Hort Innovation

Final Report

A Multi-Faceted Approach to Soil-Borne Disease Management

Project leader:

Dr Gordon Rogers

Delivery partner:

Applied Horticultural Research

Project code:

VG15010

Project:

A Multi-Faceted Approach to Soil-Borne Disease Management – VG15010

Disclaimer:

Funding statement:

This project has been funded by Hort Innovation, using the vegetable research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN 978 0 7341 4511 6

Published and distributed by: Hort Innovation

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www.horticulture.com.au

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Summary

The project, "A multi-faceted approach to soil-borne disease management" provided Australian vegetable growers with the tools and knowledge to better manage the risk of crop losses from soil-borne disease.

A key recommendation is to shift emphasis to preventative strategies to manage soil-borne diseases. Once a soil-borne disease is in a crop there are few post-plant treatment options to prevent its progression.

The project recommends growers and advisors move to a preventative approach by:

1. understanding their soil-borne disease. Correctly identifying and understanding the disease life cycle will help target management options most effectively.
2. Understanding what paddocks and seasons are most susceptible to soil-borne diseases for your key crops. Experience and new soil testing for soil-borne diseases (e.g. Predicta, project VG15009) are available to identify at risk paddocks and seasons.
3. Focusing preventative actions during the fallow and planting preparation phase, i.e. setting the soil and crop up to reduce the impact of soil-borne diseases occurs prior to planting.
4. Developing an integrated cultural, biological and chemical management plan to both target vulnerable stages of the soil-borne disease and to create a soil environment which is not favourable for the disease.

The project developed a wide range of resources to help growers and advisors build an integrated management approach tailored to their cropping system, risk levels, market requirements, soils and climate. Information on identification and control is summarised in "Soil Bourne Disease in vegetable crops - a practical guide to identification and control". Further detailed information on disease lifecycles and control options are provided in webinars and videos, with more than 6,000 views to date, together with the 11 factsheets. All project information is housed on the Soil Wealth – Integrated Crop Protection website (www.soilwealth.com.au/my-topic/soilborne-disease/).

Between 2015 and 2018, 25 face-to-face delivery activities helped more than 650 growers and advisers develop better integrated soil-borne disease management options. The annual soil-borne disease masterclass provided a "hothouse" for growers, advisers and the project team to integrate cultural, chemical and biological management options and tailor these to specific production systems. Following the masterclass, 80% of participants had introduced, or fine-tuned practices to better manage soil-borne diseases, and more than two-thirds of growers and advisers felt they were better able to manage soil-borne diseases.

Targeted research was undertaken to fill the gaps in soil-borne disease management knowledge. A RD&E prioritisation of soil-borne diseases affecting Australian vegetables was undertaken. Specific research was undertaken on 1. Control of Sclerotium rot of chillies; 2. Managing damping off in babyleaf spinach; 3. Role of cover crops in reducing soil-borne diseases in vegetable production and 4. Grafting cucumbers to disease-resistant rootstocks. These research trials further developed the knowledge and skills on cultural, biological and chemical control and their integration.

Looking forward, the following recommendations are made to further reduce the risk of soil-borne diseases;

1. Growers and advisors require training to build integrated preventative approaches to manage soil-borne diseases. Consideration be given to supporting further delivery of training events such as the Soil-borne Disease Masterclass;

2. Cultural practices are an important part of preventative strategies. To ensure that new information is developed on how best to use these cultural practices in managing soil-borne disease, support from industry will be required due to market failure preventing private investment;

3. There is a wave of new biological products hitting the market. Currently none are registered for soil-borne disease control in vegetables. There is a clear need for the vegetable industry to understand the potential role of biological products in managing soil-borne diseases.

Keywords

Soil-borne diseases, vegetables, integrated control, biological control, cultural control, chemical control, masterclass, cover crops, biofumigation, compost, crop rotation*, Sclerotinia, Fusarium, Phytophthora, Rhizoctonia*, *Sclerotium,* clubroot, nematodes, damping off.

Introduction

Soil-borne diseases cost Australia's $4 billion vegetable industry an estimated $120 million.

