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Advancing integrated pest and disease management (IPM) for vegetable brassicas – final report

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Project name:	Advancing integrated pest and disease management (IPM) for vegetable brassicas
Project number:	04/055
Applicant Group:	Fresh Vegetable Sector Brassica Product Group

A report prepared for
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Contents

1 Project objectives

The vegetable brassica industry initiated a project to update IPM for vegetable brassicas, by revising *Integrated Pest Management for Vegetable Brassicas* (the *IPM Manual*). The project objectives were to:

- update the status of insecticide resistance in diamondback moth (DBM) in New Zealand,
- incorporate newly registered products into the insecticide resistance management rotation strategy, and
- update the disease and other relevant sections in the IPM Manual.

The project team included grower groups from the major vegetable brassica-producing regions, Pukekohe, Gisborne and Manawatu/Horowhenua. Horticulture New Zealand (formerly Vegetable & Potato Growers' Federation Inc. (Vegfed)), the agrichemical industry and other industry partners supported this MAF Sustainable Farming Fund project.

The project work focused on replicated field trials at Pukekohe Research Centre (PRC); regional surveys; field trials in commercial crops at LeaderBrand, Gisborne, field days at Pukekohe; and other field studies in Auckland, Palmerston North, and Canterbury.

2 Brief outline of methodology

All chapters of the IPM Manual were updated. The sections on insects, plant diseases and disorders, insecticide resistance management and the quick reference section required major revision and improvement. Other sections were expanded, and because information on prevention and decision tools are somewhat generic for different crops, particularly for leafy vegetables, information in the recently produced Lettuce IPM Guide was incorporated into this manual where appropriate. Information on new selective pesticides was added. A comprehensive survey of the levels of resistance in DBM to the important chemical groups in the major growing regions was carried out. Growers, key agrichemical companies, and other relevant industry personnel were consulted on positioning of new selective insecticides in the insecticide rotation strategy, and an updated DBM pesticide resistance management rotation strategy was developed. The list of all registered pesticides was updated. The efficacy of a range of insecticides for control of leaf mining flies in Asian brassicas was determined and a field evaluation of the most promising pesticides was undertaken using a number of different types of Asian brassicas. The project reviewed management of vegetable brassica diseases, including bacterial head rots, ringspot and sclerotinia rot. New approaches to disease and pest control were tested in replicated small plot trials. A grower survey was carried out to determine the occurrence and economic importance of diseases and pests of Asian brassicas in New

Zealand. Field trials, undertaken in collaboration with agrichemical companies, were carried out to assess the efficacy of different spray programmes and different fungicide treatment regimes (‘new’ and currently registered fungicides) for control of downy mildew of vegetable brassicas. New research to investigate the effects of fungicide spray technology and adjuvants for brassica downy mildew control was also carried out. Relevant new information has been and will be communicated to industry by updating the IPM Manual, through articles in the NZ Grower, through direct communication to participating grower groups, and through workshop/seminars for the wider vegetable-growing community.

3 *Objectives*

Objective 1: Planning – to have meetings of stakeholders in July 2004, and team and grower meetings in 2005 and 2006.

Objective 2: Insecticide resistance in DBM − Report to Brassica Product Group of Vegfed on levels of resistance in DBM in three regions to the four major insecticide groups (spinosad, indoxacarb, synthetic pyrethroids and organophosphates). Disseminate results in the NZ Grower and in grower seminars.

Objective 3: Pesticide resistance management strategies − Meet with key stakeholders and update insecticide resistance management strategies, taking into account levels of insecticide resistance in DBM. Rotation strategies would include resistance management for aphids to the selective aphicides Chess and Pirimor. Publish in the updated IPM Manual and NZ Grower.

Objective 4: Control of leaf-mining flies in Asian brassicas. Report to the brassica product group of Vegfed on field trials at Pukekohe Research Centre to compare the efficacy of insecticides registered for use on brassicas (year 1) and novel insecticides (year 2) for control of leaf mining flies on Asian brassicas. One article on each year’s progress for the NZ Grower.

Objective 5: Control of insect pests in Asian brassicas − Report to the Brassica Product Group of Vegfed on field trials at Pukekohe Research Centre to test the existing action thresholds for caterpillar and aphid pests on Asian brassicas (year 2) and combine with testing thresholds for leaf mining flies (year 3). Recommend whether they are suitable for incorporating into the updated IPM Manual for vegetable brassicas or if further research is required.

