed Figure 3. Classification of larval density requires the conversion of density action thresholds into proportion thresholds. This was achieved by a fitted non-linear regression shown in Figure 4.

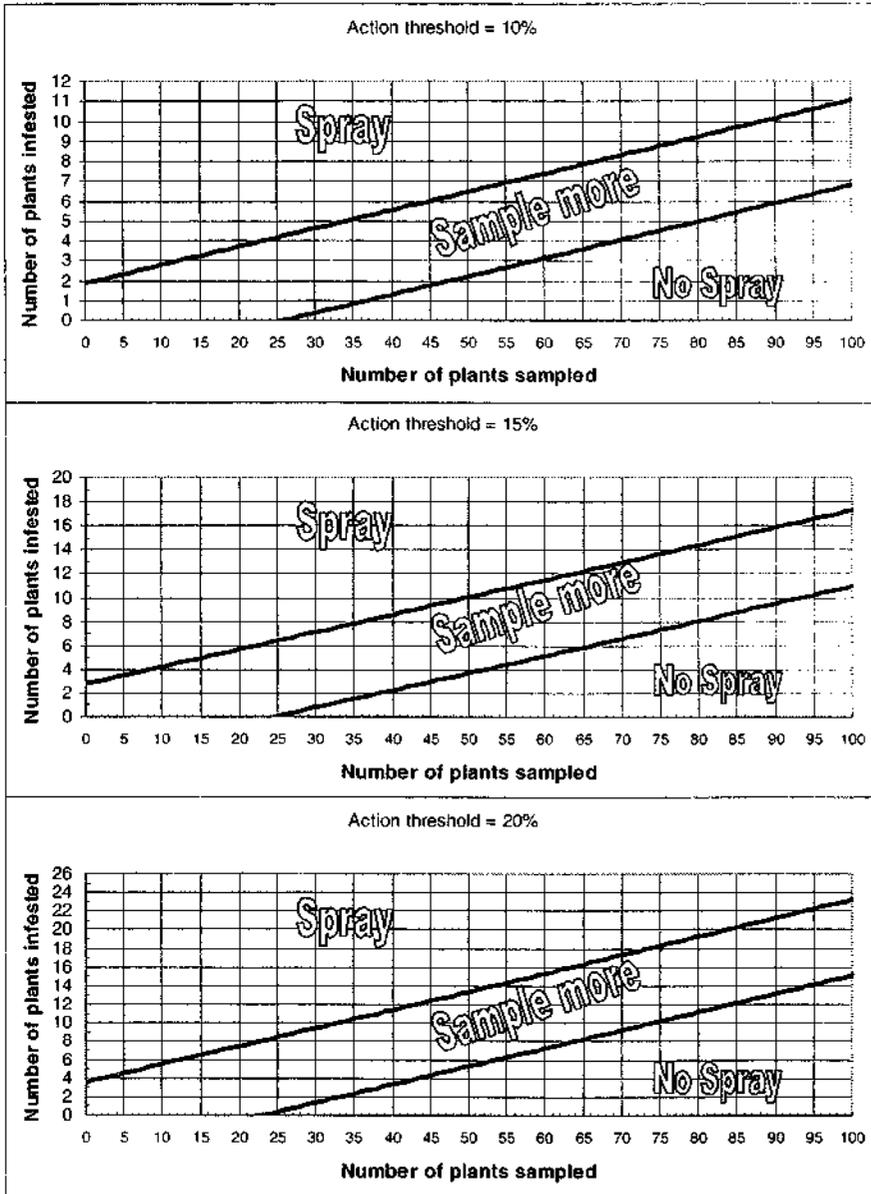


Figure 2. Stop lines for the classification of proportion of infested plants with respect to the action threshold of 10%, 15% and 20%.

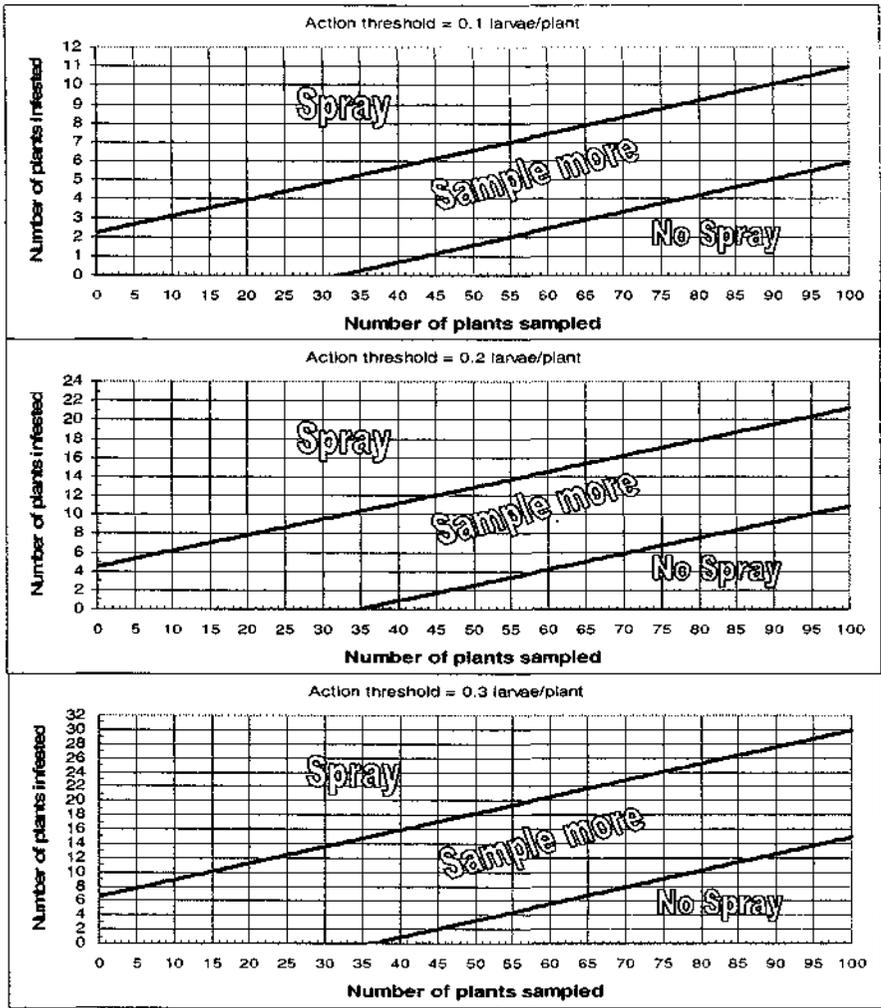


Figure 3. Stop lines for the classification of DBM densities (larvae/plant) with respect to the action threshold of 0.1, 0.2, and 0.3 larvae/plant.

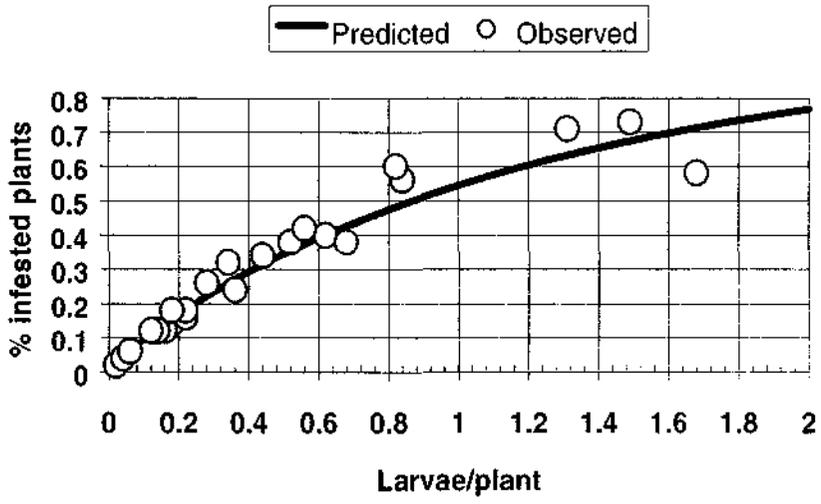


Figure 4. Conversion between number of larvae per plant and the proportion of infested plants

Accuracy and efficiency

The accuracy and efficiency of the sampling plans depends on the action threshold being targeted and the field population level. For example, At the action threshold of 15%, a minimal correct

classification rate of 95% can be expected if the proportion of infested plants is smaller than 8.4% or greater than 19.8% (Figure 5). The expected average sample size first increase with the field population level, reaching its peak at the action threshold, and then decrease with the filed population level. At the action threshold 15%, the average sample size is below 50 if the proportion of infested plants is below 7.7% or above 19.3% (Figure 5). The expected maximum sample size is 81 and the minimal sample size is 5 for reaching a no-spray decision and 28 for reaching a spray decision.

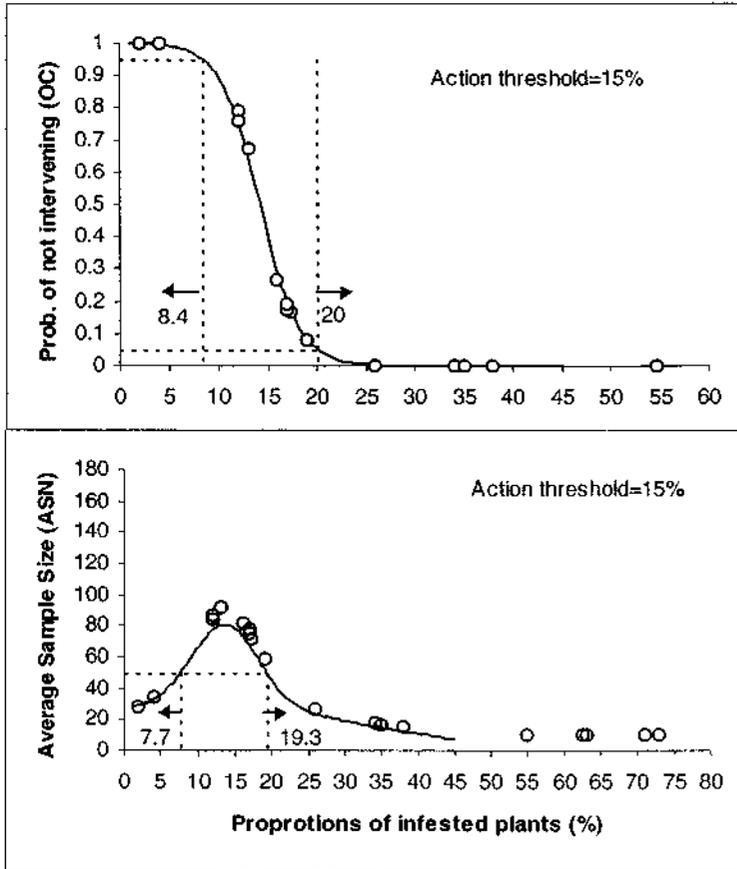


Figure 5. Probability for reaching the no-spray decision and average sample size as a function of the proportions of infested plants at the action threshold of 15%. Empty circles showed results from re-sampling analyses of 20 independent data sets.

The accuracy and efficiency as revealed by simulated sampling of independent data sets matched well with the expected accuracy and efficiency (Figure 5). At the action threshold of 15%, 12 of the 20 data sets yielded a 100% correct classification rate at a sample size of less than 35 plants. Proportions of infested plants in the other 8 data sets were close to the action threshold. However, the correct classification rates were still quite high (averaging 81%). The average sample size for these data sets were 79 plants.

Discussion

The proposed sampling plans are advantageous over enumerative sampling plans in that only the presence or absence of larva needs to be recorded for each plant and that sampling can be terminated after sampling only a small number of plants if the population level of DBM is well below or well above the specified action threshold. If the DBM population level is close the action threshold, sample size may be high but growers have the option to stop at a maximum of 50 plants and make their decision on the necessity of spray according to plant growth stage and available resources.

Sampling plans for determining whether the proportions of infested plants are below or above specific action thresholds (Figure 2) can be used in any brassica crops and under any DBM infestation levels.

since the only factors influencing the parameters of the stop lines are the action threshold and the desired error level. However, stop lines for the classification of larval density are influenced by the relationship between infestation proportion and larval density, which depends on the distribution of larvae, as well as the action threshold and the desired error level. Preliminary analyses of data collected from different states and brassica crops showed that the relationship is quite robust with respect to crop variety and DBM infestation level. Furthermore, validation of independent data sets showed similar accuracy and efficiency levels in classification of larval density as in the classification of proportions of infested plants. Hence, the proposed sampling plans for the classification of larval density (Figure 3) can also be tried in the monitoring of DBM populations.

Work scheduled for next year

More evaluation of the sampling plans will be carried out with additional data. Experiments will be conducted to quantify the saving of sampling time as compared with enumerative sampling plans. The possibility of partial sampling plan in which only part of the plant is sampled will also be explored.

Suggested work for 2000-2003

Training sessions will be held for pest scouts and growers to help them use the proposed sampling plans. General problems frequently encountered during the monitoring of DBM populations such as pest ID will also be addressed during the training sessions.

The benefits of monitoring-based spray programs over calendar-based spray programs will be assessed in field experiments. Sampling plans proposed here will be used for the monitoring of DBM populations. A less costly alternative is the monitoring of the efficiency of grower's spraying programs by analysing the seasonal patterns of DBM populations, especially population levels before and after individual sprays.

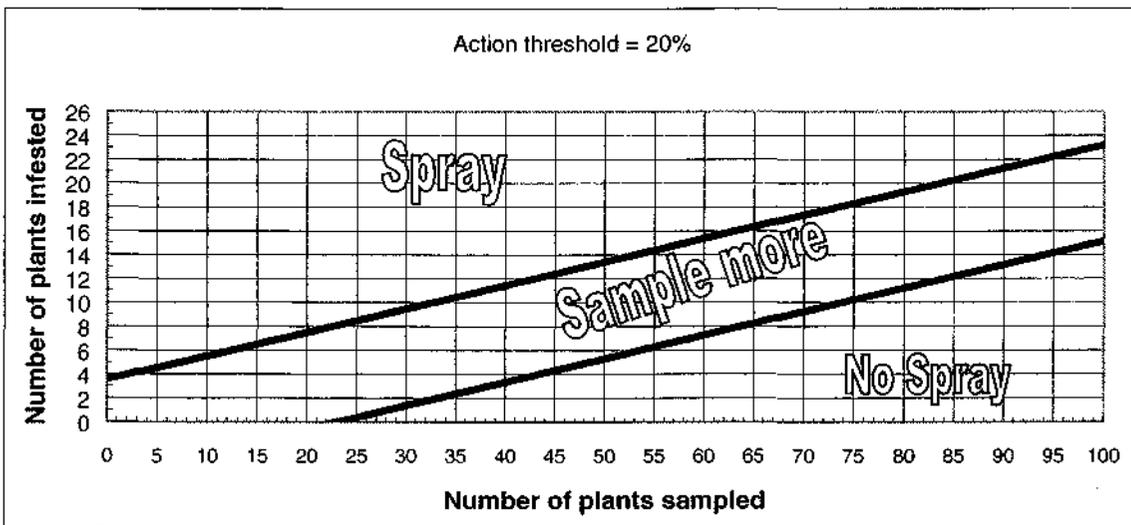
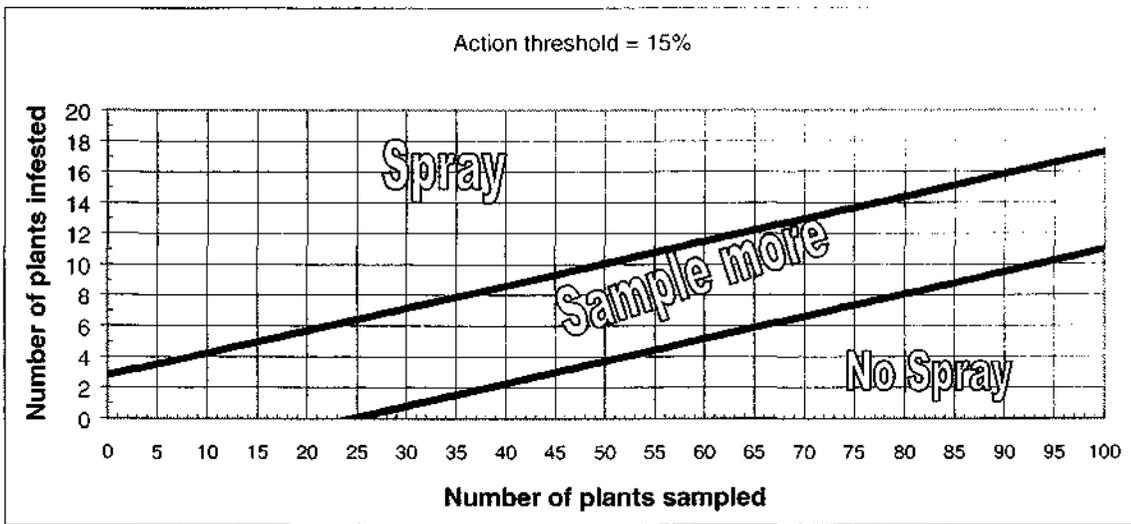
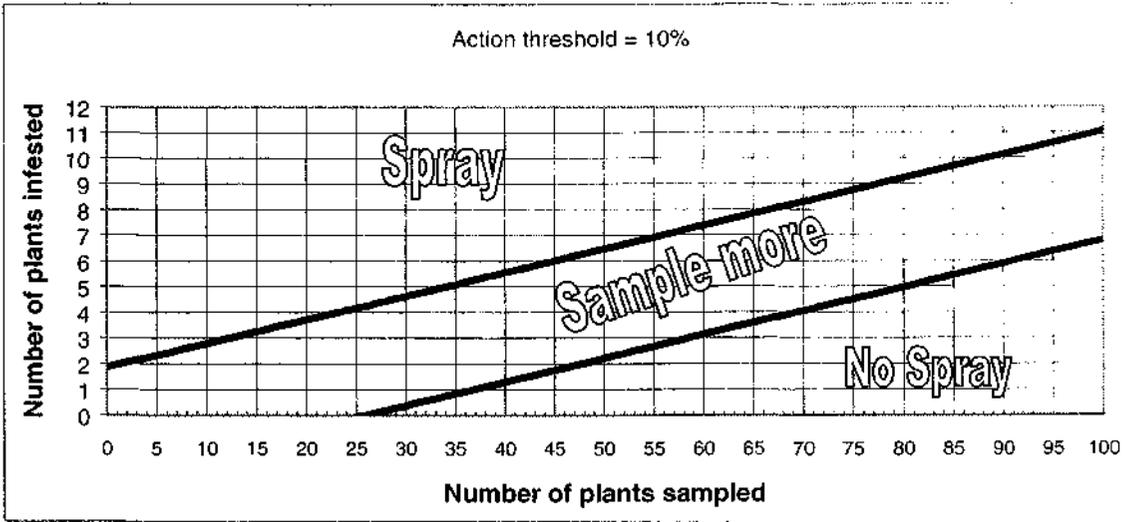


Figure 1-3. Stop lines for the classification of proportion of infested plants with respect to the action threshold of 10%, 15% and 20%.