The Australian vegetable industry has invested heavily in soil-borne disease control and epidemiological research (e.g. VG05026[1], VG05043[2], VG06092[3], VG07125[4], VG07126-2.1[5], VG09191[6]) and reviews of prior research (VG11034[7], VG11035[8], VG12048[9], VG13045[10]). The investment in vegetable soil-borne disease research in Australia has produced numerous reports on the management of *Sclerotinia*, *Fusarium*, *Phytophthora*, *Rhizoctonia*, clubroot and nematodes.

However, effective management of soil-borne disease remains the number one soil-related issue identified by Australian vegetable growers and advisers (VG13076[11]/78, VG11034[7]). Producers do not have the information, skills and knowledge they need to manage soil-borne disease in intensive vegetable production systems.

Soil-borne diseases have become more problematic due to declining chemical control options and intensification of vegetable production. The intensification of production has produced conditions more conducive to soil-borne diseases by shortening of crop rotations, pushing soils harder to meet supply contracts to large retailers and processing plants, and the growing of crops outside of their optimum growing conditions when they are more susceptible to soil-borne disease.

Growers and advisers recognise the need for more integrated, strategic soil-borne disease management options. With no one control measure maintaining efficacy against most soil-borne disease, and with few tactical management options, strategic management practices are required.

A concerted effort is needed to bring together the valuable research and management practices, from Australia and around the world, and work with growers and advisers to give them the skills to adapt this to their local conditions and production systems.

This project, which ran from 2015-2018, looked across the broad range of potential management factors, including chemical, cultural and biological options, to start to develop approaches and capacity in the vegetable industry to tap into integrated soil-borne disease management opportunities. The project also recognised that there remained knowledge gaps for some diseases and crops. Targeted research was undertaken to address some of these gaps.

Methodology

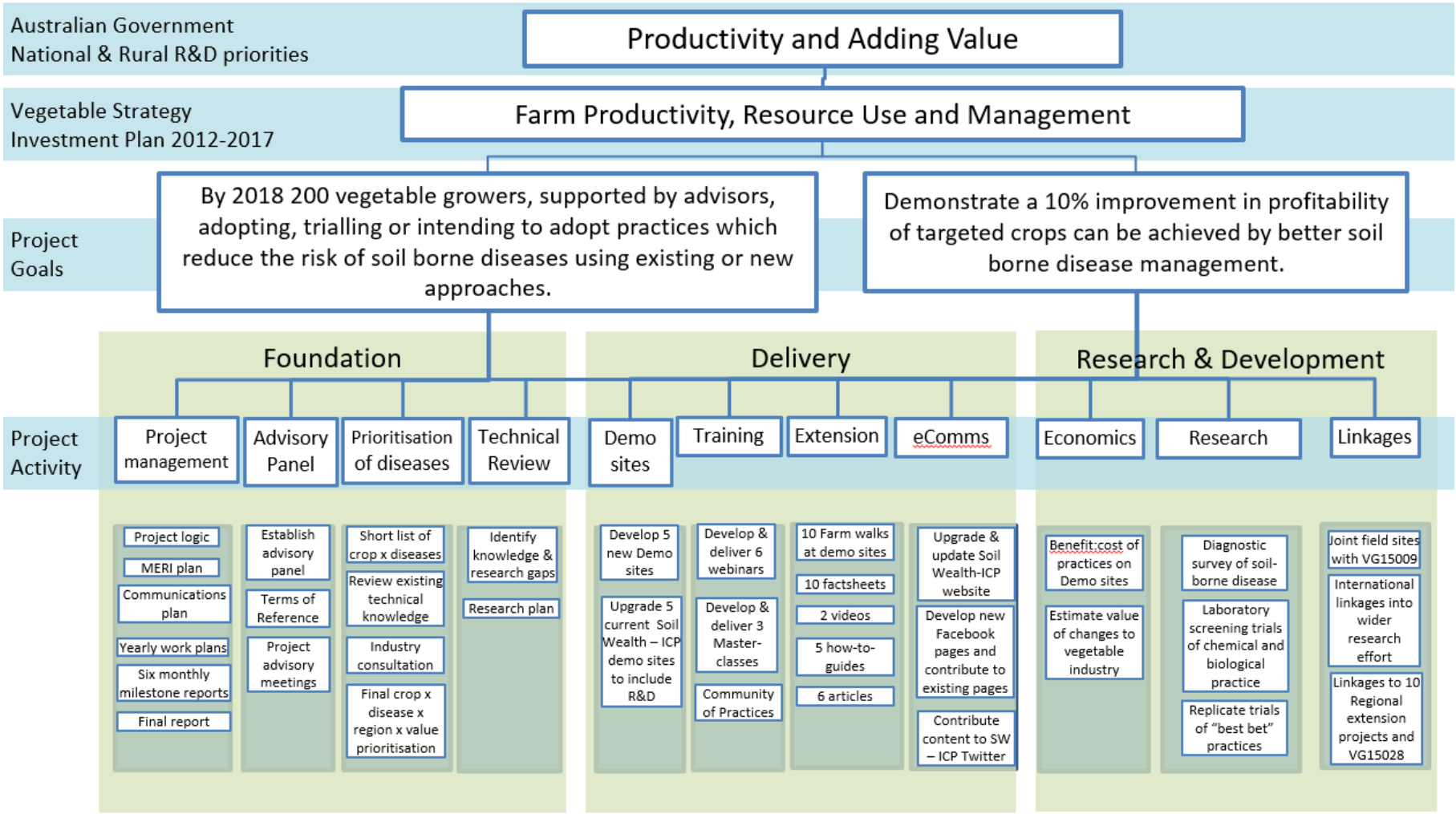
The three-year project, which ran from 2016 to 2018, aimed to:

1. **deliver** to growers and advisers effective soil-borne disease management tools and approaches by integrating existing research and practice information (approximately 60% of the project);
2. undertake targeted **research and development** to fill current information gaps (approximately 40% of the project).

The project logic shows how the project activities link within the Vegetable Strategic Investment Plan and the broader National & Rural R&D Priorities for the Australian Government (Figure 1).

The project outcome will be achieved by vegetable growers, supported by advisers, adopting, trialling or intending to adopt practices which reduce the risk of soil-borne diseases using existing or new approaches (Goal 1), and aims to achieve a 10% improvement in the profitability of targeted crops by better soil-borne disease management (Goal 2).

Figure 1. Program logic for A multi-faceted approach to soil-borne disease management – VG15010



Prioritisation

The project conducted a comprehensive gap analysis and prioritisation of soil-borne diseases, hosts and regions using a process that built on previous projects and research in the area[12]. The key components of the process included:

- A review of previous Australian soil-borne disease projects and disease priority lists
- Consideration of the Strategic Agri-chemical Review Process (SARP) priorities
- Consultation with pathologists, nematologists, advisers and agronomists
- Targeted survey of representative Australian vegetable growers
- Input from the project reference group
- Consideration of the value of production

This process resulted in identifying the following disease and crop combinations, which the project focused on, to produce integrated information on soil-borne disease management or targeted research and development (Table 1).

Table 1. prioritisation of vegetable crops and soil-borne diseases.

Crop & farm gate value[13]	**Soil-borne disease focus**
Brassicas $344 million	Clubroot (*Plasmodiophora brassicae*) Sclerotinia (*S. sclerotiorum*) Damping off (*Rhizoctonia* spp.)
Carrots $231 million	Cavity spot and forking (*Pythium sulcatum* and P *violae*) Root knot nematodes (*Meloidogyne* spp.)
Baby leaf Spinach $200 million	Damping off complex (*Rhizoctonia* spp./*Pythium* spp./ *Fusarium oxysporum*)
Lettuce $154 million	Sclerotinia (*S. sclerotiorum* and *S. minor*) Damping off complex (*Rhizoctonia solani*/*Pythium* spp., *Fusarium oxysporum*)
Capsicums & chillies $181 million	Sclerotium stem rot (*Sclerotium rolfsii*) Damping off complex (*Rhizoctonia spp.*/*Pythium* spp., *Fusarium oxysporum, Phytophthora* spp.) Root knot nematodes (*Meloidogyne* spp.)
French beans $78 million	Sclerotinia (*S. sclerotiorum*) Damping off (*Rhizoctonia* spp.) Sclerotium stem rot (*Sclerotium rolfsii*)
Leeks & celery $20 & $60	Basal plate rot (*Fusarium*) Pink root (*Pyrenochaeta terrestris*)

million

Delivery methodology

The project used a wide range of deliver methods to work with and communicate soil-borne disease management options to growers and advisers. This included:

- Demonstration sites
- Webinars
- Masterclasses
- Community of practice
- Farm walks and events
- Factsheets
- Videos
- Best-practice guide
- Articles
- Websites
- Social media

The project outputs were promoted through the Soil Wealth and Integrated Crop Protection project, and the National Vegetable Extension Network (VegNET) in each state to bring regionally topical information to growers.