Objective 6: Plant diseases − Report to the Brassica Product Group of Vegfed: (a) Results of field trials at Pukekohe that assessed the efficacy of different spray programmes and treatments using new and presently available fungicides for control of downy mildew and ringspot in vegetable brassica crops; (b) Results of field trials that investigated the effects of fungicide spray technology and adjuvants for brassica downy mildew control. Results published in updated IPM Manual and the NZ Grower. New information on use of resistant cultivars, cultural and chemical control, and biological control of above-ground and soilborne diseases of vegetable brassicas will be incorporated into the updated IPM Manual.

Objective 7: Plant diseases of Asian brassicas − Carry out field surveys to determine the occurrence and economic importance of diseases of Asian brassicas in New Zealand. A written report that will also include recommended methods for control of these diseases will be prepared for the Brassica Product Group of Vegfed on completion of the surveys.

Objective 8: Soilborne diseases − Compile new knowledge on different control strategies for clubroot. Implement new disease control methods for clubroot, based on recent research on effects of biofumigant crops on the disease, and new chemicals for clubroot control.

Objective 9: Tech transfer − Complete grower seminars in Manawatu/Horowhenua, Pukekohe and East Coast to disseminate knowledge gained in field trials and publicise the updated IPM Manual.

Objective 10: IPM manual − Final draft of updated IPM Manual with current information on resistance levels in DBM, updated insecticide rotation strategy, information on pest control in Asian brassicas, and integrated management strategies for diseases of vegetable brassicas, including Asian brassicas.

4 *Summary of results*

Milestone 1: Planning

- Regular discussions held with agrichemical companies, local growers, and project members contributed to production of a greatly improved Brassica IPM Manual.

Milestone 2: Insecticide resistance in DBM insect pest control

- Resistance surveys were completed for 5 regions for the four key insecticidal modes of action, spinosad (Success™ Naturalyte™), indoxacarb (Steward®), a standard synthetic pyrethroid, (lambda cyhalothrin, Karate® with Zeon) and a standard organo-phosphate (methamidophos, Tamaron®). The areas surveyed were around Pukekohe, Gisborne, Levin, Carterton and Lincoln. All field populations were compared directly with an insecticide-susceptible lab strain of DBM held in quarantine at Mt Albert Research Centre for 14 years. There were still high levels of resistance to the synthetic pyrethroid, but reduced, low or no resistance to methamidophos. There was no resistance to spinosad or indoxacarb, although there was tolerance in two field populations to indoxacarb. This tolerance may be due to natural genetic variation, which is likely to be higher in field populations than in the laboratory population. It appears that resistance in DBM to synthetic pyrethroids is stable but resistance may be decreasing to organo-phosphates.
- The lack of any detected resistance in DBM to spinosad or indoxacarb may be attributed to the adoption of the rotation strategy for these two products by most vegetable brassica growers in the important growing regions.

- Baseline susceptibility surveys were undertaken for Du Pont's new insecticide, Coragen™ (chlorantraniliprole) against DBM from different regions and within the Pukekohe region and compared with the susceptible strain.

Milestone 3: Pesticide resistance management

- The main focus has been on resistance management of DBM. The status of resistance in DBM has been updated (see milestone 2). With this information, we are recommending an update of the DBM insecticide resistance management rotation strategy, which will be published in the IPM manual and in the Grower. This strategy was last updated in 2001 and published in the Grower (December 2001) and on the NZ Plant Protection website,

  www.hortnet.co.nz/publications/nzpps/resistance/index.htm

- The Du Pont product Coragen™ (chlorantraniliprole) is to be registered worldwide next year and in New Zealand it is to be registered for use on vegetable brassicas for control of Lepidopteran species of insect pests. We recommend that this IPM-compatible larvicide is positioned in the early window as an alternative to Btk products and Success™ Naturalyte™.

- Resistance management for aphids has been discussed with relevant industry personnel. The key aphicides are pirimicarb and pymetrozine (Chess®). We recommend that growers consider rotating the use of these two classes of insecticides to ensure that pests are not continually exposed to the same toxins, which could lead to the development of resistance.

- The IPM Manual is being updated to include a pesticide resistance section and resistance management strategies for the important pests and diseases, with references to published strategies, including those on the NZ Plant Protection website (see above).

Milestone 4: Control of leaf-mining flies in Asian brassicas

- The field trials in 2005 to 2007 were funded by FRST and will continue until June 2008. These trials used short rotation brassicas such as Bok Choi.