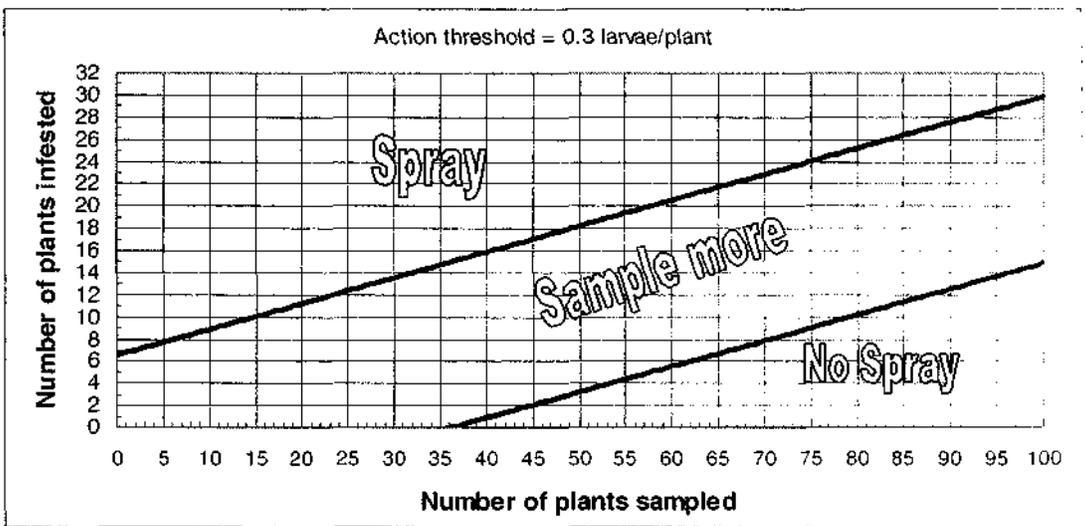
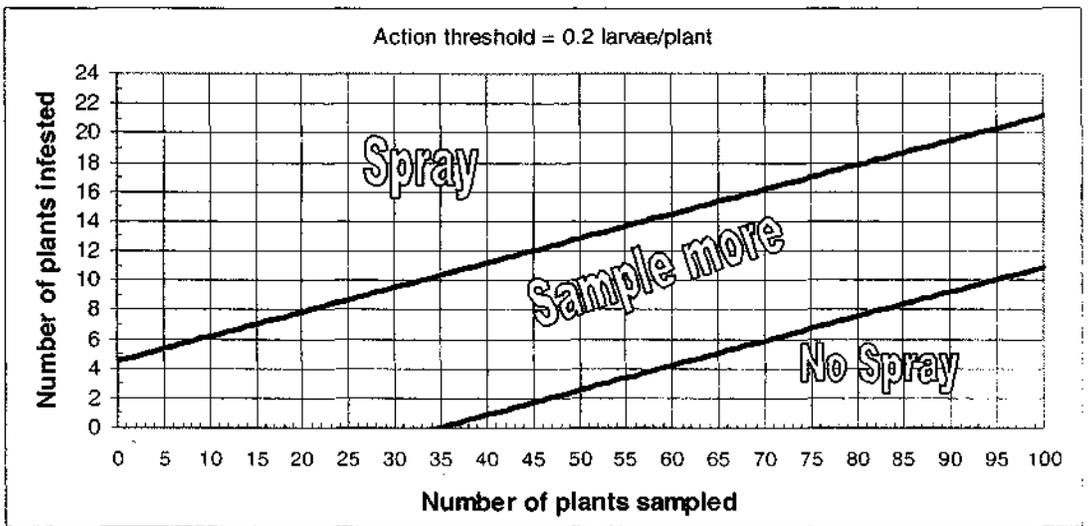
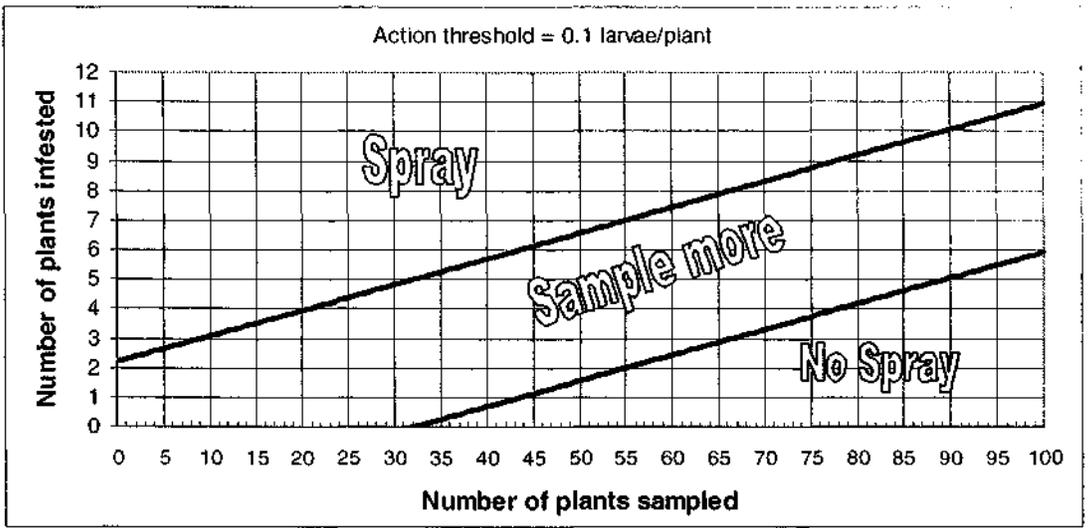


Figure 4-6. Stop lines for the classification of DBM densities (larvae/plant) with respect to the action threshold of 0.1, 0.2, and 0.3 larvae/plant.

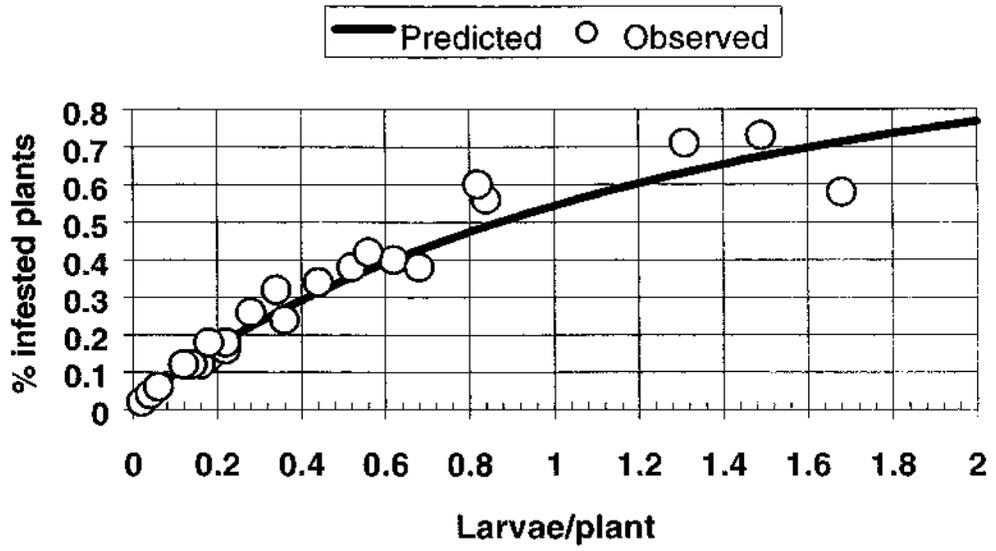


Figure 7. Conversion between number of larvae per plant and the proportion of infested plants

SUMMARY OF DIAMONDBACK MOTH PROJECT ACTIVITIES IN WESTERN AUSTRALIA, 1998/99

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1. SEASONALITY OF LOCAL DBM POPULATIONS

Introduction

Field surveys of *Plutella xylostella*, diamondback moth (DBM), were conducted in the metropolitan area of Perth in between October 1998 and April 1999. The two main areas of brassica production in southwest WA are in the Perth Metropolitan area, and in Manjimup, where the focus is on cauliflower production.

Materials and Methods

DBM larvae and adults were sampled weekly in commercial broccoli crops on two horticultural properties within the metropolitan area of Perth. Properties were surveyed for four cycles between late spring and autumn (Table 1).

Table 1. Sites and dates of DBM survey in the metropolitan region of Perth.

Grower	Location	Cycle I	Cycle II	Cycle III	Cycle IV
Galati	Wandi (south)	30 Oct – 7 Jan	7 Jan – 18 Feb	18 Feb – 1 Apr	1 Apr – 29 Apr
Jambanis	Carabooda (north)	30 Oct – 24-Dec	24 Dec – 4 Feb	4 Feb – 1 Apr	1 Apr – 29 Apr

Moth sampling

Sticky traps were changed weekly. The traps consisted of a piece of card covered with Tacgel® and baited with a pheromone lure and sheltered by a cardboard roof suspended from a wooden stake.

Larvae sampling

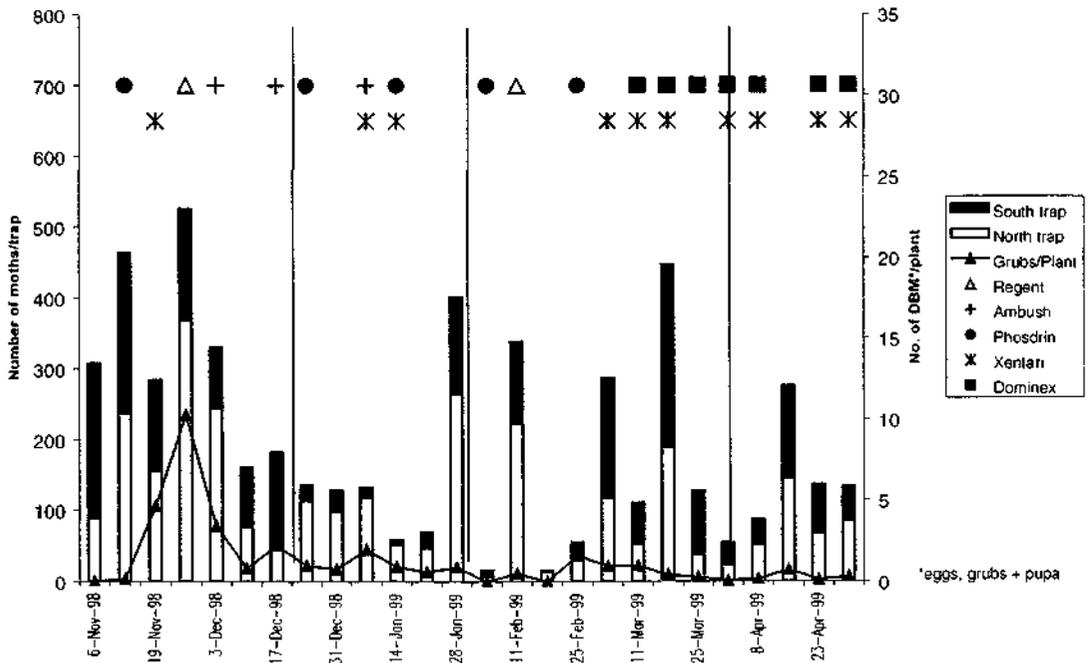
Every week the crop at each trapping site was inspected and the number and size of DBM eggs, larvae and pupae were recorded. At each site, 50 plants were inspected for the first 4 weeks, then 30 for the next 4 weeks and 20 for the remaining visits. This reduction in numbers of plants assessed corresponded with increases in the size of the plants over time.

Results and Discussion

As in 1997/98, moths numbers peaked in late November, declined over the hotter summer months of December and January, and rose again in February and remained high (over 200/trap/week) until sampling ended in April (Fig. 1).

Generally, numbers of larvae in crops peaked in early December, mid-January and again in late March (Fig 1.). We kept in close contact with growers, and gave them feedback as to the levels of pests in their crops, and spray recommendations within 24 hr of counts being taken. The growers were keen to receive this information, but we have not evaluated the extent to which they valued this feedback and its influence on their pest management strategies. Note that one grower sprayed the crops being monitored with a range of chemicals, some used cocktails, mixing up to three active ingredients in a spray.

DBM Traps and Scouting results (Carabooda; W.A.)



DBM Traps and Scouting results (Wandi; W.A.)

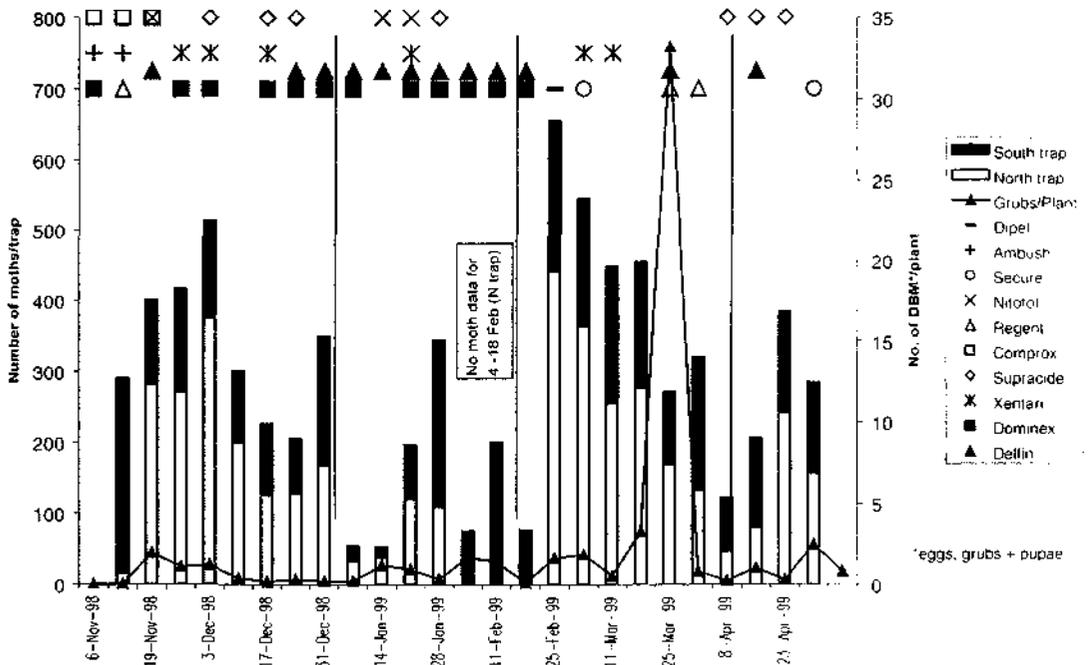


Figure 1. DBM numbers sampled weekly in commercial broccoli crops on two horticultural properties within the metropolitan area of Perth and spray applications, 1998/ 99

2. PARASITOID ACTIVITY

Prior to this work being done, little quantitative data existed on the species and activity of DBM parasitoids found in WA. To encourage Industry to adopt integrated pest management strategies for control of DBM, it is important that we establish the activity and species of DBM parasitoids present.

Materials and Methods

Parasitoids were surveyed by collecting DBM eggs, grubs and pupae from five properties in the Metropolitan area every fortnight, starting in summer (3rd December, 1998) and ending in mid-autumn (23rd April, 1999). In addition, a few collections were made from crops in the Manjimup region located in the southwest of WA. During each visit, immature DBM collected in a 30-minute period were returned to the laboratory, sorted and counted then caged on 6-8 week old canola plants at 22 °C. Following this, emergence cages were checked every 1-2 days and any adult moths or wasp parasitoids were removed for a period of 3 weeks. Parasitoids were preserved and identified to species level.

Results and Discussion

A total of 1,802 *P. xylostella* were collected, of which 234 (13%) were parasitised. Live specimens (moths or parasitoids) were not recovered from 34% of *P. xylostella* collected. Seven species were found parasitising DBM, of which *Diadegma semiclausum*, followed by *Apanteles ippeus* (Fig. 2, Fig 3) were the dominant species found in the metro area.