The Soil Wealth and Integrated Crop Protection project website housed all outputs on a specific soil-borne disease page on the website (https://www.soilwealth.com.au/my-topic/soilborne-disease/), Soil wealth and ICP webinars were used to deliver a wide range of content from the project through six webinars, the project used the Soil wealth and ICP Factsheet format to develop 11 factsheets, which were promoted via the Soil Wealth and ICP newsletter along with AUSVEG weekly updates. The project farm walks were promoted through Soil Wealth and ICP newsletter and calendar.

Research and development methodology

The project has a focused research component which, which investigates new methods for managing damping off complex in babyleaf spinach, *Sclerotium rolfsii* and damping off in capsicums, cavity spot in carrots, Sclerotinia in lettuce and Fusarium wilt in cucumbers.

A range of methodologies was used to determine the efficiency and economics of new management options including:

- Replicated field trials - Damping off in spinach, Tasmania(Appendix 12); Sclerotium rot of chilli: best bet fungicides and biologicals, Queensland (Appendix 13); Effect of planting density on the incidence of soil-borne disease and yield of chillies, Queensland (Appendix 14); Fusarium control using grafted cucumber, NSW (Appendix 16); The use of cover crops in reducing the risk of Sclerotinia in lettuce production, Tasmania (Appendix 25).
- Demonstration trials – Soil-borne disease management in greenhouse capsicums, South Australia (Appendix 17); The effect of custom-made composts on the performance of carrot crop and soil health, Western Australia (Appendix 18); Calcium cyanamide ($CaCN_2$) fertiliser effect on *Pythium* spp. and other soil-borne diseases in carrots, Western Australia (Appendix 19).
- Glasshouse pot trials – Spinach and best bet fungicide and biologicals trials, New South Wales (Appendix 15).

The project linked closely with the South Australian Research and Development Institute (SARDI) project developing DNA testing methods to quantify disease inoculum in vegetable soils (VG15009).

The Team

The project was undertaken by the following team from three organisations:

AHR (Applied Horticultural Research)
Dr Gordon Rogers
Dr Kelvin Montagu
Dr Natalie Elias
Marc Hinderager
NSW Department of Primary Industries
Dr Len Tesoriero
RMCG
Dr Doris Blaesing
Donna Lucas

Outputs

The project conducted more than 25 face-to-face delivery activities. The geographical spread of these training and farm walks and industry events are outlined in Figure 1, along with the location of research and demonstration sites. Details of the training and events are provided in Table 3 and Table 4.

Webinars, factsheets, videos, articles and the how-to-guide made information on managing soil-borne diseases to a wider audience and provides a legacy for the project. All this material is housed on the soil-borne diseases page of the Soil Wealth – Integrated crop Protection website (https://www.soilwealth.com.au/my-topic/soilborne-disease/). Details of these outputs are provided in Table 5-7.