- Seven insecticides were tested for field control of the leaf mining fly Scaptomyza flava. Acephate, deltamethrin, endosulfan and fipronil gave good control of the flies and reduced damage to an acceptable level. Indoxacarb and spinosad were much less effective at reducing leaf damage. Abamectin, which is not registered for use on brassicas, also gave very good control of the leaf mining fly.

- In the late season trial (autumn), deltamethrin gave best leaf miner control but this option is not suitable as an IPM option where we want to maximise the impacts of natural enemies.

- The seasonal trials showed that the two key larvicides used in rotation to manage DBM (spinosad and indoxacarb) are not effective against leaf miners so other insecticidal options may be required in Asian brassica crops. Abamecton and fipronil gave good leaf miner control and should be considered when trying to conserve natural enemies. Fipronil is toxic to hymenoptera, including the important aphid and caterpillar parasitoids but is considered less harmful to insect predators.

Milestone 5: Control of insect pests in Asian brassicas

- The insecticide field trials for leaf miner fly control were also assessed for control of other insect pests, the damage they caused, and impacts on natural enemies. Trials included testing spinosad, endosulfan, acephate and abamectin in the early trials, and indoxacarb, fipronil, deltamethrin and abamectin in the late season trial.
- The spring and autumn trials had low populations of insects, but the summer trial had reasonably high populations of DBM larvae and predators, particularly hover flies. In the summer trial, there was some evidence of a failure of deltamethrin to control DBM. The data is still to be analysed, but may be due to a non-target negative impact on predators due to its broad-spectrum activity, or possibly resistance in DBM to this product.

Milestone 6: Plant diseases

- Nitrogen and calcium fertiliser applications can affect head rot of broccoli.
- Adjuvant surfactants and nitrogen fertilisers can increase the susceptibility of cauliflower and broccoli heads to head rot.
- Spray technology can have a considerable effect on the efficiency of delivery of fungicide applications to brassicas.

Milestone 7: Plant diseases of Asian brassicas

The questionnaire, sent out to 66 growers of Asian brassicas, revealed that:

- 67% of Asian brassica growers know about the IPM programme for vegetable brassicas,
- 44% of Asian brassica growers use the vegetable brassica IPM programme,
- 94% of growers scout their crops for pests and diseases at least once a week,
- clubroot, downy mildew, and bacterial leaf spot are the three main diseases of Asian brassicas, and clubroot is the hardest disease to control,
- DBM, white butterfly, and aphids are the three main pests of Asian brassicas, and slugs are the hardest pest to control.

Milestone 8: Soilborne diseases

- A first draft of a literature review on ‘Integrated control for clubroot of vegetable brassicas’ (update 2007) was completed and submitted to Crop & Food Research’s editorial system.

Milestone 9: Tech transfer

- 6 scientific papers produced

- 3 conference papers
- 5 poster papers
- 11 reports
- 5 seminars or field days

Milestone 10: IPM manual

- IPM manual submitted to Crop & Food Research editor for publication.

5 Extension activities

March 2005: Graham Walker and Peter Wright met with vegetable brassica growers and Vegfed regional representatives to outline the Advancing IPM for Vegetable Brassicas project; 7 March, Palmerston North.

March 2005: Production of a brochure on the Advancing IPM for Vegetable Brassicas project.

May 2005: Dr Cheah presented an update on integrated management for clubroot at a seminar at the Fruitfed growers' workshop on 18 May 2005, Levin.

March 2006: Presentations by Peter Wright and Graham Walker at grower meetings (Hort NZ Brassica and Leafy crops group), 1 March 2006, Lincoln.

March 2006: Presentations by Peter Wright and Graham Walker on Brassica IPM at Vegetable Technical Conference 2006, 14-16 March 2006, Pukekohe.

February 2007: Graham Walker, Nicholas Martin and Peter Wright updated vegetable brassica growers and Horticulture NZ regional representatives on the Advancing IPM for Vegetable Brassicas project; 19 February 2007, Pukekohe.

6 Publications associated with the project

Cameron PJ, Fletcher JD. 2005. Green peach aphid resistance management strategy. In: Pesticide resistance: prevention & management strategies. Editors N.A Martin, R.M. Beresford, K.C. Harrington. Hastings, NZ. New Zealand Plant Protection Society, 2005: 109-114.