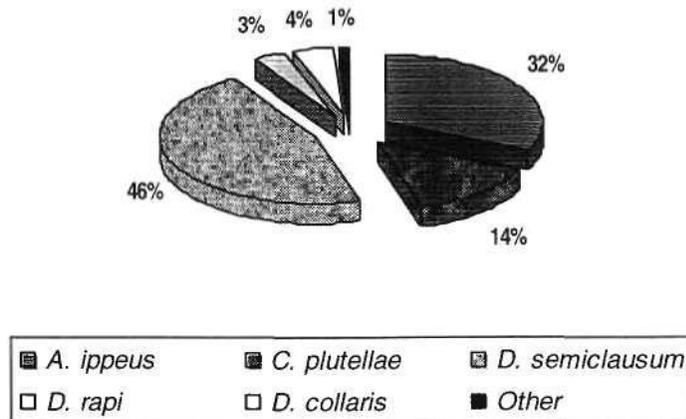


Figure 2. Parasitoid species reared from DBM in Western Australia, 1998-99

Parasitoids recovered ex-DBM from Western Australia, 1998-99

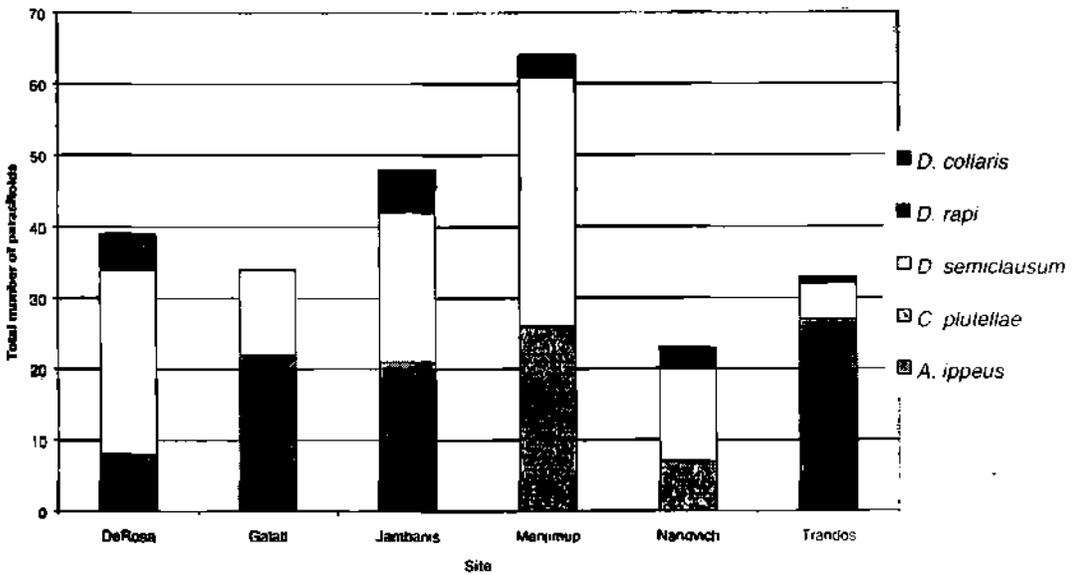


Figure 3. Parasitoid species reared from DBM collected in metropolitan and southwest regions of WA

Diadegma semiclausum also emerged from DBM collected in Manjimup, but not *A. ippeus*. Large numbers of *Cotesia plutellae* were also collected from the Manjimup site.

Other species of parasitoids recovered in small numbers were *Diadegma rapi*, *Trichomalopsis* sp., *Diadromus collaris*, *Brachymeria phya* plus one other (single specimen damaged, not yet able to identify).

The *P. xylostella* from which moths or parasitoids were not recovered were probably exposed to insecticides prior to being collected, and had died after being collected. Interestingly, 20% of *P. xylostella* collected from the Carabooda site were parasitised, despite the existence of a heavy spray program including Ambush[®], Phosdrin[®] and Dominex[®].

ACKNOWLEDGMENT

Dominic McCosker and Linnet Cartwright provided technical assistance. In Manjimup, grub collections for the parasitoid survey were done by Stewart Learmonth and Mark Stanaway. Andras Szito kindly supplied his taxonomic skills to help identify the parasitoids. Natarsha Zilm photographed the parasitoids. This study was funded by Agriculture WA and by the HRDC. Lastly, I thank the growers who kindly allowed us to conduct studies on their properties.

Local Dispersal of Diamondback Moth

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Introduction

Insecticide resistance has been a major issue in the control of the diamondback moth (DBM). One proposed strategy to combat this problem is the restriction of groups of insecticides to specific parts of the year or the window strategy. Effective implementation of the strategy requires the knowledge of dispersal distance of DBM, as the latter determines the minimal area where the strategy can be effectively administered. Information on dispersal distance is also critical for the designing of some other important control strategies such as crop-break, mating disruption, and trap-and-kill.

Methods

The dispersal of DBM is studied with the mark-release-recapture methods. In brief, a number of the moths are marked and released at one or more points within a host field. Attempts are then made to recapture some of the released individuals through some form of capturing mechanisms. Based on the relative numbers of marked individuals recaptured at particular distances to the release points, the average dispersal distance and the distances within which a certain proportion of the marked individuals are likely to remain can be estimated. In the current study, most mark-release-recapture experiments used fluorescent powder as the marking agent and delta pheromone traps as the capturing mechanism.

During the July 1998 – July 1999 budget year, four mark-release-recapture experiments were conducted. Two experiments used the discrete plot design and two used the grid design. In the discrete plot design, traps were laid out in groups in isolated square plots within a continuous brassica field and the centres of one or two plots are used as the release points. The distance between a non-release plot and a release plot varied from 40m to 160m. Within each plot, 25 traps were laid out in a 5 x 5 pattern with an inter-trap distance of 10 m. In the grid design, traps were laid out in a grid pattern across a continuous patch of a brassica field. The inter-trap distance was again 10m. One experiment used the 7 x 19 grid and the other 5 x 21 grid. The total number of moths released at one time varied from 1000 to 3000.

Results

Results from the two experiments of discrete plot design were shown in Figure 1. The majority of the released moths (84% - 100%) were captured in the release plots. Recapture rates in the non-release plots ranged 0 - 12%. In one release none of the marked moths were captured in the adjacent plots, although one of them was only 50m away from the release plot.

Total recaptures of individual traps in the two grid-based experiments were shown in Figure 2. It can be seen that most recaptures were made around the release point. However, small number of recaptures were also made in traps placed 100m away or further. Analyses of the relationships between the proportions of recaptures and distance to the release points (Figure 3) suggests an average dispersal distance of 30 – 60m. Distances within which 95%, 99%, and 99.9% of the released moths would remain were estimated at 180m, 300m and 510m, respectively. Examination of daily catches suggests that wind may affect the direction of flight when it is relatively strong (>7m/s) and consistent by forcing a downwind movement.

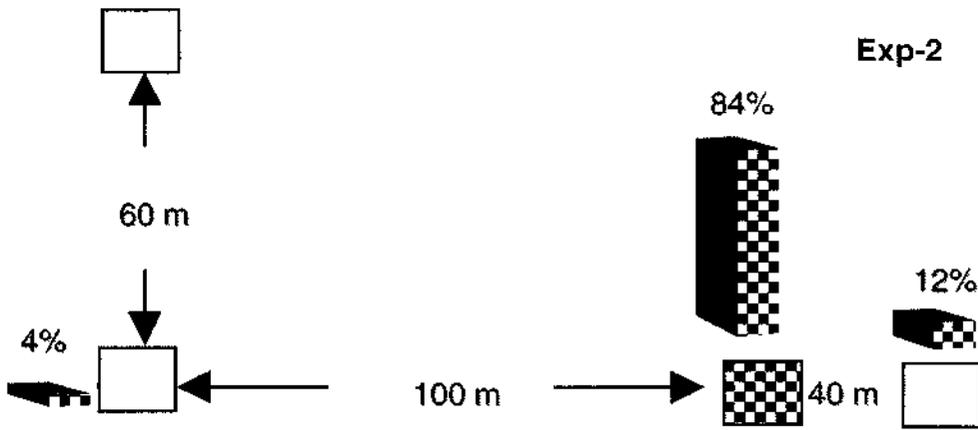
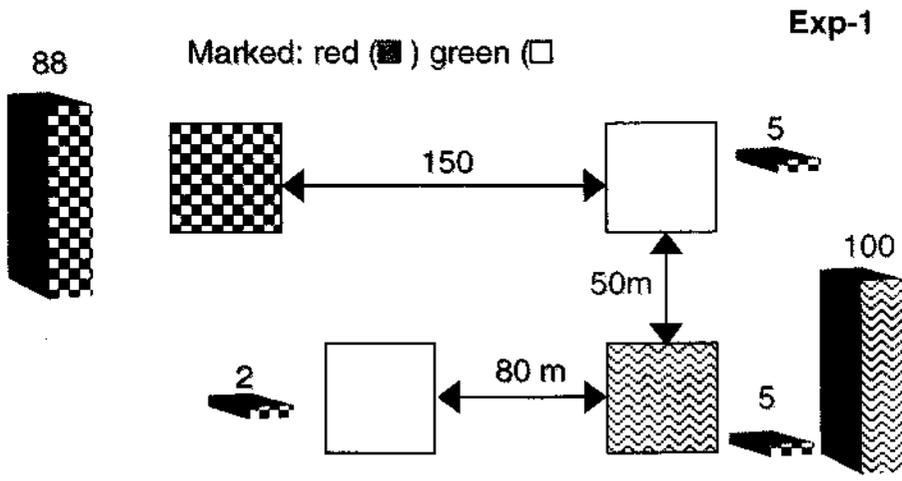


Figure 1. Layout (rectangles) and results (3D bars) of two mark-release-recapture experiments using the discrete plot design. Patterned rectangles indicates release plot and blank rectangles non-release points. Different releases were filled with different patterns. Results from a particular release were shown with 3D bars of the same pattern.

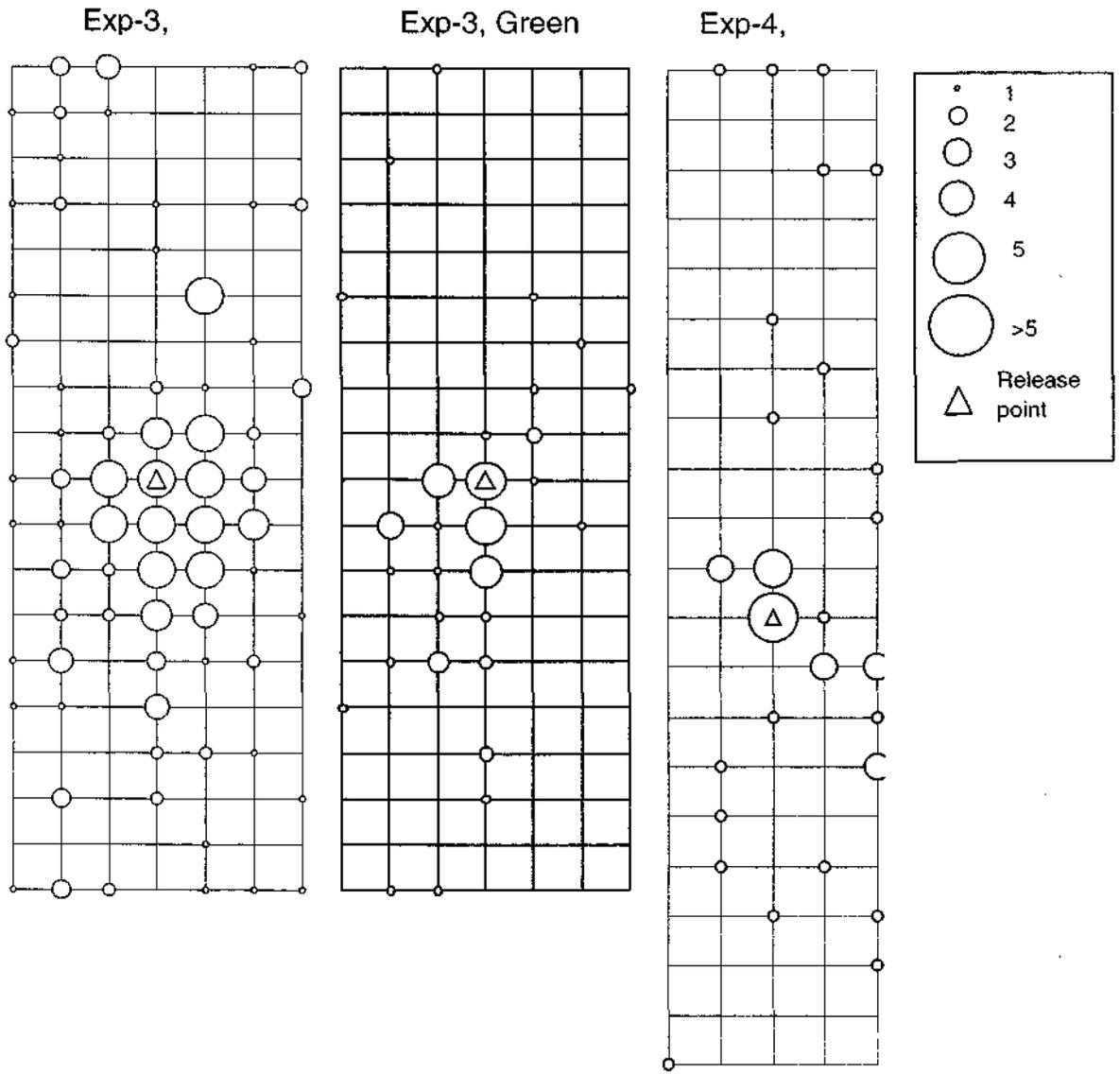


Figure 2. Total recaptures of individual traps in the two grid-based experiments. Circles shows traps where recaptures were made, the larger the circles the high the recaptures.

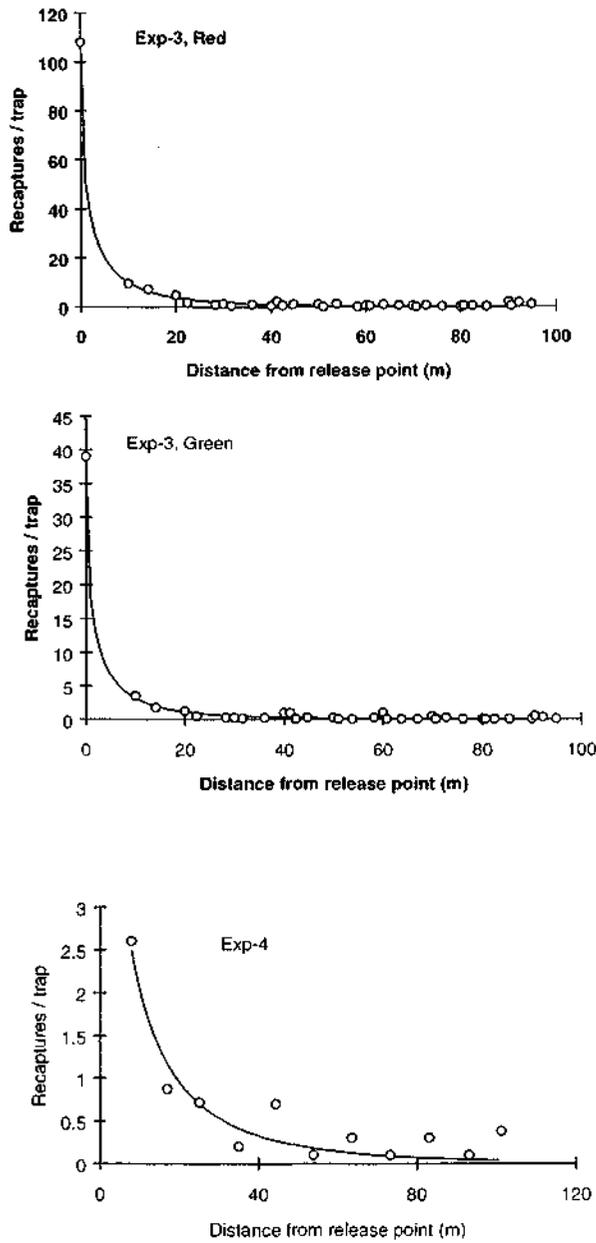


Figure 3. Relationships between the proportions of recaptures and distances to the release point in the two grid-based experiments. Circles shows traps where recaptures were made, the larger the circles the high the recaptures.

Discussion

Results collected so far suggests that DBM moths do not tend to fly far when the host plants are abundant. The longest dispersal distance recorded over the last two years was 278m. Assuming similar dispersal distances of males and females, a minimal separation distance of 1 km between neighbouring brassica crops is recommended for farmers wishing to practice independent dispersal-related control strategies, such as the two-window strategy currently being promoted.

Work scheduled for next year

Apart from more pheromone-based dispersal experiments, separate experiments will be conducted to assess possible differences in the dispersal of males and females. Yellow sticky buckets, light traps, and or sweep net will be used to capture moths of both sexes.

Suggested work for 2000-2003

To better understand the local dispersal of DBM , we plan to study the dispersal of the insect from disrupted environments such as a harvested crop. We also plan to investigate the influence of spring influx of DBM from canola and weeds on DBM populations fluctuations in commercial crops and on resistance management.

Brassica IPM Handbook: 1998/99 Progress

Leigh James

NSW Agriculture

The *Brassica* IPM Handbook was distributed to *Brassica* growers throughout Australia in 1998/ 99. The handbook contained five initial modules:

1. Integrated pest management - what does it really mean?
 2. Crop monitoring - the key to informed decision-making
 3. Insecticide resistance management - getting the best from your sprays while getting the better of DBM
 4. The role of *Bacillus thuringiensis* in managing diamondback moth
 5. How fast does diamondback moth develop?
- Front cover shows co-operators and collaborators - a truly nationwide effort
 - Inside front cover shows sponsors including major national resellers. The alliance with these resellers is very important for disseminating the Insecticide Resistance Management strategy for DBM
 - The importance of crop monitoring was highlighted in the handbook and examples of monitoring regimes and suggested thresholds were tabulated for growers
 - Brochures for new chemistry products (Regent[®] and Secure[®]) for 98/99 were placed in Appendix (NSW) as extra information for growers
 - Secure[®] was launched in November 1998 and became the second new chemistry for DBM control - 2 window strategy could now be launched (eastern states) - less pressure on Regent[®]
 - Chemical families were tabulated on the back of the IRM strategy to assist growers in identifying the chemical families to prevent same family rotations
 - Bts have important role in the new DBM IRM strategy
 - The handbook modules for 1998/99 provided growers with an idea of how many generations of DBM to expect at certain locations. This forewarns growers of what to expect at certain temperatures, enabling them to monitor and act appropriately.