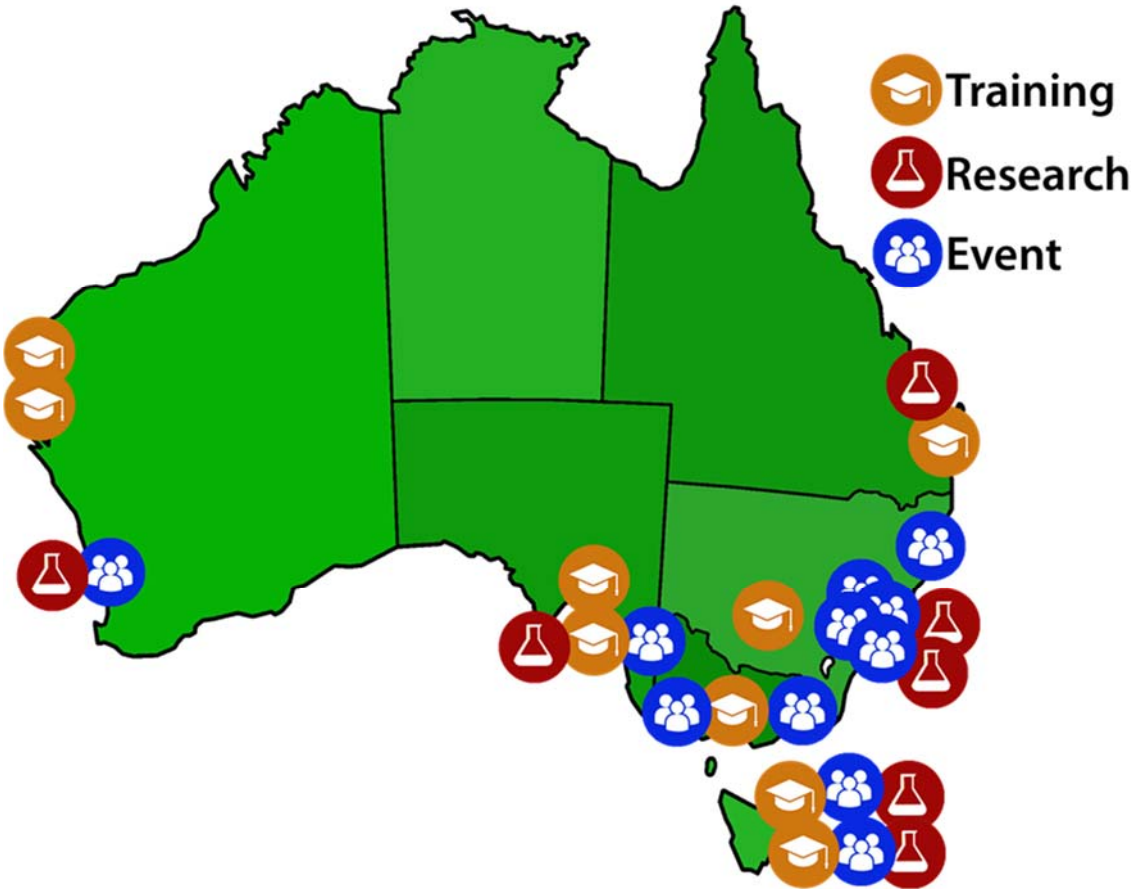


Figure 2. The location of face-to-face training, farm walks and industry events, and research and demonstration site

Delivery – Training

Webinars

A series of six webinars were produced providing information on managing specific soil-borne disease or cultural practices. These were based on material from the soil-borne disease masterclass (
Table 2). A further two webinars were produced under the Soil Wealth and Integrated Crop Protection project which provided specific information on cover crops based on the masterclass. All webinars are housed on the soil-borne diseases page of the Soil Wealth – ICP website (https://www.soilwealth.com.au/my-topic/soilborne-disease/).

Table 2. Soil-borne disease webinar series.

Webinar	Description	URL
The role of soil DNA testing in managing the risk of soil-borne diseases	The webinar covered better managing soil-borne diseases in vegetables using DNA testing. Practical guidance was provided on how the DNA technology is being used and the type of information it provides.	https://www.soilwealth.com.au/resources/videos-and-apps/the-role-of-soil-dna-testing-in-managing-the-risk-of-soilborne-diseases-how-is-it-being-used-and-what-can-it-do-webinar-recording/
Fusarium wilt management in vegetables	The latest techniques in managing the soil-borne disease Fusarium wilt in vegetable crops including Solanaceae, legumes, cucurbits and sweet potatoes	https://www.soilwealth.com.au/resources/videos-and-apps/fusarium-wilt-management-in-vegetables-with-dr-len-tesoriero-webinar-recording/
Nematodes in vegetable soils managing the bad and good ones	The webinar focused on the pest nematode, outlining the life cycles of the root-knot and root-lesion nematodes and how this can be used to target control measures	https://www.soilwealth.com.au/resources/videos-and-apps/nematodes-in-vegetable-soils-managing-the-bad-and-good-ones-with-dr-sarah-collins-webinar-recording/
Nutrition management and plant disease	This webinar covers nutrition and disease relationships, and the effect of different forms of nitrogen and other nutrients on soil-borne disease	https://www.soilwealth.com.au/resources/videos-and-apps/nutrition-management-and-plant-disease-with-dr-len-tesoriero-webinar-recording/
How to manage Sclerotinia in vegetable crops	The webinar provides an overview of how to manage Sclerotinia in vegetable crops	https://www.soilwealth.com.au/resources/webinar-recordings/how-to-manage-sclerotinia-in-vegetable-crops-with-dr-len-tesoriero-webinar-recording/
How to control Pythium in vegetable crops	The webinar provides an overview of how to manage Pythium in vegetable crops	https://www.soilwealth.com.au/resources/weblinks/how-to-control-pythium-in-vegetable-crops-with-dr-len-tesoriero/