Cameron PJ, Walker GP. 2005. Diamondback moth resistance management and prevention strategy. In: Pesticide resistance: prevention & management strategies. Editors N.A Martin, R.M. Beresford, K.C. Harrington. Hastings, NZ. New Zealand Plant Protection Society, 2005: 49-54.

Cameron PJ, Walker GP. 2005. Tomato fruitworm resistance management and prevention strategy. In: Pesticide resistance: prevention & management strategies 2005. Editors N.A Martin, R.M. Beresford, K.C. Harrington. Hastings, NZ. New Zealand Plant Protection Society, 2005: 55-60.

Cheah, L-H and Falloon, RE. 2006. Integrated disease management for clubroot of vegetable brassicas. Pp. 126-137 in: Ramdane Dris ed. Vegetables: Growing environment and mineral nutrition. WFL Publisher, Fin-00980 Helsinki, Finland.

Cheah, L-H., Gowers S, Marsh AT. 2006. Clubroot control using Brassica break crops. Acta Horticulturae 706: 329-332.

Martin NA. 2005. Thrips insecticide resistance management and prevention strategy. In: Pesticide resistance: prevention & management strategies. Editors N. A Martin, R. M. Beresford, K. C. Harrington. Hastings, NZ. New Zealand Plant Protection Society, 2005: 78-89.

Martin NA, Workman PJ, Hedderley D. 2006: Susceptibility of *Scaptomyza flava* (Diptera: Drosophilidae) to insecticides. New Zealand Plant Protection: 59: 69-74.

Martin NA, Workman PJ. 2006: Control of *Scaptomyza flava* (Diptera: Drosophilidae) in Asian brassicas. Abstract and Talk at the Australian and New Zealand Entomological Societies Conference, 24-27 September 2006, University of Adelaide, South Australia. Abstract page 14.

Walker GP, Martin NA, Griffin B, Falloon R, Teulon, D. 2005. Research on pesticide risk reduction. Poster at: Integrating Initiatives for Pesticide Risk Reduction Workshop, Wellington, 1 December 2005. ERMA.

Walker GP, Clearwater JR, Winkler S, MacDonald F, Wallace AR. 2006: Monitoring of *Thysanoplusia orichalcea* in New Zealand. 5th International Workshop on the management of diamondback moth and other crucifer pests at Beijing, 24-27 October. Conference proceedings: in press.

Wright P. 2006: Survey of growers of Asian brassicas – results and analysis. Crop & Food Research Confidential Report No. 1709. A report prepared for MAF Sustainable Farming Fund and Horticulture NZ.

Wright PJ 2007. Effect of copper and surfactants on head rot of broccoli. (Poster) New Zealand Plant Protection Society 60th Annual Conference, August 2007, Napier.

Wright PJ 2007. Effect of nitrogen and calcium for control of head rot of broccoli. (Poster) New Zealand Plant Protection Society 60th Annual Conference, August 2007, Napier.

Wright PJ 2007. Spray technology for control of foliar diseases of cauliflower. (Poster) 16th Biennial Australasian Plant Pathology Society Conference, September 2007, Adelaide.

Wright PJ 2007. Effects of copper sprays and adjuvants on bacterial soft rot of cauliflower. (Poster) A 16th Biennial Australasian Plant Pathology Society Conference, September 2007, Adelaide.

7 Future plans

In 2007-08, further FRST-funded research will include field trials assessing leaf miner control in Chinese cabbage.

Future work is focused on transferring the IPM tools developed in vegetable brassicas to the forage and seed brassica industries to increase sustainable controls, in particular for DBM, available to the whole brassica industry in New Zealand. A small SFF project is underway, led by a Canterbury vegetable growers group, to assess resistance levels in DBM, and determine whether the recently established white butterfly parasitoid, *Cotesia rubecula*, has established in that region. The project is a precursor to a potentially larger project focusing on the forage and seed industries in the South and North Island where common practice is to use broad-spectrum insecticides, which is disrupting natural controls of key pests.

Also, research funded by FRST is continuing to investigate the non-target impacts of Bt toxins that are now available in brassica plants transformed to express Bt toxins, which have been developed by Dr Mary Christey at Crop & Food Research. The work focuses on assessing the impacts of Bt toxins on the predators and parasitoids of key brassica pests, including non-target pests such as aphids and the polyphagous lepidopteran pests, *Helicoverpa armigera* and *Spodoptera litura*.