Some planned new topics for 1999/ 2000

- Importance of good spray coverage *Draft complete*
- *Brassica* information on the Internet *Draft prepared*
- Other sources of *Brassica* information *Draft complete*
- IRM strategy 99/00 *Draft complete*
 - will include placement of Success[®] in the same window as Secure[®]
 - the new AVCARE insecticide groupings will be included
- Pages of colour photographs of pests and beneficial insects in brassicas

Promoting *Plutella* IPM in Tasmania

HRDC National *Plutella* Project VG970014 1998-99

Julia French (Agricultural Officer) and Lionel Hill (Entomologist)
Department of Primary Industries Water and Environment

State industry overview

The brassica industry in Tasmania comprises of three components Fresh (year round sequential plantings), Processing (summer-autumn), Seed (annual crop) representing a \$20M industry with approximately 200-250 growers.

	Processing	Fresh	Seed
Crops	Broccoli, Cauliflower, Sprouts	Broccoli, Cauliflower, Cabbage, Sprouts, Swedes	Seed of Broccoli, Cauliflower, Cabbage, Sprouts, Swedes, Chinese cabbage
Companies	Simplot, McCains	Perfecta Produce, Harvest Moon	South Pacific Seeds Hendersons +others
Ha	600	*	160
Tonnes	9000T	*	300kg
Field Officer No.	9	6	9
Growers No.	130	*	90
Agronomy	Serve-Ag, Roberts, Agronico, Websters	Serve-Ag, Company staff	Company staff
Major pests	<i>Plutella</i> , slugs, cabbage white butterfly, aphids	<i>Plutella</i>	<i>Plutella</i>

* To be confirmed

Fluorescent Dye evenings

Peter Hughes presented his spray application demonstration on November 1998 to a group consisting of approximately 12 agricultural advisers and growers in the NW plus another 20 in the Coal River valley.

At the request of Simplot freezing factory field office two more application workshops were undertaken in February 1999. One was rained out, although around 10 growers turned up for presentation of their brassica folders and a project overview. The final evening generated sufficient interest for some growers to borrow the dye and light to examine their own spray methods.

Dye has also been given to field officers from South Pacific Seeds to demonstrate application methods with their growers.

Field Officer presentations

Two presentations were made to meetings of the advisory agronomists about the *Plutella* research, one with the dominant pesticide retailer Serve Ag and the other with field officers from Simplot. They pointed out that the mid January Secure[®]/Regent[®] date coincides with the peak of planting of processing crops here so that Secure[®] would never be used on them. However fresh market crops are planted earlier.

Plutella collection

At request of a Serve Ag agronomist keen about Bt results, *Plutella* pupae were collected from two commercial crops treated with either SPs or Bts to send for resistance testing, but instead there was approximately 95% parasitoid emergence of *Diadegma* and *Diadromus*.

Nursery Meeting

Hill's Transplants which is the seedling nursery that supplies 95% of seedlings in Tasmania, has been consulted twice this year, most recently Nancy accompanied Lionel and Julia. Hills predominantly use an outdoor system for rearing seedlings. The peak season for seedling brassica production coincides with the peak planting of processing brassicas in January. The crop hygiene is meticulous in an environment which is very weed free and sterile with the hinterland mostly pasture. It is intended to sample larvae there soon. Hills have sprayed routinely with SP for years and now also use Bts. The plants are present only 5 weeks. Most moths on the property are immigrants from crops 0.5 km or more away.

Handbook distribution

About 140 Handbooks have been distributed to field officers, agronomists and a large proportion of the processing and seed producers.

Visit to Victoria

In February, Julia visited Nancy Endersby as a training exercise. One day was spent scouting a number of crops with the E.E. Muir & Sons scout trained by Nancy. Scouting methods were learned as was identification of the suite of pests and beneficials. A brief tour of the Knoxfield site was undertaken and then more time spent in the entomology labs. The rearing protocols, facilities and resistance screening process were observed. A tour of the Boomaroo seedling nursery at Lara was undertaken with the employee who conducts all the spraying, and is responsible for weekly scouting.

Grower Meetings

Nancy Endersby presented an overview of the project at two state meetings. One on the northwest coast at Devonport and one in Coal River Valley at Campania in the states south. These were well attended with the northern group consisting predominantly of field officers (by specific invitation) and the southern of growers (50% seed growers). Discussions were lively and clarified the concepts underlying resistance management.

Media

Media coverage after Nancy's visit included articles in Tasmanian Country, Friday June 18th 1999 and The Advocate, June 16th 1999, and a radio interview with Maryanne Ellis on ABC radio's Country Hour 16th June 1999. Nancy has now achieved the status of "Mainland Expert"!

Other pests

The numbers of cabbage centre moths - *Hellula* caught in the light trap at Stony Rise has increased over the last few years. Seed growers have reported damage that could be due to this species. The work this season will help confirm the levels of damage and field activity.

Seasonal catches

Plutella moth catches in the light trap over the last 7 years reveal a trend of increasing numbers each year (Figure 1) excluding 1997 for unknown reasons. Claims by field officers that numbers of *Plutella* are over-wintering in the local crops requiring a continuous schedule of spraying, will be investigated. It is planned to ascertain this over winter.

Plutella catches in Stony Rise light trap January 1992 to July 1999
The trap does not seem to detect autumn populations in crops

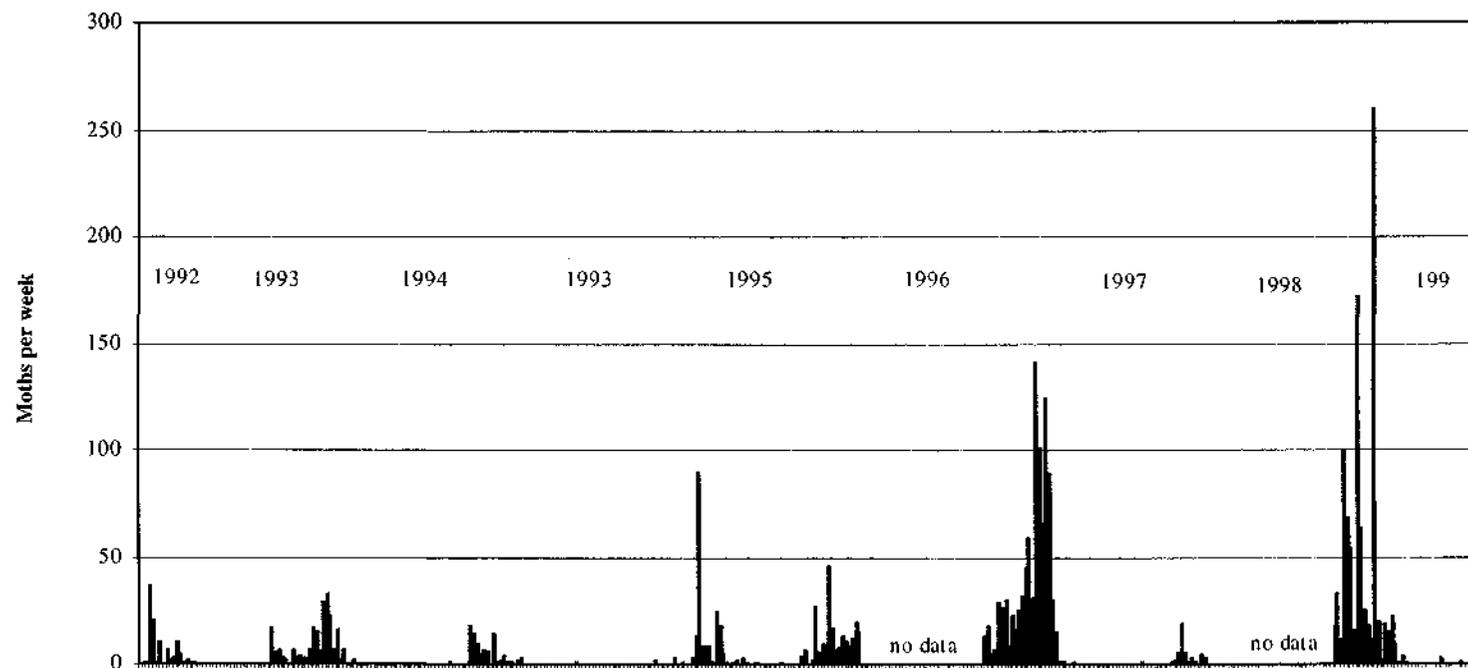


Figure 1. Light trap catches of *Plutella xylostella* for 1992-9.

Next season

Monitor Parasitism

The interest and curiosity generated in us and many field officers by the preliminary high parasitism counts will be followed up by rearing out samples over the season from 3-4 crops to get a feel for the distribution of parasitism during the season.

Scout Commercial Crops

The DPIWE IPM team is undertaking to collate a *Brassica* benchmark for pesticide applications for Tasmanian growers. To complement this and generate a more biologically complete data set for future reference, it is proposed to monitor some commercial crops using the pheromone trap, and full counts of eggs, larvae, other pests and beneficials. This will also hopefully also provide some convincing local data for use in extension activities and to guide future work by contributing to an understanding of where growers are at with IPM/IRM.

Seed growers issues

The seed industry is a high value component of the Tasmanian brassica industry and there seem to be some specific application and timing issues. Their crops are in the ground for an extended period of time, growing to heights around 1.5-2m. The essential pollination of the crop is by bees and they must not be killed by any spray applications. These need closer examination to facilitate potential resolutions. This will be done by fostering links with the field officers and growers over the next year. An invitation has been received to address them later in the season.

INSECTICIDE RESISTANCE UPDATE

Nancy Endersby, Peter Ridland and Jing ye Zhang

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1. CURRENT STATUS OF PERMETHRIN RESISTANCE IN AUSTRALIAN DBM

High levels of resistance to permethrin continue to be detected in populations of diamondback moth from Queensland (Figure 1) using a leaf dip bioassay, while resistance levels in populations from the other states are relatively low. There has been a significant decrease in permethrin resistance level in diamondback moth in Werribee in Victoria since the 1994 testing.

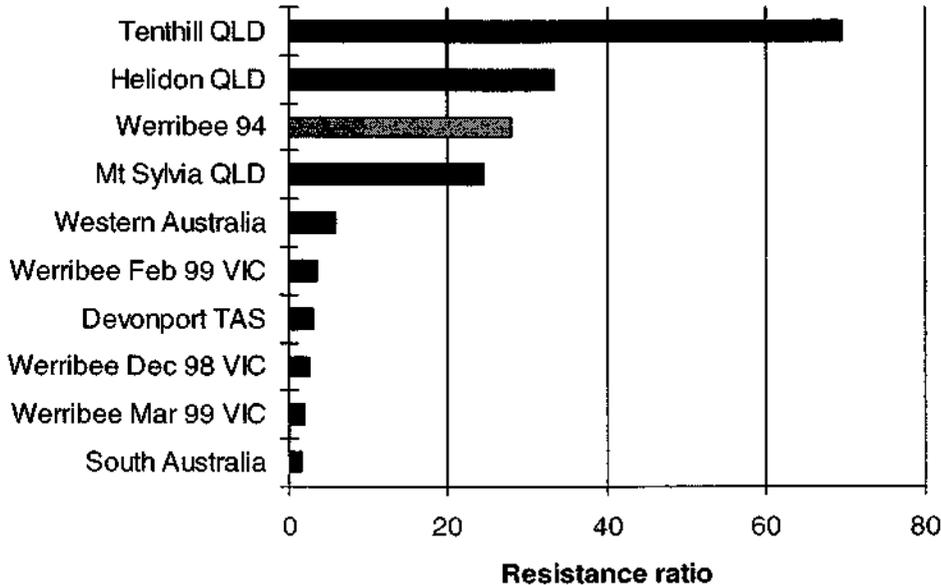


Figure 1. Resistance ratios (RR) of permethrin for Australian DBM populations, 1998/99 (compared with the susceptible laboratory population)

2. PERMETHRIN RESISTANCE LEVELS OF DBM ON WEEDS & CANOLA IN VICTORIA, 1998/ 99

Introduction

The resistance status of DBM populations on cruciferous weeds, canola and *Brassica* forage crops outside of major vegetable growing areas may have important implications for insecticide resistance management. In Victoria there are some extensive canola crops to the north west of the vegetable growing district of Werribee South. This is a preliminary study of resistance levels to permethrin in some DBM populations from non-vegetable brassicas in Victoria.

Methods

Populations were tested from the following host plants and locations:

- Cruciferous weed sp. 1, Balliang East (37° 50'S 144° 21'E) (31 km from Werribee South)
- Canola, NE of You Yangs, 1.8 km NW of Kirksbridge Rd cnr 37° 52' S 144° 27' E (23 km from Werribee South)
- Cruciferous weed sp. 2, NE of You Yangs, 1.8 km NW of Kirksbridge Rd cnr 37° 52' S 144° 27'
- Cauliflower, Whites Road, Werribee South (37° 57'S 144° 42'E)
- Mizuna, Stratford (37° 58' S 147° 05' E)
- Broccoli, Duncans Rd, Werribee South (37° 57'S 144° 42'E)

A leaf dip bioassay after Tabashnik and Cushing (1987) was adopted. Cabbage (*Brassica oleracea* var. *capitata* cv. Green Coronet) leaf discs of 4.5 cm diameter were dipped for 5 s in distilled water solutions of formulated insecticide and hung vertically to dry in a fume hood for 2 h. Control discs were dipped in distilled water only. Four replicates of each concentration were made.

Discs were placed in 5 cm diameter plastic Petri dishes (Gelman®). Ten third instar *P. xylostella* larvae were placed on to each disc and allowed to feed at 28°C. Mortality was assessed at 48 h. Dead larvae were those which did not move when touched with a paintbrush.

Analysis

Probit analysis (POLO-PC, LeOra Software) was used to estimate LC₅₀ and slope of the regression line for each population. LC₅₀ is the concentration expected to cause 50% mortality of the population. The fit of the data to the probit analysis model was measured by χ^2 . If the model fits, the calculated value of χ^2 will be less than the value in the χ^2 table for the appropriate degrees of freedom. Heterogeneity factor (χ^2/df) was used to account for any lack of fit. The index of significance for potency estimation (g) was used to calculate 95% confidence intervals for potency (relative potency is equivalent to resistance ratio). Parallelism of the probit regression lines implies a constant relative potency at all levels of response (Finney 1971).

RESULTS

Probit analysis of the data showed that parallel slopes could not be fitted for the Waite and the Balliang East populations. The toxicity ratio for the Balliang East population was calculated at LC₅₀ (LC₅₀ [Balliang East]/ LC₅₀ [Waite]) (the ratio is different at other LC values due to different slopes). Confidence intervals in this non-parallel situation were calculated as described by Robertson and Preisler (1992). Using this method, if the 95% confidence intervals include 1, then the LC₅₀ of the population is considered not significantly different from the LC₅₀ of the Waite population ($P=0.05$). Probit analysis of the data showed that parallel slopes also could not be fitted for the Waite and the Werribee Feb 99 populations and the Waite and the Werribee Mar 99 populations.

Probit analysis of the data showed that parallel slopes could be fitted for the Waite and the You Yangs canola populations. The toxicity (or resistance) ratio and 95% confidence intervals for You Yangs canola is calculated as the reciprocal of the relative potency and confidence intervals provided by the POLO analysis (derived from the parallel slope). Probit analysis of the data showed that parallel slopes could also be fitted for the Waite and the You Yangs weed populations, the Waite and the Werribee Dec 98 populations and the Waite and the Stratford mizuna populations.

The Balliang East, You Yangs canola, You Yangs weed, Stratford mizuna and Werribee Dec 98 populations showed a very low level of resistance to the synthetic pyrethroid, permethrin, compared with the susceptible Waite population in a leaf dip bioassay (Table 1).

The Werribee Dec 98 and You Yangs canola populations showed the same response to permethrin. When the two populations were analysed together, the slope was the same and both populations were statistically equivalent - we could fit a common probit line through both data sets (Table 2).

Table 1. LC₅₀ and LC₉₅ values of permethrin for DBM populations from weeds, canola and vegetable crops in Victoria, 1998/ 99

Date collected	Population	Host	n	Controls	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀	95% confidence intervals	LC ₉₅	95% confidence intervals
29/10/98	Waite	Lab	280	40	2.08 ± 0.24	1.31	0.07	34.1	26	8.4	5.8 – 11.1	51.9	36.1 – 91.5
	Balliang East	Weed 1	280	40	1.02 ± 0.16	1.47	0.15	38.2	26	18.3	6.7 – 32.1	759.6	340.6 – 3982.2
29/10/98	Waite	Lab	281	40	2.40 ± 0.41	1.20	0.15	31.1	26	20.1	12.3 – 26.6	97.4	68.2 – 196.9
	NE of You Yangs	Canola	280	40	2.45 ± 0.36	0.96	0.08	25.0	26	45.0	31.7 – 57.8	211.0	154.4 – 347.3
29/10/98	Waite	Lab	281	40	2.40 ± 0.41	1.20	0.15	31.1	26	20.1	12.3 – 26.6	97.4	68.2 – 196.9
	NE of You Yangs	Weed 2	280	40	1.82 ± 0.21	1.48	0.09	38.4	26	44.5	29.4 – 61.6	356.8	224.6 – 765.3
27/10/98	Waite	Lab	280	40	2.87 ± 0.33	2.68	0.15	69.6	26	19.4	13.0 – 26.0	167.4	115.8 – 292.9
	Stratford	Mizuna	280	40	1.76 ± 0.23	0.71	0.07	18.6	26	12.9	9.5 – 16.6	61.6	42.8 – 110.4
7/12/98	Waite	Lab	281	40	2.40 ± 0.41	1.20	0.15	31.1	26	20.1	12.3 – 26.6	97.4	68.2 – 196.9
	Werribee Dec 98	Cauliflower	119	40	2.38 ± 0.41	1.16	0.17	11.6	10	52.9	34.1 – 73.3	259.6	161.4 – 716.1
15/02/99	Waite	Lab	281	40	2.42 ± 0.26	1.61	0.08	42.0	26	9.6	6.4 – 13.2	36.0	24.3 – 75.6
	Werribee Feb 99	Cauliflower	280	40	1.65 ± 0.20	1.16	0.07	30.2	26	33.2	22.7 – 44.7	331.6	213.0 – 666.2
12/03/99	Waite	Lab	279	41	2.68 ± 0.37	1.28	0.10	33.4	26	4.9	3.3 – 6.4	20.1	14.5 – 34.7
	Werribee Mar 99	Broccoli	281	40	1.71 ± 0.27	0.65	0.10	17.0	26	9.6	5.0 – 14.3	88.2	60.7 – 160.0

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

Table 2. Comparison of DBM populations from commercial vegetable crop (Werribee) and canola (You Yangs)

Population	n	Controls	Slope ± s.e.	Het.	g	χ ²	df	LC ₅₀	95% confidence intervals	LC ₉₅	95% confidence intervals
Werribee Dec 98 & You Yangs canola	399	80	2.42 ± 0.26	0.98	0.05	42.0	26	47.9	34.1 – 56.9	229.1	176.3 – 333.8

n=number of subjects, Het.=heterogeneity, s.e.=standard error, df=degrees of freedom

Resistance ratios ranged from 1.8 to 3.4 compared with the susceptible laboratory population (Waite) (Figure 2). 95% confidence intervals are shown in Table 3.