8 *Financial statement*

Period	Date	Amount	Balance	Running total
1 Jul-Sep 05	31/01/2006	$73,756.35	-$73,756.35	
2 Oct-Dec 05	31/01/2006	$73,648.67	-$147,405.02	
3 Jan-Mar 06	18/04/2006	$88,107.60	-$235,512.62	
4 Apr-Jun 06	26/07/2006	$34,712.56	-$270,225.18	
Implementation			**$324,000.00**	
Jul-Sep 05	1/09/2005	$28,640.77	$295,359.23	$28,640.77
Jan-Mar 06	1/04/2006	$46,643.11	$248,716.12	$75,283.88
Apr-Jun 06	1/07/2006	$26,745.69	$221,970.43	$102,029.57
Jul-Oct 06	1/11/2006	$42,135.29	$179,835.14	$144,164.86
Nov-Feb 07	1/03/2007	$25,248.17	$154,586.97	$169,413.03
Mar-Jun 07	1/07/2007	$27,265.50	$127,321.47	$196,678.53
Jul - Sep 07		$15,101.00	$112,220.47	$211,779.53

Appendices

Appendix 1 Brochure on the Advancing IPM for Vegetable Brassicas produced in March 2005

Appendix 2 Wright PJ 2007. Effect of copper and surfactants on head rot of broccoli. (Poster) New Zealand Plant Protection Society 60th Annual Conference, August 2007, Napier.

Appendix 3 Wright PJ 2007. Effects of copper sprays and adjuvants on bacterial soft rot of cauliflower. (Poster) A 16th Biennial Australasian Plant Pathology Society Conference, September 2007, Adelaide.

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Appendix 5 Wright PJ 2007. Spray technology for control of foliar diseases of cauliflower. (Poster) 16th Biennial Australasian Plant Pathology Society Conference, September 2007, Adelaide.

Appendix 6 Walker GP, Martin NA, Griffin B, Falloon R, Teulon, D. 2005. Research on pesticide risk reduction. Poster at: Integrating Initiatives for Pesticide Risk Reduction Workshop, Wellington, 1 December 2005. ERMA.

Appendix 7 Cameron PJ, Fletcher JD. 2005. Green peach aphid resistance management strategy. In: Pesticide Resistance: prevention & management strategies. Editors N.A Martin, R.M. Beresford, K.C. Harrington. Hastings, N.Z. New Zealand Plant Protection Society, 2005: 109-114.

Appendix 8 Cameron PJ, Walker GP. 2005. Diamondback moth resistance management and prevention strategy. In: Pesticide Resistance: prevention & management strategies. Editors N.A Martin, R.M. Beresford, K.C. Harrington. – Hastings, N.Z. New Zealand Plant Protection Society, 2005: 49-54.

Appendix 9 Cameron PJ, Walker GP. 2005. Tomato fruitworm resistance management and prevention strategy. In: Pesticide Resistance: prevention & management strategies 2005. Editors N.A Martin, R.M. Beresford, K.C. Harrington. Hastings, N.Z. New Zealand Plant Protection Society, 2005: 55-60.

Appendix 10 Martin NA. 2005. Thrips insecticide resistance management and prevention strategy. In: Pesticide Resistance: prevention & management strategies. Editors N. A Martin, R. M. Beresford, K. C. Harrington. Hastings, N.Z. New Zealand Plant Protection Society, 2005: 78-89.

Appendix 11 Martin NA, Workman PJ, Hedderley D. 2006: Susceptibility of Scaptomyza flava *(*Diptera: Drosophilidae*) to insecticides. New Zealand Plant Protection: 59: 69-74.*

Appendix 12 Cheah, L-H., Gowers S, Marsh AT. 2006. Clubroot control using Brassica break crops. Acta Horticulturae 706: 329-332.

Clubroot Control Using Brassica Break Crops

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Keywords: biofumigants, brassica crops, clubroot, isothiocyanates, *Plasmodiophora brassicae*

Abstract

Clubroot of brassicas, caused by *Plasmodiophora brassicae*, is the most serious disease of New Zealand's vegetable brassica crops, reducing marketable yields and sometimes totally destroying crops. We investigated the potential of *Brassica* break crops containing high levels of glucosinolates for use in an integrated clubroot management strategy. Two trials were carried out to compare the efficacy of two species of *Brassica* break crops (*B. rapa* and *B. napus*), and to investigate the optimum time required for break crop residues to decompose and provide clubroot control. Seedlings of *Brassica* break crops were grown to about 70 days, ploughed and rotary-hoed to a depth of 12 cm. The plant material was left to decompose for about 1, 2 or 3 months before cauliflower or broccoli were planted as main crops. In the first trial *B. rapa* reduced the mean clubroot severity score on cauliflower root systems, and increased plant top weights compared to plants from untreated plots or from plots treated with cauliflower residues. *Brassica napus* did not reduce the clubroot score. Gas chromatography analysis showed that *B. rapa* had a higher total isothiocyanates (ITCs) than *B. napus*. *B. rapa* released larger quantities of 4-pentenyl ITC than *B. napus*. In the second trial we found that both 2- or 3-month decomposition treatments reduced clubroot severity compared to the untreated or broccoli residue treatments. The 3-month decomposition treatment gave slightly better disease control than the 2-month treatment. The treatments had little effect on plant top weight.

INTRODUCTION

Clubroot of brassicas, caused by *Plasmodiophora brassicae* Woronin, is the most serious disease in New Zealand's brassica growing areas, reducing marketable yields and sometimes totally destroying crops. The above ground symptoms of the disease include wilting of leaves during hot and dry days. Infected roots become severely distorted to form galls (clubs), which characterise the disease.

Good progress has been made towards controlling clubroot through the use of chemicals (Cheah et al., 1999), disease-resistant cultivars (Falloon et al., 1997), and biological control (Cheah et al., 2001). We have also identified *Brassica* spp. with high levels of glucosinolates (GSLs) as biofumigants that could be used as a component of an integrated disease management strategy for clubroot. Upon tissue disruption, GSLs are hydrolysed by endogenous myrosinase to release isothiocyanates (ITCs), thiocyanates and nitriles. ITCs are highly biocidal to a range of organisms including fungi (Sarwar et al., 1998). In a previous field trial (Cheah et al., 2001) we showed that two species of *Brassica* reduced clubroot severity on root systems of Chinese cabbage plants.

This paper reports the results of two field trials to further evaluate two species of *Brassica* (*B. rapa* and *B. napus*) as biofumigants and the optimum time required for their residues to decompose and provide clubroot control. These two *Brassica* lines were screened and selected for their high levels of GSLs in plant tissues by Crop & Food Research at Lincoln, NZ.

MATERIALS AND METHODS

A field trial was carried out at a commercial grower's property on clubroot-infested soil (pH 6.5). In the first trial (Table 1), seedlings of *B. rapa* L. (turnip) and *B. napus* L. (rape) were transplanted (10 plants/m^2) into field plots and grown for about 70 days. The plants were then ploughed and rotary-hoed to a depth of 12 cm. The plant material was left to decompose for about 4 weeks. Cauliflower (cv. Visto) seedlings were transplanted into the trial plots. Control plants were either left untreated or were treated with cauliflower crop residues, which were taken from the remnants of a commercial cauliflower crop, rotary hoed into the plots and allowed to decompose as described above. Samples of root and stem tissues were taken after they were rotary hoed. The samples were freeze-dried and ground and then analysed for released ITCs by gas chromatography using the method of Warton et al. (2001).

In the second trial (Table 3), seedlings of *B. rapa* (10 plants/m^2) were grown, ploughed and rotary hoed as described above. In this trial the plant materials was left to decompose for 2 and 3 months before broccoli (cv. Legacy) was transplanted as the main crop. All treatments were planned such that the main crops were transplanted at the same time. Irrigation was applied immediately after rotary hoeing at 1 litre/m^2 using a hand-held watering can. A total of 4 irrigations were applied. Control plants were either left untreated or treated with broccoli crop residues.

The trial design was a randomised block with six replications, each consisting of four (first trial) or six treatments (second trial). Each treatment plot consisted of a single row of 20 plants at 1.0 m row spacing. After three month's growth, plants were harvested and top weights were recorded. All roots were lifted and scored for clubroot on a 0-5 scale, where 0 = healthy root systems and 5 = complete clubbing of the tap root.

RESULTS

In the first trial, *Brassica rapa* reduced the clubroot score on cauliflower root systems compared to the untreated control plants or plants treated with cauliflower residues (Table 1) and increased the top weight of the plants, although the increase was not significantly different from that with cauliflower residues. *B. napus* did not reduce the clubroot score. Symptoms of stunting were observed on some of the treated plant seedlings, but they soon recovered.