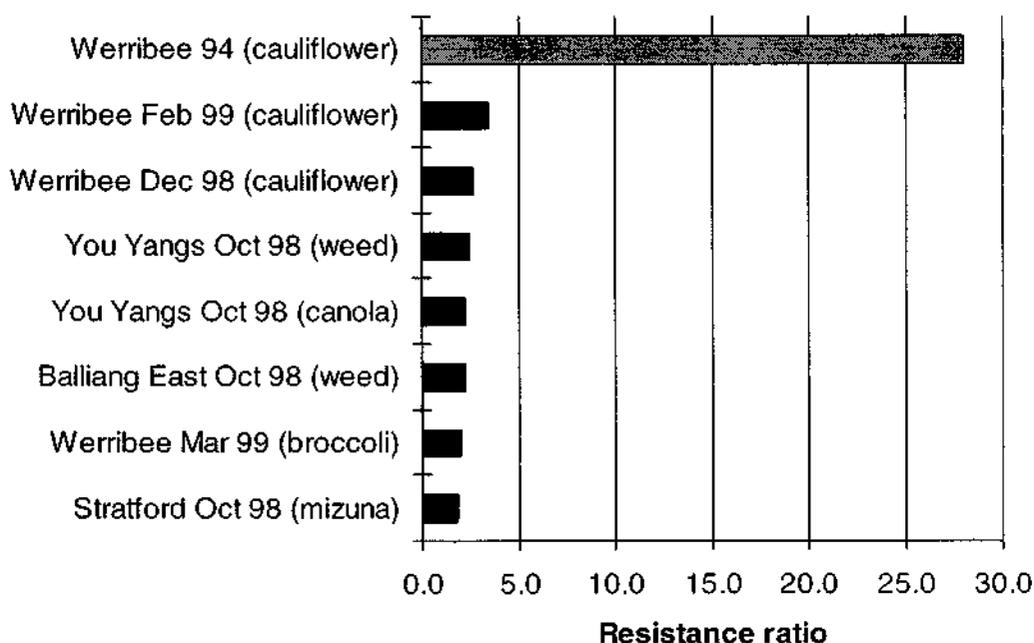


Figure 2. Levels of permethrin resistance in Victorian populations of DBM collected from weeds, canola and vegetable brassicas (resistance ratio (RR) compared with the susceptible laboratory population)

Table 3. Resistance ratios and 95% confidence intervals of populations of diamondback moth from Victoria for permethrin

DBM population	Test Date	Resistance Ratio	95% c. i.		Gen	
			lower	Upper		
Balliang East	9/12/98	2.2	1.2	4.0	F1	calculated at LC ₅₀
You Yangs canola	2/02/99	2.2	1.6	3.0	F2	parallel slope with Waite
You Yangs weed	2/02/99	2.5	1.6	3.7	F2	parallel slope with Waite
Werribee Dec 98	2/02/99	2.6	1.8	3.9	F1	parallel slope with Waite
Werribee Feb 99	22/03/99	3.4	2.4	4.9	F1	calculated at LC ₅₀
Werribee Mar 99	19/04/99	2.0	1.1	3.4	F1	calculated at LC ₅₀
Stratford	10/02/99	1.8	1.2	2.5	F2	parallel slope with Waite

DISCUSSION & CONCLUSIONS

A DBM population from a canola crop about 25 km west of Werribee and another population from a Werribee vegetable grower's property were statistically equivalent with respect to response to permethrin. The resistance ratio (compared with the Waite) was only about 2.6 x. One explanation of these results is that there was a movement of relatively susceptible moths into the vegetable areas in the spring. An alternative hypothesis is that the permethrin resistance levels in the vegetable areas have declined due to the substantial reduction in use of synthetic pyrethroids by growers. We intend to do a lot more testing in spring 1999 to assess permethrin resistance status of a number of crops throughout the Werribee area and in nearby canola crops. If we can confirm the hypothesis of substantial movement of susceptible moths into the vegetable regions this will be most helpful for delaying development of resistance to the new chemistries.

3. Other new insecticides

Baseline toxicity data for most of the new insecticides registered or soon to be registered for DBM have now been obtained for one population of DBM from each state in Australia.

Who benefits now and in the future?

IRM strategy

Growers using the insecticides

Chemical companies

Next steps

a) 1999/ 2000

Baseline data for most of the new insecticides has been obtained, but there are more compounds on the way and they will need to be tested. AIRAC is currently considering a proposal to contribute funds to a National resistance testing program. The program aims to monitor for substantial changes in susceptibility to new insecticides registered or approaching registration for control of DBM in Australia.

Proposed insecticides to be monitored

1. fipronil
2. chlorfenapyr
3. spinosad
4. emamectin benzoate
5. indoxacarb
6. novaluron
7. a synthetic pyrethroid
8. *Bacillus thuringiensis*
9. an organophosphate - e.g. methamidophos

Field populations of DBM will be tested at the end of each IRM strategy window (i.e. twice per year) with a diagnostic dose. In the event of significant changes in response being detected, more detailed testing of the population would be undertaken to establish its resistance status.

If the AIRAC members decide to fund the proposal, we hope work will commence as part of the final year of the current project and will continue as part of a second National DBM project if this eventuates.

Results of our studies of resistance levels in DBM populations from weeds and canola are still preliminary. This area needs further study and we will continue it in the final year. We would also like to continue the research in a second project.

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Efficacy of Five New Insecticides and Their Impact on Two Species of Natural Enemies of Brassica Pests

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Objectives

1. To compare the relative efficacy of five new insecticides (Regent®, Secure®, Success®, Proclaim® and Avatar®)
2. To assess the relative toxicity of the five new insecticides to the cabbage white parasitoid, *Cotesia glomerata*, and the cabbage aphid parasitoid, *Diaeretiella rapae*

Methods

Efficacy against DBM

A field experiment was conducted between March 29 and April 9, 1999 in a commercial cabbage field in Virginia, SA. During the course of the experiment, the cabbages were of small to medium size. Three double-rows of the cabbage field were used for the experiment. The experiment was designed as complete random blocks. Six blocks were laid out in the experimental area, with 2 blocks along each double-row. Within each block, 6 plots each containing at least 30 cabbages were laid out. The 6 treatments, five insecticides and a control, were randomly assigned to the 6 plots of each block. The treatments were applied with 15L knapsacks. Application rates for the five insecticides were based on their respective recommended rates (Table 1). In addition to the insecticides, each 15L solution also contained 4ml of the surfactant Citowet®. For the control, only the surfactant was added. Two applications of the treatments, separated by 8 days, were made. Larval numbers assessed 1 day before the first application and 2 days after each application. Data were analysed with ANOVA and Duncan's multiple range tests.

Table 1. Application rates

Treatment	Rate per 15L	Rate per 1L
Regent®	3.75ml	0.25ml
Proclaim®	4.5g	0.3g
Secure®	6ml	0.4ml
Avatar®	3.75g	0.25g
Success®	6ml	0.4ml

Toxicity to parasitoids

Impact of the insecticides on the two parasitoids was studied using leaf discs. The parasitoids were confined in ventilated cylindrical arenas (7mm x 25mm diam.) formed by a foam pad with a central hole sandwiched between two glass plates. Ventilation was provided by 2 plastic tubes (30mm x 5mm diam.) inserted through the foam pad wall into the test arena from two opposite directions. Driven by a suction device, air flows from outside into the arena through one tube and out again through the other tube. The foam pad and glass plates were held together by two clamps. One leaf disc (treatment or control) was placed in between the foam pad and the lower glass plate, forming the floor of the test arena.

Six experiments were conducted between March 8 and August 3, 1999, 5 for *D. rapae* and 1 for *C. glomerata*. For each experiment, 30 test arenas were used, 5 for each treatment and control. Three to 8 adult parasitoids were introduced into each test arena. The experiment was run for 24 hours under room temperature (21-23°C) and no direct sunlight, at the end of which the number of adult parasitoids surviving was recorded. Treatments were applied with a 1-litre atomiser to cabbage plants grown in a

field plot in the Waite Campus of the Univ. of Adelaide. The same application rates of the chemicals and surfactants as in the efficacy experiment were used (Table 1). The control plants were only sprayed with water and the surfactant. To prevent the washing off of the chemicals, the test plants (including the control plants) were covered on top with a plastic sheet ca. 1m above the plants. Leaf discs were cut from the test plants at a series of times after the spraying, ranging from 2 hours to 9 days. Data were analysed with chi-square proportion tests.

Results

Efficacy against DBM

Pre-treatment larval density in the 36 plots (6 treatment x 6 blocks) from 8.5 to 9.5 per 10 plants. There were no significant differences ($P>0.05$) in larval density among treatments (Table 2).

Table 2. ANOVA of pre-treatment density of DBM larvae

Source	SS	DF	MS	F	P
Treatment	5.1389	5	1.0278	0.0945	0.9923
Block	213.8056	5	42.7611	3.9298	0.0091
Error	272.0278	25	10.8811		
Total	490.9722	35			

Two days after the first application of the treatments, larval density in plots treated with the 5 insecticides was reduced by 98-100%. However, there were no significant differences among the treatments ($P>0.05$) (Table 3).

Table 3. Separation of means by Duncan's Multiple Range Tests ($\alpha=0.05$). Two days after the first application.

treatment	Mean/10 plants	significance grouping
Success®	0.5	A
Avatar®	0.6667	A
Secure®	0.8333	A
Regent®	1.5	A
Proclaim®	1.8333	A
Control	4.8333	B

Two days after the second application of the treatments, larval density in plots treated with the 5 insecticides was reduced by 79-94%. Again there were no significant differences among the treatments ($P>0.05$) (Table 4).

Table 4. Separation of means by Duncan's Multiple Range Tests ($\alpha=0.05$). Two days after the second application

treatment	Mean/10 plants	significance grouping
Proclaim®	0	A
Secure®	0	A
Success®	0	A
Avatar®	0.16667	A
Regent®	0.5	A
Control	6	B

Toxicity to *Diaeretiella rapae*

Two hours after the application of the treatments (Day 0), Regent® and Secure® showed significant toxicity ($P<0.05$) to *D. rapae* in 4 of the 5 experiments performed (Figure 1). In contrast, Proclaim® and Avatar® were significantly toxic ($P<0.05$) in only one experiments. The toxicity status of

Success® was not as clear cut as the other 4 insecticides. It caused significantly higher mortality than the control in 3 experiments but showed similar mortality rate in control in the other two experiments.

Two experiments were available for toxicity assessment at day 3. Secure® showed significant toxicity ($P < 0.05$) in both experiments. Mortality caused by Regent® was higher than that by Success®, Proclaim®, Avatar® and the control in both experiments but the differences were not significant ($P > 0.05$) (Figure 1).

At day 7, none of the insecticides showed significant toxicity to *D. rapae* (Figure 1). However, the mortality rate caused by Secure® and Regent® were still about twice as high as that caused by the control, whereas the mortality rates caused by the other 4 insecticides were comparable to control.

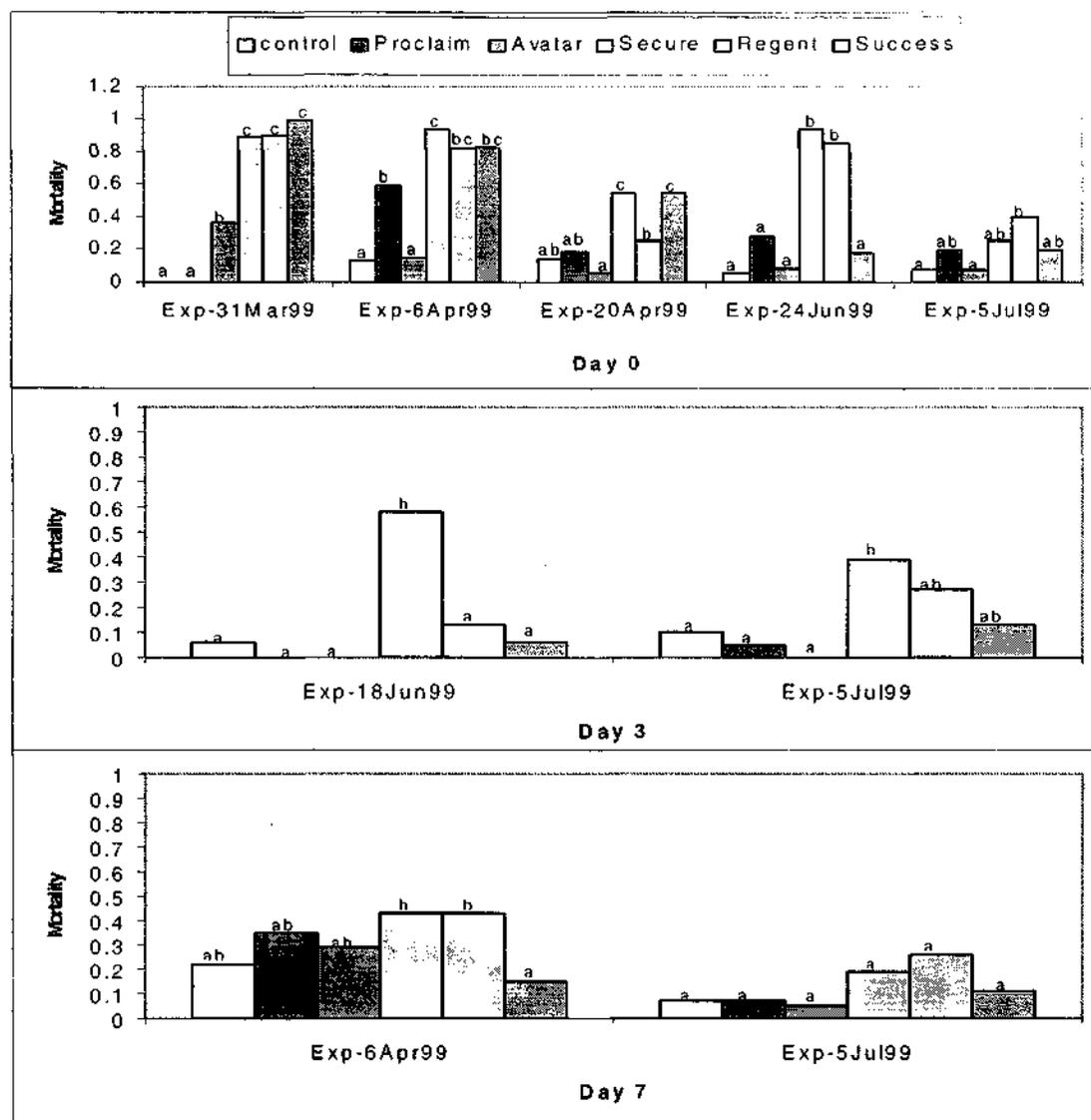


Figure 1. Toxicity tests of five insecticides, Proclaim®, Avatar®, Secure®, Regent®, and Success®, to *Diaeretiella rapae*, a parasitoid wasp of cabbage aphid. Bars not sharing a common letter for the same experiments are significantly different at $\alpha = 0.05$.

Toxicity to *Cotesia glomerata*

Only Regent® and Secure® showed significant toxic effect on this parasitoid (Figure 2). The toxic effect was still seen for both insecticides 3 days after the treatment. By day 7, however, only Secure

remained toxic. Regent caused higher mortality than Secure on day 0 and day 3 but the opposite was true on day 7.

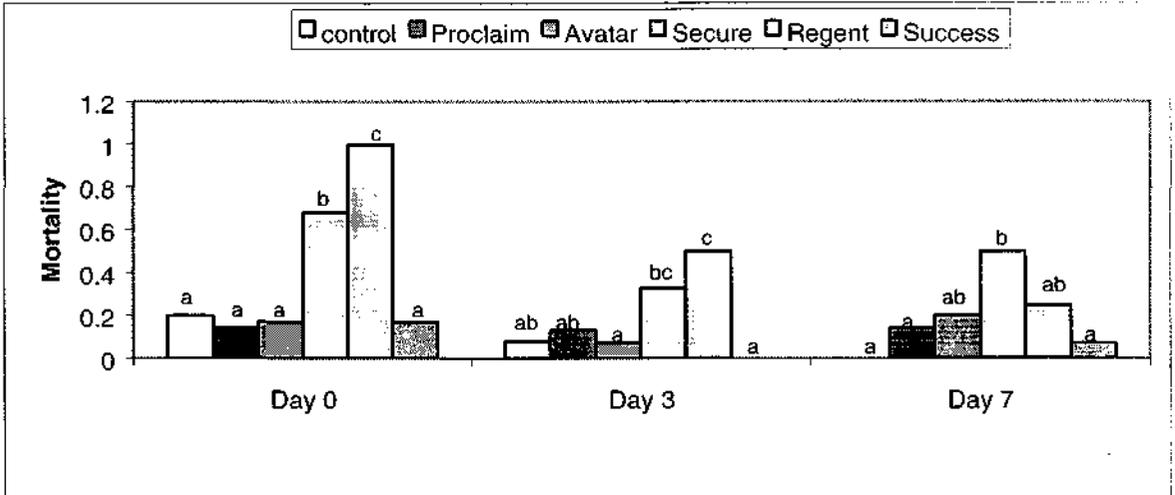


Figure 2. Toxicity tests of five insecticides, Proclaim®, Avatar®, Secure®, Regent®, and Success®, to *Cotesia glomerata*, a parasitoid wasp of cabbage white butterfly. Bars not sharing a common letter for the same experiments are significantly different at $\alpha=0.05$.