Total ITCs released by *B. rapa* in this experiment were more than that of the *B. napus* (Table 2). However, there were differences in the ITC spectra of the two biofumigant brassica species. *B. rapa* produced a little secondary-butyl ITC whereas *B. napus* had virtually none, and the reverse was the case with methyl thiobutyl ITC. *B. rapa* produced less 3-butenyl and 2-phenylethyl ITCs than *B. napus*, but the major difference was that larger quantities of 4-pentenyl ITC were released by *B. rapa*.

In the second trial there was a high clubroot score for the untreated control and crop residue treatment plants (Table 3). The 2- or 3-month decomposition treatments with or without irrigation reduced the disease severity on root systems. There was no significant difference in disease severity between plants in the 2- and 3-month treatments but plants in the 3-month decomposition treatment had a slightly lower disease score. Irrigation did not improve clubroot control. No symptoms of stunting were observed on any of the treated plant seedlings.

Table 1. Mean clubroot score on root systems and top weight of cauliflower after soil treatment with *Brassica* spp.

Treatment		Rate (plant/m^2)	Mean clubroot score$^+$	Mean top weight (g/plant)
1.	*B. rapa*	10	0.3	227.7
2.	*B. napus*	10	1.7	170.7
3.	Crop residues	-	1.7	202.3
4.	Untreated	-	1.1	141.3
	LSD (P=0.05)		0.7	65.0

$^+$clubroot score; 0=healthy, 5=complete clubbing on root systems

Table 2. Concentration of isothiocyanates from hydrolysed brassica plant tissues.

	Isothiocyanate concentration (umol/g dry matter)					
Brassica spp.	sec-Butyl	3-Butenyl	4-Pentenyl	Me Thiobutyl	2-Phenylethyl	Total
B. rapa	1.04	1.19	9.13	0	4.33	15.69
B. napus	0.08	3.43	0.87	0.74	6.82	11.94

Table 3. Mean clubroot score on root systems and top weight of broccoli after soil treatment with *B. rapa*.

	Treatment	Mean clubroot score*	Mean top weight *B. rapa* (g/plant)
1.	2 mo decomposition	1.0	503.5
2.	3 mo decomposition	0.5	507.8
3.	2 mo decom + irrigation	1.1	574.6
4.	3 mo decom + irrigation	0.3	582.7
5.	Crop residue control	2.6	520.0
6	Untreated control	2.0	472.2
	LSD (P=0.05)	0.9	144.0

DISCUSSION

The present results support our previous findings (Cheah et al., 2001) that *Brassica* tissues actively suppress *P. brassicae* in the soil. The stunting symptoms on plant seedlings may indicate that 1-month decomposition of crop residues was insufficient time for the tissues to break down completely before transplanting of seedlings. Symptoms did not show on seedlings of the 2- or 3-month decomposition treatments, indicating that these time periods are better than 1-month treatment for decomposition of crop residues.

The mechanism of biofumigant action against clubroot involved is not fully understood. However, ITCs that are present within the tissues of *Brassica* are thought to be involved (Smolinka et al., 1997). Our field trial results showed that *B. rapa* gave better control of clubroot than *B. napus*. ITC analysis showed that the two lines had different ITC spectra and this may play an important role in clubroot suppression. *B. rapa* released more total ITCs and if this difference was significant then there could have been a threshold effect, with the *B. rapa* line releasing enough ITCs to control the disease. However, the major difference between the two lines is the much larger quantity of 4-pentenyl ITC released by *B. rapa* and it is thought more likely that this may be the reason for the difference in clubroot suppression. More experiments should be carried out to study the effect of individual ITCs on the clubroot pathogen. Irrigation immediately after rotary hoeing the break crop to improve release of ITCs and disease control was suggested by Matthiessen and Kirkegaard (2002), but our results did not show any significant differences between irrigation and no irrigation treatments.

There may be several modes of action of disease control operating at the same time. Apart from the release of ITCs the *Brassica* crops may also act as ‘bait’ or ‘catch’ crops to stimulate the germination of resting spores of *P. brassicae* and reduce the population of inoculum in the soil (Murakami et al., 2000). The increase of plant materials in the soil may also improve drainage and thus reduce clubroot infection.

Our results showed that *Brassica* spp. with high levels of glucosinolates control clubroot on brassica crops and could be used as a component of an integrated disease management strategy for clubroot.

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