Discussion

It appears that each of the five new insecticides were equally effective against DBM. They differ, however, in their toxicity on the two parasitoids. For the cabbage aphid parasitoid, Avatar® and Proclaim® appear to be relatively non-toxic, whereas Regent® and Secure® appear to be toxic for at least 3 days. The toxicity of Success® against this parasitoid is not yet clear. In some experiments, Success® showed similar toxicity as Regent® and Secure® but in others it was found to be quite harmless. More experiments are needed to determine its toxicity to this parasitoid. Only one toxicity experiment has been done for the cabbage white butterfly parasitoid. The result showed that Regent® and Secure® were toxic to this parasitoid for up to 7 days. The other 3 insecticides appear to be non-toxic.

Suggested work for 2000-2003

- Testing of newly registered insecticides. Possibly neem-based products
- Assess the adulticidal activity of the five new insecticides, 2 OPs, 2 SPs, and 1 carbamate.

SMALL PLOT TRIALS WITH DBM

Nancy Endersby and Peter Ridland

Institute for Horticultural Development, Knoxfield, Private Bag 15, South Eastern Mail Centre VIC 3176

1. Oviposition patterns on cabbage seedlings

Ten cabbage seedlings (cv Green Coronet) were harvested daily for the first 14 days after transplant and assessed for eggs and larvae of diamondback moth and cabbage white butterfly. We wanted to answer the question "when and where are the eggs laid during the first two weeks of seedlings being in the ground?" This knowledge will assist in improving strategies to protect the young growth stages of brassicas from transplant to about 5 weeks after transplanting. The first DBM egg was found three days after transplanting (Figure 1) and the first CWB eggs were observed four days after transplanting. The first CWB larva was observed on a plant eight days after transplant and the first DBM larva was recorded at eleven days after transplant (Figure 2).

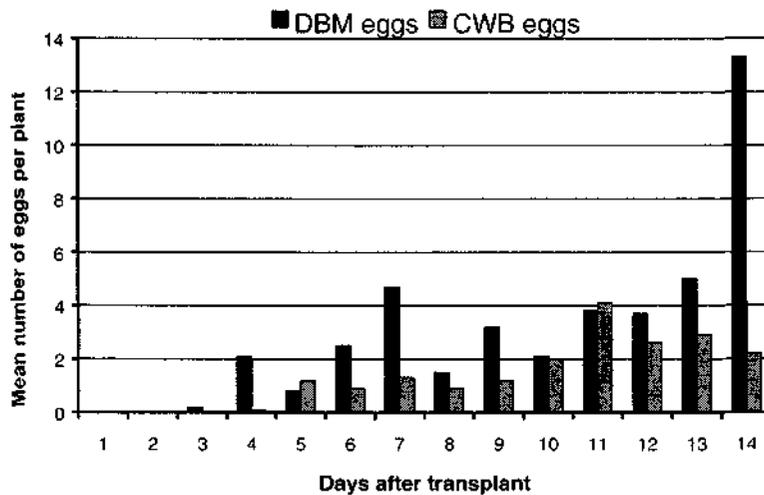


Figure 1. Number of eggs on seedlings 1 to 14 days after transplant, 20-Jan-99 to 2-Feb-99, Cabbage (cv. Green Coronet), IHD Knoxfield, Victoria

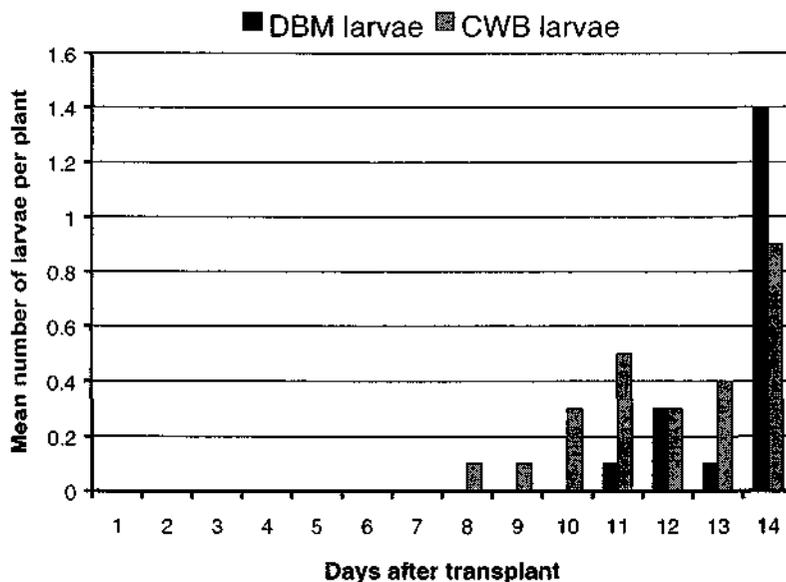


Figure 2. Numbers of larvae on seedlings 1 to 14 days after transplant, 20-Jan-99 to 2-Feb-99, Cabbage (cv. Green Coronet), IHD Knoxfield, Victoria

DBM eggs were mainly laid on the leaves (Figure 3). In total, 205 eggs were laid on the adaxial surface and 189 were laid on the abaxial surface. Only 34 eggs were found on the petiole and one on the stem. The majority of CWB eggs (141 out of 194) were laid on the underside of the leaf (Figure 4).

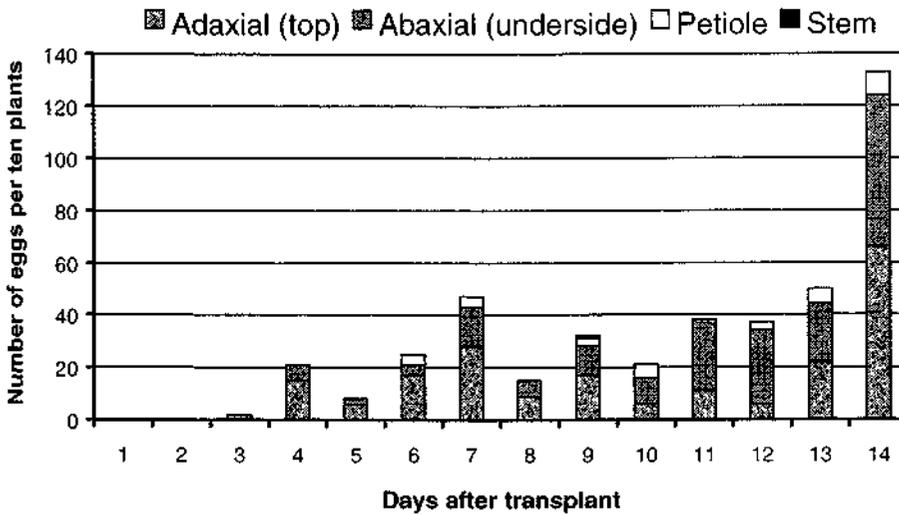


Figure 3. Position of DBM eggs on leaves, assessed from 1 to 14 days after transplant, 20-Jan-99 to 2-Feb-99, Cabbage (cv. Green Coronet), IHD Knoxfield, Victoria

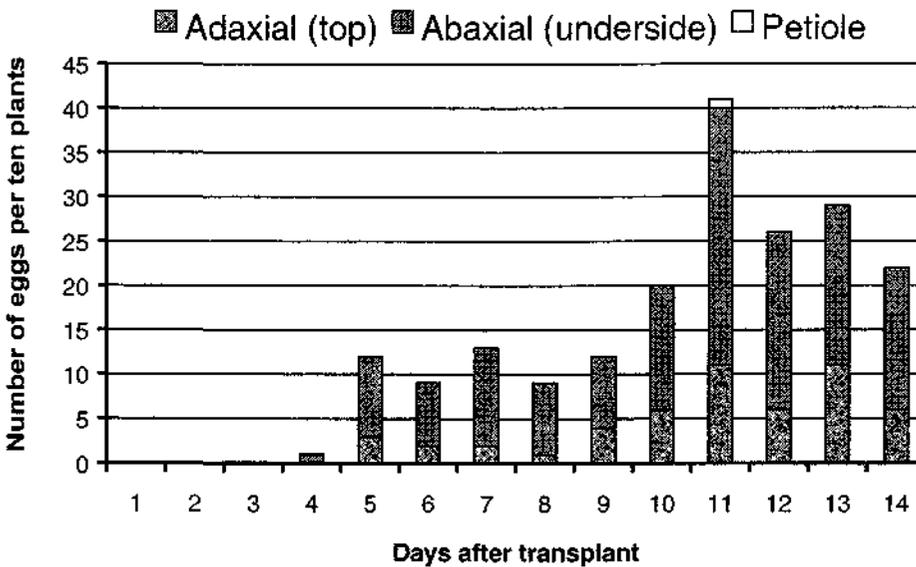


Figure 4. Position of CWB eggs on leaves, assessed from 1 to 14 days after transplant, 20-Jan-99 to 2-Feb-99, Cabbage (cv. Green Coronet), IHD Knoxfield, Victoria

The majority of DBM eggs (243 of 429) were laid on the lower part of the plant (Figure 5), while most CWB eggs (160 of 194) were laid on the upper leaves (Figure 6).

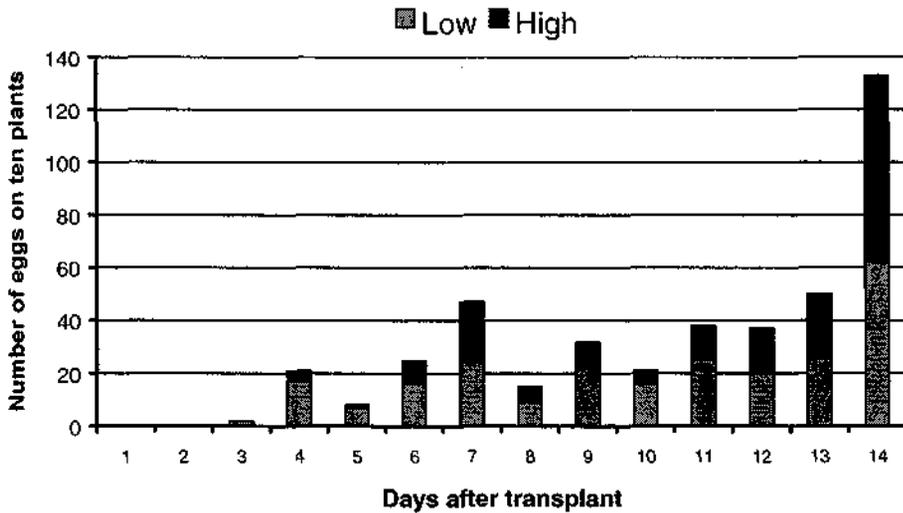


Figure 5. Position of DBM eggs on seedlings, 1 to 14 days after transplant, 20-Jan-99 to 2-Feb-99, Cabbage (cv. Green Coronet), IHD Knoxfield, Victoria [Low = leaves 1-7, High = leaf 8+, leaves 1 and 2 are cotyledons]

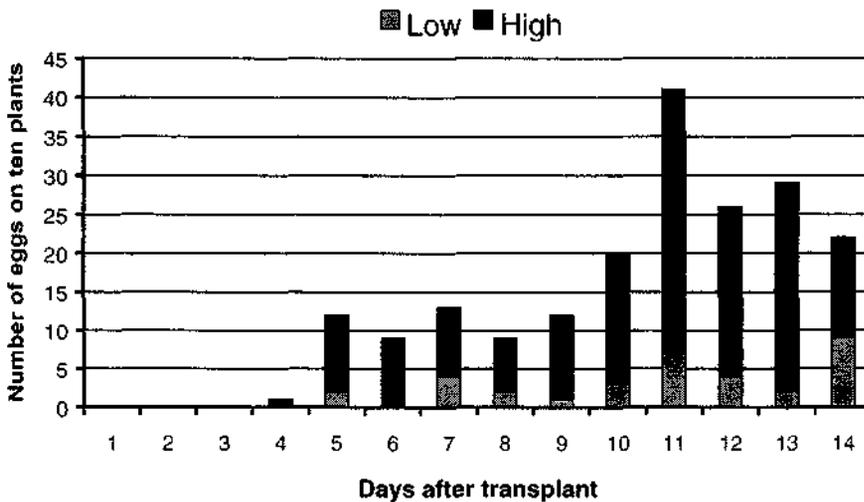


Figure 6. Position of CWB eggs on seedlings, 1 to 14 days after transplant, 20-Jan-99 to 2-Feb-99, Cabbage (cv. Green Coronet), IHD Knoxfield, Victoria [Low = leaves 1-7, High = leaf 8+, leaves 1 and 2 are cotyledons]

Conclusion

The seedling assessment identified some differences in egg placement between CWB and DBM. The majority of CWB eggs were laid on the upper leaves of the plant and on the underside of the leaf. The majority of DBM eggs were laid on the lower leaves of the plant, but eggs were equally likely to be laid on either side of the leaf.

2. Field evaluation of Bt mixed with milk powder or dimethoate

INTRODUCTION

Hamilton & Attia (1977) found dimethoate to be highly antagonistic to activity of *Bacillus thuringiensis* (Bt) in laboratory leaf dip bioassays with diamondback moth larvae. Mixing dimethoate with Bt is a common practice of vegetable *Brassica* growers in Victoria who aim to target aphids at the same time as diamondback moth larvae. The practice is not recommended, but should be investigated fully in case Bt efficacy is being jeopardised.

Milk powder and other substances such as molasses and sugar are being used as feeding stimulants particularly for heliothis control in Queensland (Murray 1999). Skim milk powder has been used as a protectant to improve persistence of insect viruses used as biological control agents and as a feeding stimulant to increase ingestion of microbial insecticides. If a benefit can be shown through further studies with DBM, then knowledge can be made available to growers.

METHOD

A small field trial was conducted at IHD, Knoxfield to generate some information about the effects of dimethoate and milk powder on efficacy of Bt. Four insect assessments and three spray applications were made (Table 1).

Table 1 . Timetable of activities for Bt, milk and dimethoate trial undertaken at IHD Knoxfield, Victoria.

Date	Activity	Weeks after transplant
26-Feb-99	Transplanting (400 cabbage cv. Green Coronet)	0
30-Mar-99	Insect count #1 (pretreatment)	5
01-Apr-99	Spray application # 1	5
07-Apr-99	Insect count #2 (post treatment 1)	6
08-Apr-99	Spray application #2	6
14-Apr-99	Insect count #3 (post treatment 2)	7
16-Apr-99	Spray application #3	7
22-Apr-99	Insect count #4 (post treatment 3) (FINAL)	8

Products and rates used in the trial are shown in Table 2.

Table 2. Treatments and rates used in Bt, milk and dimethoate trial undertaken at IHD Knoxfield, Victoria.

			Surfactant
1	Bt + dimethoate	Dimethoate = Yates ROGOR® insecticide 100 ml Pack, 300 g/ L dimethoate, rate [vegetables] 10 ml/ 10 L	Monsoon® 30 ml/ 100L
2	Bt + milk powder	Delfin® WG and Veanavite®	Monsoon® 30 ml/ 100L
3	Control (water)	Control = water	Monsoon® 30 ml/ 100L
4	Milk powder	Veanavite® Calf Food, rate 1.0 kg/ ha	Monsoon® 30 ml/ 100L
5	Bt	Bt = Delfin® WG, rate [cole crops – high volume] 25 g/ 100 L	Monsoon® 30 ml/ 100L

RESULTS

Pretreatment:

- no significant difference in egg numbers between treatments (Figure 7).

Post treatment 1:

- no significant difference between 3 Bt treatments
- Bt + dimethoate had significantly fewer larvae than the control and milk
- Bt alone and Bt + milk had significantly fewer larvae than the milk treatment

Post treatment 2:

- no significant difference between 3 Bt treatments
- each Bt treatment had significantly fewer larvae than the control and milk
- equivalent numbers of larvae in control and milk treatment

Post treatment 3:

- no significant difference between 3 Bt treatments
- each Bt treatment had significantly fewer larvae than the control and milk
- milk treatment had significantly more larvae than the control

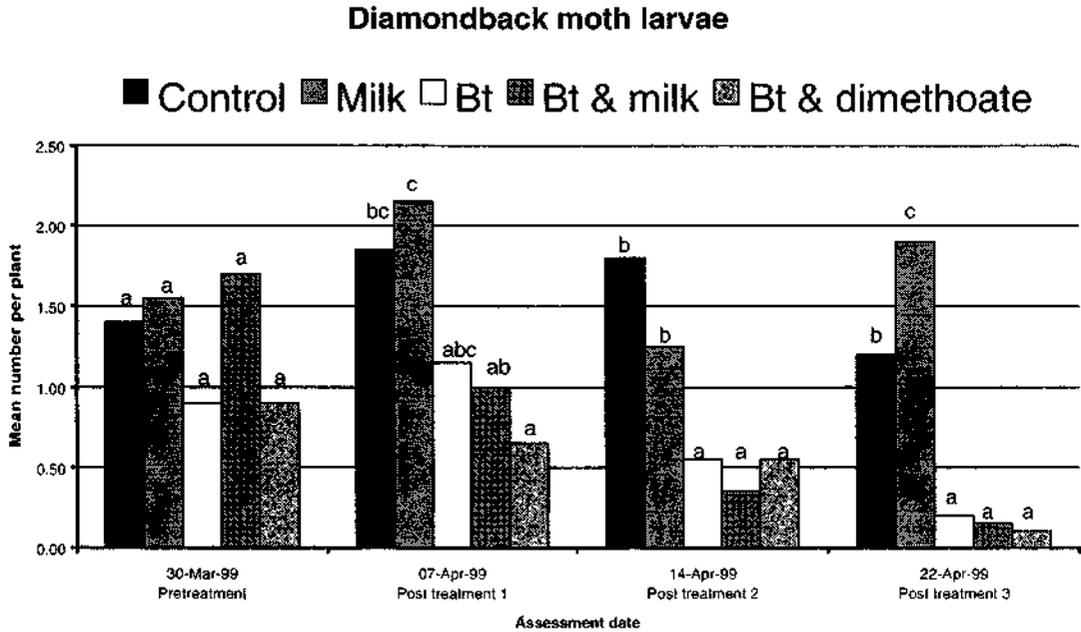


Figure 7. Effect of applications of *Bacillus thuringiensis*, milk powder and dimethoate on numbers of DBM larvae on cabbage plants

CONCLUSION

Addition of milk powder or dimethoate to Bt had no effect on efficacy towards DBM larvae in the field experiment.

Other trials in progress:

- surfactant trials in oviposition cages
- testing of *Diadegma semiclausum* & *Diadromus collaris* with 5 new insecticides

Who benefits so far and in the future?

Bt and milk, dimethoate type studies will benefit growers in the future. Information about the influence of commonly used surfactants on oviposition by DBM may also benefit growers. Information about the susceptibility of beneficial insects to the new insecticides is important and may influence where they are positioned in the IRM strategy windows.

Next steps

a) 1999/ 2000

- Repeat Bt, milk, dimethoate trial in the laboratory as a bioassay of DBM larvae
- Dose response and feeding consumption of Bt ± milk powder
- Dose response of Bt ± dimethoate
- Continue surfactant studies in oviposition cages

b) Future funding

- Compare oviposition on plain cabbage and Savoy
- Compare oviposition on White Rock and Prestige cauliflower
- Resistant varieties
- Egg recruitment patterns
- Bioefficacy of Bt in the field
- Source of spring moths: Role of canola, weeds and forage brassicas
- Study difference between Werribee and Cranbourne in detail. Where are the moths coming from and can we do anything to control them at the source?

References

Hamilton, J. T. and Attia, F. I. (1977). Effects of mixtures of *Bacillus thuringiensis* and pesticides on *Plutella xylostella* and the parasite *Thyraeella collaris*. *Journal of Economic Entomology* 70: 146 -148.

Murray, D. A. (1999) Australian Grain, June - July 1999.

'Proof of concept' trials to evaluate the use of *Zoophthora radicans* for DBM control and a lure and kill system for DBM

Richard Vickers, CSIRO Division of Entomology

Autodissemination of pathogens - Proof of Concept Trial

Objective: To determine if early-season epizootics can be established in DBM infested fields using fungus-loaded pheromone traps to promote fungus dispersal

Introduction

- *Zoophthora radicans* collected from DBM infested cabbages, Toowoomba, April 1999
- Culture established in CSIRO labs, Brisbane
- 3-C CSIRO pheromone blend 4-10 X more attractive than 2-C blend
- Proof-of-concept trial is part of the ACIAR-funded DBM project

Issues:

- Optimum trap design (male entry and exit, conditions for fungal survival)
- Trap placement and density
- Male movement after leaving trap (distance travelled over time; deposition of fungi)
- Where do infected adults die - on ground or crop?
- Impact on populations

And beyond: Assuming success with the proof-of-concept trials, I would seek to continue the evaluation on a larger scale, where damage assessments would be incorporated. Additional issues include

- Best isolate
- Specificity
- Mass production

Funding

- HRDC
- ACIAR

'Attract and kill'

Negotiations have commenced with Novartis/ IPM Technologies re trials to evaluate the 3-C blend in the Novartis 'Sirene' paste. The paste, which incorporates pheromone, protectants and an insecticide, will achieve control if sufficient males are removed from the population to keep subsequent generations below the economic threshold.

Issues

- Pheromone dose and longevity
- Insecticide type and dose
- Placement (frequency, position, crop contamination)
- Attraction vs landing
- Impact on population

Funding

- Voluntary contributions through HRDC

Mating disruption

3 M are developing a sprayable micro-capsule and have expressed an interest in trialing the 3-C blend as a mating disruptant.

Advantages (over hand-applied dispensers)

- Ease of application
- Better pheromone distribution

Disadvantages

- Longevity (currently 3-4 weeks)
- Determining release rates is complicated

Funding

- Voluntary contributions through HRDC

- **Annual Report 1998/99 – HRDC Advancing management of diamondback moth in crucifer vegetables crops**

B. Houlding, presented by J. Duff

Queensland

1. Resistance strategy

- Queensland strategy sent to AIRAC for approval for distribution to growers. Feedback required Bt strains not to be rotated. Preferred trade names not to be supplied.
- Changed strategy presented and distributed to growers at monthly meeting (April). Database kept of recipients.
- Strategy also discussed with local resellers (April). Positive cooperation received. No difficulties foreseen in implementing. Not much evidence seen of Secure® in action.
- Strategy presented again at launch of Secure® (May).
- Grower meeting (June/July) reminded growers time to switch to Secure®. Growers still happy with change of products.
- Grower group asked that trade names be provided as well as active ingredients.

2. Handbook

- Distributed to growers (March) from central DPI contact. Database kept enabling sending updates, especially of Strategy.
- QDPI note on diamondback moth in Queensland, full size monitoring sheet and Queensland resistance strategy were added to Handbook.

3. Field trial

Established field trial in conjunction with ACIAR team members for demonstrating control options available for controlling centre grub. Aim was to test current practices being used by growers and also test compatibility with Resistance strategy. Pest was in too low numbers so will repeat next season. Area used for other DBM research in ACIAR project.

4. ACIAR update

- Analysis of yellow sticky trap data is showing some correlation between adult catches on traps and eggs in the crop, as well as between eggs in the crop and subsequent larvae. Analysis is ongoing. More information available from B. Houlding.
- J. Duff and M. Zalucki to report on other ACIAR project activities and those will highlight the more interesting research results.

5. New HRDC project

- At least current budget for support for extension activities (including the printing costs for Handbook updates, field trial) and casual labour for data collection which complements ACIAR and HRDC activities in Queensland.
- Budget for attendance at international DBM workshop and annual project workshops
- Research areas for project – not necessarily by Qld –
 - Wider measurement of Bt resistance in Queensland.
 - Feasibility for commercial releases of any biocontrol agents for use in brassica pest management

Research findings for the ACIAR Project 9213- Improvement in Integrated Pest Management of *Brassica* Vegetable Crops in China and Australia.

Some of the more interesting results to date are listed below in a summarised format. If you require more information then full reports could be sent to interested parties by contacting John Duff at QDPI.

Acceptance of Diamondback Moth Eggs for Parasitization by *Trichogramma* in the Laboratory

Liu, Shu-sheng

(Department of Plant Protection, Zhejiang Agricultural University, Hangzhou 310029, China)

Llewellyn, Richard

(BioResources, 69 Ipswich St., Toowoomba Qld 4350, Australia)

Duff, J.D.

(CRC for Tropical Pest management, c/- QDPI Gatton Research Station, Locked Bag 7, Mail Service 437, Gatton Qld 4343, Australia)

DBM egg exposure procedures

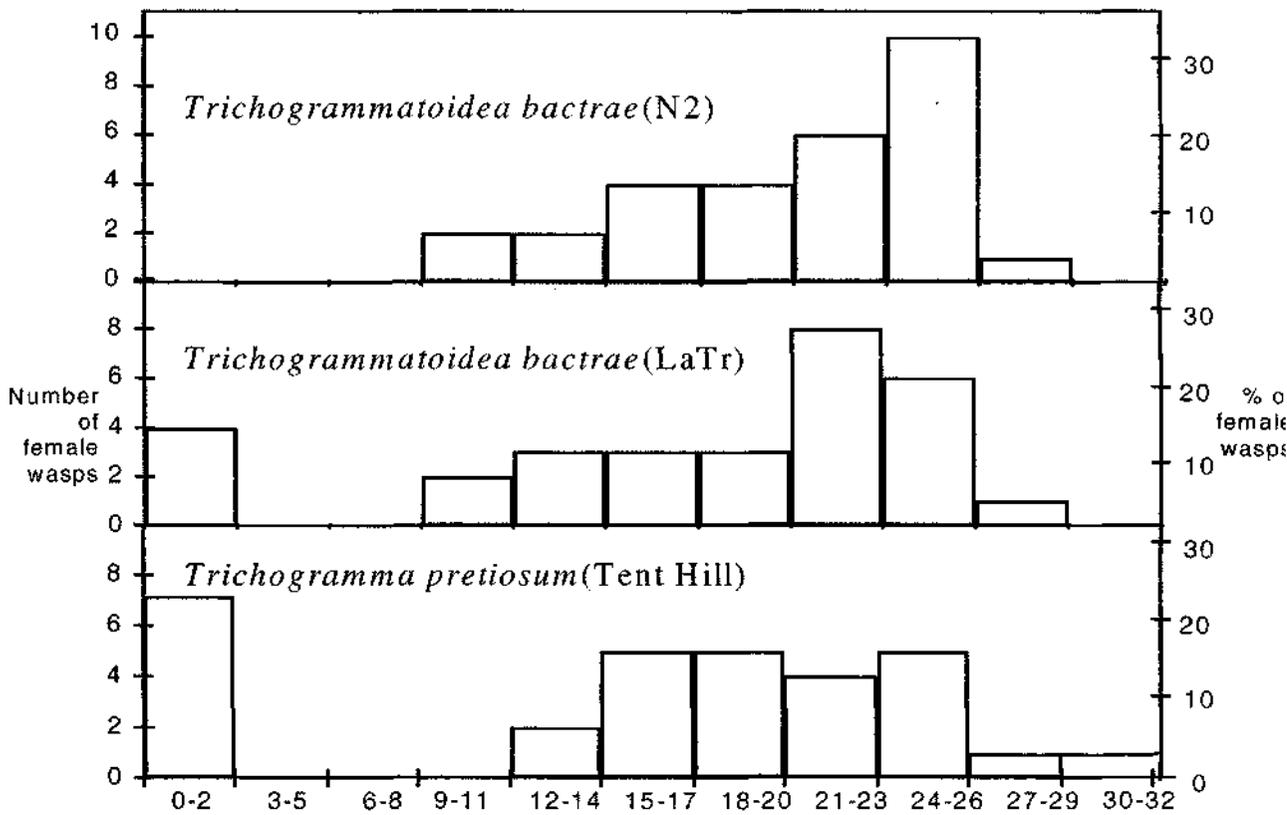
- (1) Plastic bags bearing DBM eggs were cut into egg cards containing about 50 eggs/card;
- (2) Clean glass vials (50×15mm) were prepared, a tiny strip of 20% honey solution was brushed on the bottom of each vial to serve as food for the female wasps;
- (3) A sample of wasps was tapped onto a white sheet of paper. About 50 wasps of each strain were collected singly into vials to be sexed under a microscope to obtain 30 female wasps for each strain;
- (4) A DBM egg card was introduced into each vial and exposed to the female wasp at 25-26°C for 4 h. The wasp was then discarded and the exposed DBM eggs were maintained at 23-28°C (temperature in an air-conditioned room) for parasitoid development;
- (5) Six days later, the number of parasitised (black) eggs in each vial was counted.

There were 30 replicates for each strain of parasitoid.

Mean number of DBM eggs parasitised in a 4-h test by three strains of egg parasitoids.

Strain of parasitoid	All wasps tested		Wasps with successful parasitization	
	n	Mean number (\pm S.D.) of DBM eggs parasitised	n (%)	Mean number (\pm S.D.) of DBM eggs parasitised
Tent Hill	30	16.0 \pm 9.56	23 (77)	20.5 \pm 4.48
LaTr	30	17.1 \pm 8.25	26 (87)	19.7 \pm 5.02
N2	30	20.5 \pm 4.93	30 (100)	20.5 \pm 4.93

(ANOVA, $F = 0.299$, $p = 0.7425$) or when all wasps were included (ANOVA, $F = 2.693$, $p = 0.0732$).



Number of DBM eggs parasitized per female wasp

Figure 1. The distributions of female wasps in terms of number of DBM eggs parasitised per female in each of the three parasitoid strains tested.

Laboratory susceptibility of *Plutella xylostella* larvae to 12 Australian isolates of the hyphomycete fungus *Beauveria bassiana*.

Jun Ma

(Department of Plant Protection, Hunan Agricultural University, Changsha 410128, China)

David Holdom

(Department of Entomology, The University of Queensland, QLD 4072, Australia)

John Duff

(Queensland Department of Primary Industries, Gatton Research Station, Gatton QLD, 4343, Australia)

Among 12 isolates, 6 isolates originally found in *P. xylostella* still show pathogenetic capabilities to this insect at two conidial concentrations tested. A higher level of mortality occurred in these 6 isolates when compared with the other isolates. This indicates that all of these isolates have some specificity to their original host. Isolate EFD14 is not only the most virulent at high dose but also high mortality, 73.33% at dose of 10^6 conidia/ ml. In laboratory test 2, isolate EFD14 was found competing with a contaminant causing the death of the larvae. The control also exhibited a high percentage of mortality due to this unknown contaminant, as shown in Figure 5. Whether these two pathogens would not in concern increase the mortality of *P. xylostella* is not clear. In a field situation it may be possible to find such a complex situation where different pathogens invade the insect at the same time. This makes it necessary to understand how these pathogens interact.

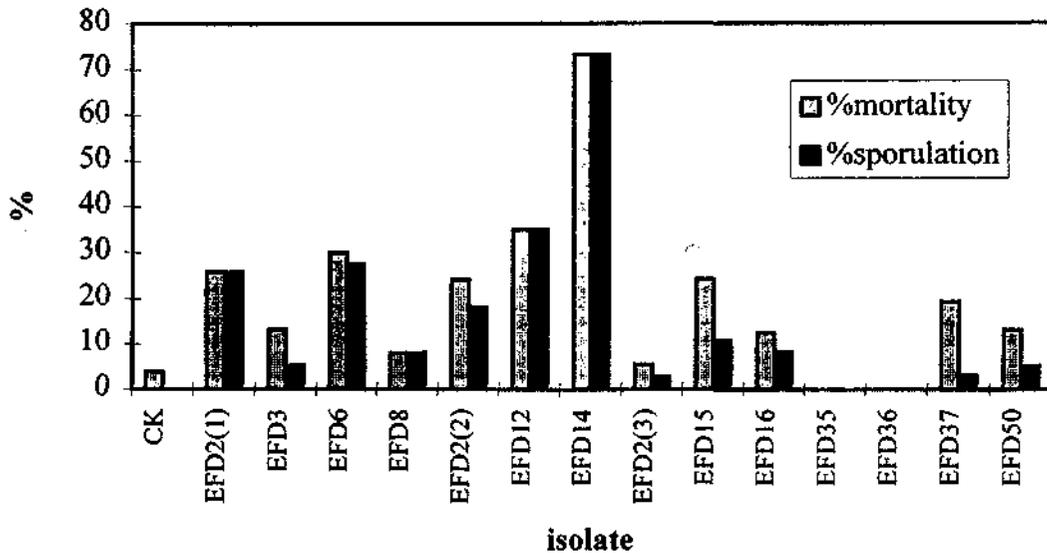


Figure 1. Susceptibility of *Plutella xylostella* to 12 Australian isolates of *Beauveria bassiana* at concentration of 10^6 conidia/ ml; CK (control) was the average value of three experiments; Numbers in brackets denote replicate experiments.

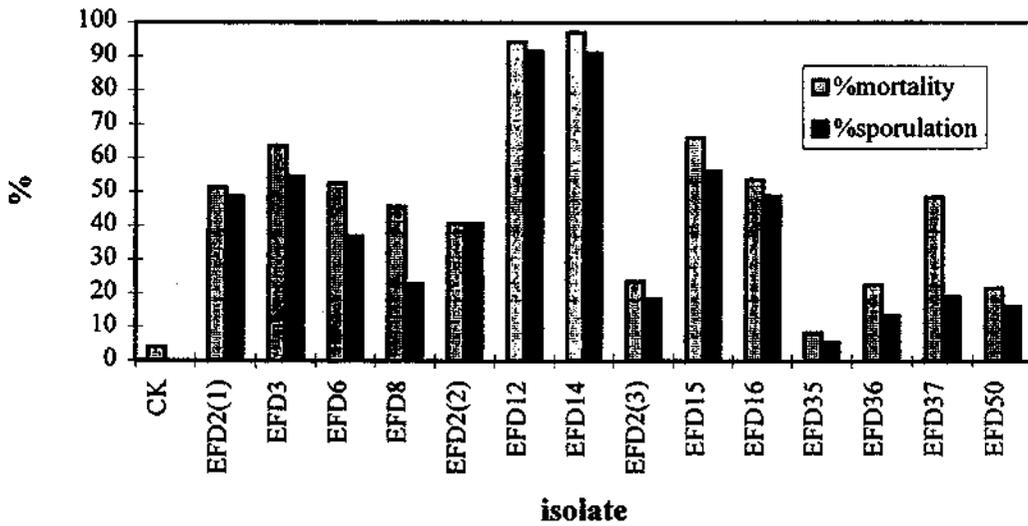


Figure 2. Susceptibility of *Plutella xylostella* to 12 Australian isolates of *Beauveria bassiana* at concentration of 10^7 conidia/ ml; CK (control) was the average value of three experiments; Numbers in brackets denote replicate experiments.

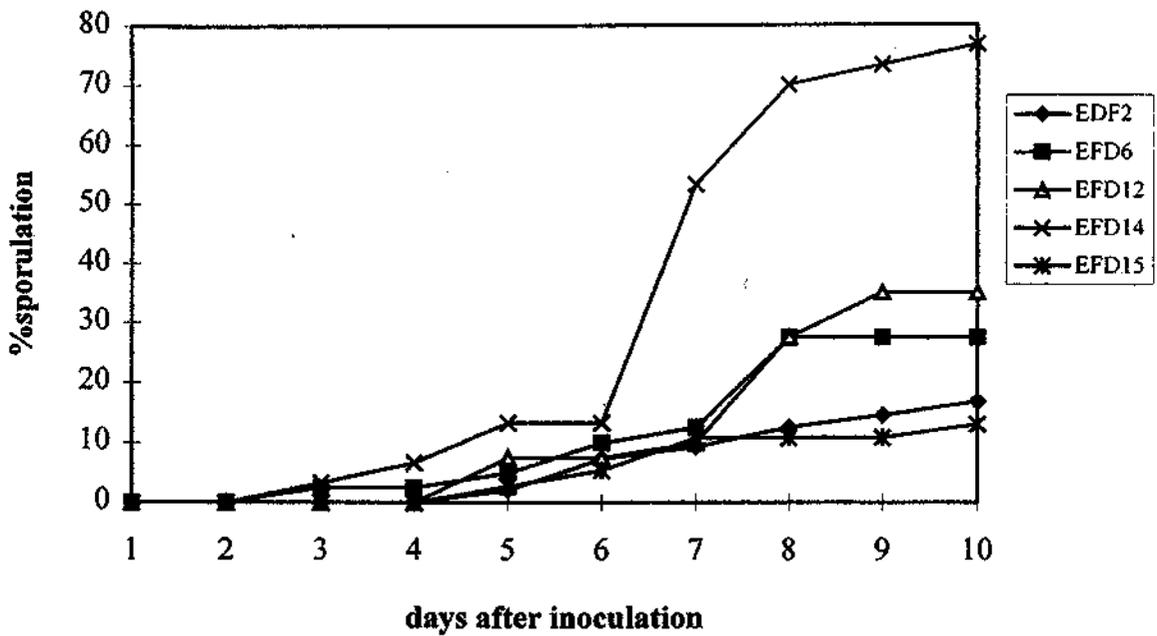


Figure 3. The effect of isolate of *Beauveria bassiana* and time on sporulation ($\geq 10\%$) of *Plutella xylostella*, inoculated with 10^6 conidia/ ml.

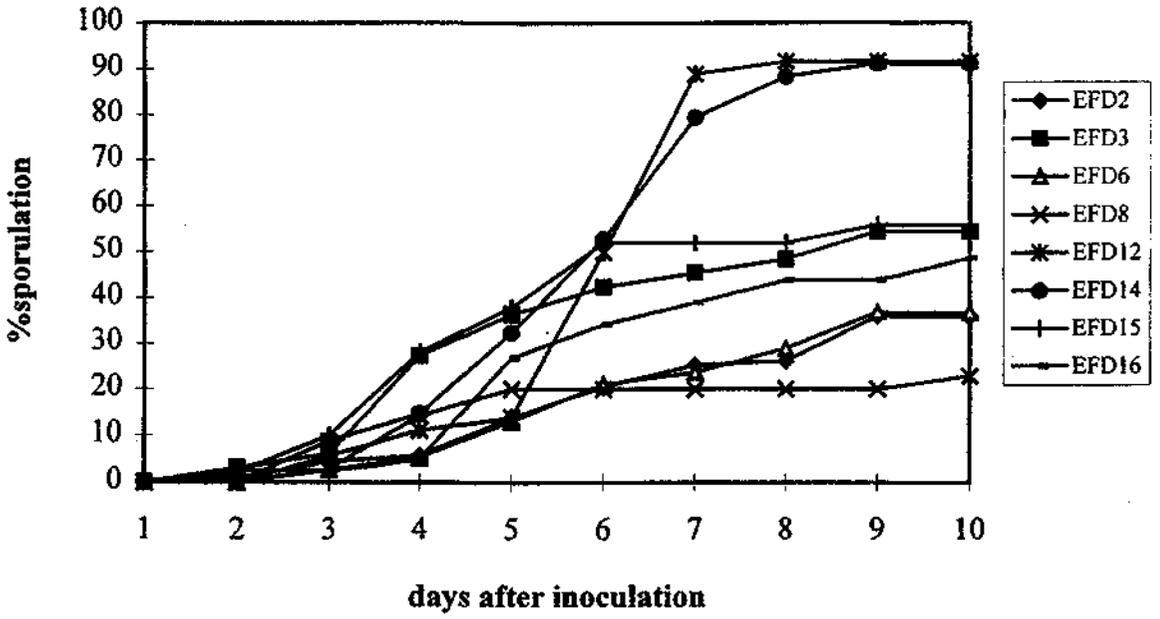


Figure 3. The effect of isolate of *Beauveria bassiana* and time on sporulation ($\geq 10\%$) of *Plutella xylostella*, inoculated with 10^7 conidia/ml.

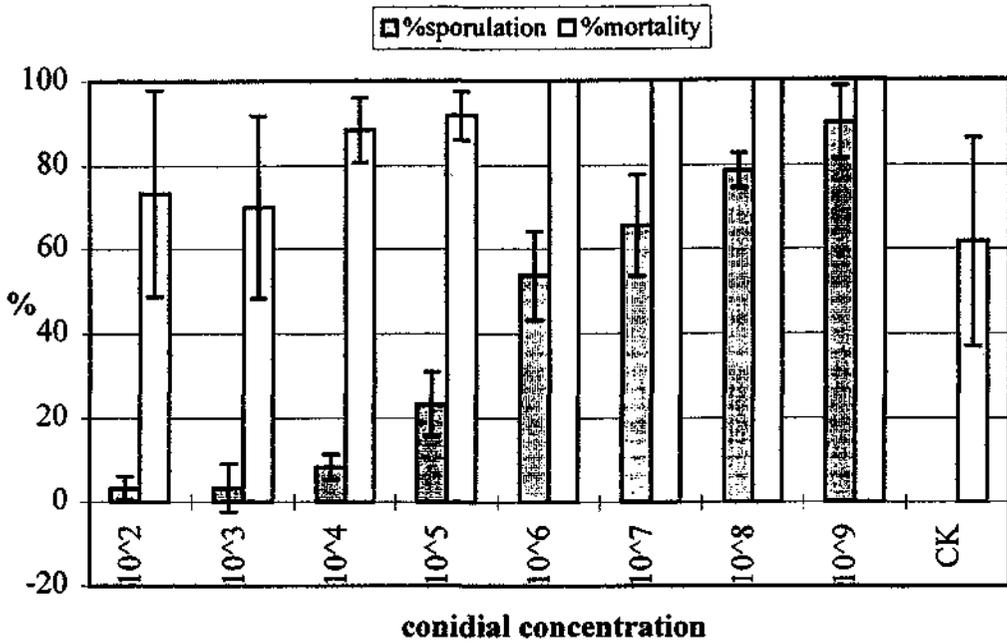


Figure 5. The effect of conidial concentrations of isolate EFD14 of *Beauveria bassiana* on the mortality and sporulation of *Plutella xylostella*.

Behaviour of larvae of Diamondback moth, Plutella xylostella L. on glasshouse and outdoor-exposed brassica crops

Diamondback moth (DBM), *Plutella xylostella* Linnaeus is a key insect pest in vegetable crops. The biology and ecology of DBM have been well reviewed since the Canadian entomologist Harcourt first carried out long term research on it in 1960s. However, detailed reports of the behaviour of larvae especially the young instar larvae have not been available. This report describes our observations on the behaviour of young instar larvae of DBM.

1. Materials and Methods

1.1 Preparation of brassica crops

The potted seedlings of broccoli (var. Pacific) and cabbage (var. Warrior) were cultured in a glasshouse in QDPI Gatton Research Station. They were watered twice a day. The seedlings were used for oviposition when they had 6–10 full spread true leaves. Meanwhile, some potted broccoli plants were put out of the glasshouse and exposed in the field two weeks prior to use to get similar characters such as leaf toughness with those broccoli cultured in the field.

1.2 DBM for behaviour observation studies

When the DBM colony was stably maintained in the laboratory, potted brassica plants were put into the oviposition cage for a few hours. The plants were then taken out and put into an air-conditioning room (25–27°C). Plants were carefully checked and all eggs on the stem and most eggs on the leaves were removed to leave only one to three eggs on each leaf. A fine felt tipped pen was used to mark eggs on the leaves and each leaf numbered to aid in recording of the egg during the course of the experiment. The eggs were checked a couple of times before they hatched with a hand magnifier and all unmarked eggs, which were missed before, were removed.

1.3 Behaviour observation

When the eggs were close to hatching, that was, the folded larva body shape and black head capsule could be seen with naked eye or a hand lens, continuous observation were made. Records were made of the hatching time, the time that the larvae moved before mining, the site selected and the time from the start of mining to when the larva was completely hidden within the leaf mine. The distance between the egg shell and the point where the larva began mining was recorded. After all hatched larvae were completely buried into the leaf, regular observation of each mine site was made at 08:00, 14:00 and 20:00. If the larva left the mine site early and moved away to choose a new mine site, the time that this occurred was recorded and the direction of the larva moved was also recorded. Once the larva emerged, the length of the mining tunnel was measured and the shape was described. The time of larvae emergence from mine site was also recorded to determine how long the larvae stayed within the leaf. All the mining tunnels were cut open and observed under the microscope to see if the larvae moulted within the leaf. The old head capsule and skin provided evidence of moulting. This was necessary to determine if the larvae change their mining sites at the first or the second instar.

1.4 Survival of young instar DBM larvae

The survival of young instar DBM larvae was recorded during the observation and the reason for such death determined where possible.

2 Results and Analysis

2.1 Glasshouse broccoli

With the glasshouse broccoli, the first instar larvae bit the egg shell and crawled out in 1 or 2 minutes. The minute larvae then moved on the leaf seeking a suitable site to burrow into. When the larvae started to burrow, the head wagged on the leaf. It was probably to remove the wax of the leaf, or to determine if the site was suitable, for some larvae changed site after wagging for a few seconds. The way the larvae moved was quite irregular, some crawled directly forward, some moved forth and back, others crawled over the whole leaf; some larvae moved quickly, others moved slowly and stopped occasionally. Thus the distances travelled by the larvae were usually longer than that between the egg shell and the mining site. Table 1 gives the results of behaviour of young instar larvae on glasshouse broccoli leaves. The results showed that under laboratory conditions, the newly hatched DBM larvae moved on the broccoli leaves for about 25 minutes and selected a mine site, which was about 30 millimetres away from the egg shell, before burrowing into the leaf. It took the larvae nearly 3 hours to hide themselves totally inside the leaf. After 60 hours or so, the larvae emerged and began to feed on the surface of the leaf. The mining tunnel was usually about 10 millimetre long, though the shape was quite irregular.

Since the larvae moved irregularly on the leaves, the time from hatching to start mining and the distance between the egg shell and the mining site have a poor correlation ($r = 0.23$, $n = 103$). On an old leaf, the larva would crawl for a long time but it was usually restricted to the same leaf. Occasionally, a few individuals crawled to the leaf petiole and moved to another leaf or made silk threads to drop down to a new leaf. During the process, about half of the first instar larvae were observed to mine close to a leaf vein and burrow into the leaf away from the vein.

Both the first and some second instar larvae (65%, $n = 40$) were observed to mine. During this process, changing of mining sites was a normal phenomenon. 86% ($n = 125$) of young instar larvae relocated mining sites and 49% ($n = 84$) of the larvae changed mining sites twice or more.

Table 1. Behaviour of young instar larvae of DBM on glasshouse broccoli

	n	Mean	SD	Range
Egg stage (hrs)	104	75.35	5.61	62-93
Time from hatch to start of mining (min)	104	25.63	22.29	5-170
Time from start to mine to finish burrowing into the leaf (hrs)	106	2.84	0.69	1.33-5.7 5
Time inside the leaves (hrs)	80	59.47	12.06	46-118.5
Distance between the egg shell and mining site (mm)	122	30.70	31.40	3-260
Length of tunnel (mm)	110	9.62	3.49	4-21

The first instar larvae fed only inside the tunnels. However, 75% (n = 57) of them changed mining sites. Most (84%, n = 63) of the first instar larvae moulted inside the tunnel into the second instar larvae. However, it is unknown if the second instar larvae continue mining in the same tunnel after moulting.

After moulting and emergence from the tunnel, the second instar larvae moved to other feeding sites and made window-like damage. The shape of mining tunnel was irregular, although it was usually narrower at first and then became wider later on. The third instar larvae made both window-like damage and holes while the fourth instar larvae made holes in the leaf. The 1st, 2nd, 3rd and 4th instar larvae were 1-2 mm, 2-3 mm, 3-5 mm and 5-12 mm long respectively. The larvae of the later three instars spun silk threads and moulted on the surface of the leaf.

The survival of young instar larvae was quite high (93%, n =157) in the laboratory at 25-27 °C. Only one dead larva was observed on the leaf and several larvae were found missing

2.2 Outdoor-exposed broccoli and glasshouse cabbage

The behaviour of young instar larvae of DBM on the outdoor-exposed broccoli is shown in Table 2. 80%(n=30) of the first instar larvae moulted in the leaves and 81%(n=27) of the second instar larvae were found mining. All the young instar larvae changed mining site during this mining stage and 83%(n=30) of them changed mine sites more than once. The survival rate of the young instar larvae throughout the whole mining stage was 81%(n=36).

Table 2. Behaviour of young instar larvae of DBM on outdoor-exposed broccoli

	n	Mean	SD	Range
Time from hatch to start of mining (min)	14	40	12.09	20~60
Time from start to mine to finish burrowing into the leaf (hrs)	28	3.73	1.44	1.5~7.83
Time inside the leaves (hrs)	23	78.69	14.55	54~112.67
Distance between the egg shell and mining site (mm)	22	32.55	26.27	4~97
Length of tunnel (mm)	27	10.48	3.13	5~17

Limited data were recorded on the behaviour of DBM larvae on the glasshouse cabbage (Table 3).

Table 3. Behaviour of young instar larvae of DBM on glasshouse cabbage

	n	Mean	SD	Range
Time from hatch to start of mining (min)	15	102.47	57.53	23~222
Time from start to mine to finish burrowing into the leaf (hrs)	16	3.20	0.95	1.84~5.42
Distance between the egg shell and mining site (mm)	23	67.78	39.90	4~150
Length of tunnel (mm)	13	10.15	3.74	6~17

Table 4 shows the behaviour difference of DBM larvae on the three treatment crops. The young instar larvae of DBM crawled for a longer time on cabbage leaves than on broccoli before mining. The larvae took a longer time to burrow into the outdoor-exposed leaves than into the glasshouse exposed leaves and the larvae stayed longer inside the exposed leaves than those leaves from glasshouse. The length of tunnels among the three treatments showed no significant difference.

Table 4. Behaviour difference of young instar larvae of DBM on brassica crops

	glasshouse broccoli	outdoor- exposed broccoli	glasshouse cabbage
Mean time from hatch to start of mining (min)	25.63 b*	40.00 b	102.47 a
Mean time from start to mine to finish burrowing into the leaf (hrs)	2.84 b	3.73 a	3.20 ab
Mean time inside the leaves (hrs)	59.47 b	78.69 a	--
Mean distance between the egg shell and mining site (mm)	30.70 b	32.55 b	67.78 a
Mean length of tunnel (mm)	9.62 a	10.48 a	10.15 a

* the difference of letter in each row showed the significant difference of means (LSD methods, $P < 0.05$)

Brassica Pest and Disease Management (IPM Research to Practice™ for Brassicas)

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Project Synopsis

The aim of the project is to encourage the industry to utilise the research and development (R&D) work they are funding. This will be done by extending the "Research to Practice™" training model, to assist the *Brassica* industry to adopt integrated pest management (IPM) techniques to combat the problems of clubroot and diamondback moth in particular. The training model will rework data from the latest National vegetable R&D levy funded projects into a series of standard presentations which will be presented at workshops and used to form the basis of a Best Practice manual.

Clubroot and diamond back moth alone cost the *Brassica* industry in excess of \$25 million annually. R&D programs in the past few years have established a wide range of new methods for growers to control major pests and diseases. Despite the ground breaking technology in these fields, growers are still unsure as to how to use the new and sometimes complex technology on their farms. So complex that about 44% of growers want to wait and see other people in the industry use IPM first (Bernard *et al.* 1998). Research to Practice™ gives growers the confidence of trialing new technologies on farm to ensure that they remain the leaders in vegetable production technology.

Despite the large investment of vegetable growers R&D levy funds to support the development of IPM, 56% of growers are uncertain about IPM and over 65% of growers would like more printed information and grower nights on IPM (Bernard *et al.* 1998). The scientific approach of focusing on specific problems tends to filter down to growers from researchers through agribusiness to growers. Current researchers are keen to have their scientific results used directly on farm and growers would like more information in a user friendly format that works 'in the field'. In addition, IPM in Brassica crops is essential for the \$120 million per annum industry to remain sustainable. For similar reasons the Research to Practice™ training model was developed for viticulture.

Research to Practice™ is an innovative training program that was first developed for IPM adoption in the wine grape industry. It comprises intensive, interactive two day workshops based on a documented series of best management practice using Adult Learning Principles. The series has been very successful with more that 750 participants at over 30 workshops nationally. Reports from growers have indicated that they apply less chemicals for the season without any reduction in yield and quality, saving some growers up to \$5,000 per hectare per season. The success of the training series has meant that GWRDC and the CRCV viticulture have had a greater grower profile for their support and funds.

The specific objectives of this project are to inform growers of new findings of levy funded research, to develop in partnership a National steering committee, to customise Research to Practice™ model for *Brassica* crops, to deliver a National pilot program, to evaluate the adoption/success of the project and to establish future National R&D priorities.

Bernard, M., Ridland, P. and Endersby, N. (1998) Pest Management Survey of Victorian *Brassica* Growers: DBM Project Workshop, Waite Campus, Adelaide. September 21-23, 1998.

Key aim

To improve vegetable production by facilitating the integration of specific research project outcomes on integrated pest management (IPM) into vegetable production systems.

Project Outcomes

To develop a training package for *Brassica* growers

This package will provide growers with the latest information on pest and disease management

The training will give growers confidence to use the tools and knowledge gained to plan ongoing pest and disease management

Ultimately, this will help growers meet customer and environmental requirements.