Masterclasses

The project delivered three soil-borne diseases masterclasses. Due to demand, an additional five other training events across the major vegetable growing regions were delivered (Table 3).

Table 3. Training events and location delivered by the project.

Training	length	Date	location
Soil-borne disease masterclass	2 days	August 2016	Ipswich, Queensland
Soil-borne disease workshop	1.5 hours	October 2016	Mount Barker, South Australia
Irrigation management to reduce damping-off in leafy vegetables	1 day	October 2016	Cambridge, Tasmania
Soil-borne disease masterclass	2 days	August 2017	Devonport, Tasmania
Soil-borne disease workshop and Farm Walk (Vietnamese)	4 hours	April 2017	Carnarvon, Western Australia
Soil-borne disease workshop and farm walk (English)	4 hours	May 2017	Carnarvon, Western Australia
Soil-borne disease workshop	1 day	September 2018	Griffith, New South Wales
Soil-borne disease masterclass	2 day	September 2018	Mawson Lakes, South Australia

Delivery – Extension

Farm walks and events

The project team delivered or contributed to more than 17 farm walks and industry events as detailed in Table 4**.**

Table 4. Farm walks and industry events featuring soil-borne disease activities.

Event	Topic	When	State
Farm walk	Cover crops and soil-borne diseases	May 2016	Cambridge, Tasmania
Farm walk	Cover crops and soil-borne diseases	October 2016	Mt Baker, SA
Farm walk	Biofumigant cover crop for reducing soil-borne disease	December 2016	Richmond, NSW
Farm walk	Role of cover crops in managing soil-borne disease	February 2017	Cambridge, Tasmania
Greenhouse Cucumber Field Day	Soil-borne Disease project overview	May 2017	Woolgoolga, NSW
Farm walk	Fusarium resistant rootstocks – what's the latest?	May 2017	Rossmore NSW
East Gippsland Vegetable Innovation Day	Managing baby spinach damping off, root rot and wilt	May 2017	East Gippsland, Victoria
NRM workshop and farm visit	Control of soil-borne diseases An overview	May 2017	Deloraine, Tasmania

NRM workshop	Control of soil-borne diseases An overview	May 2017	Scottsdale, Tasmania
AgLink meeting	Management of soil-borne diseases and disease complexes	May 2017	Healesville, Victoria
Horticulture field day	pest and disease detection and management	May 2017	Mt Baker, SA
Farm walk	Managing soil-borne disease	June 2017	Cowra, NSW
VegNET	Managing key diseases of brassica and lettuce crops	June 2017	Richmond, NSW
VegNET Brassica growers' field day	Clubroot control	August 2017	Bathurst, NSW
Sydney markets VegNET stall	Management of soil-borne diseases	April 2018	Flemington, NSW
Farm walk	Can cover crops reduce Sclerotinia in lettuce?	May 2018	Richmond, Tasmania
Vegetables WA field day	Damping off diseases and their control	May 2018	Gingin, Western Australia

Factsheets

Eleven factsheets were produced (Table 5). All factsheets are housed on the soil-borne diseases page of the Soil Wealth – ICP website (https://www.soilwealth.com.au/my-topic/soilborne-disease/). The factsheets are also included in the Appendices.

Table 5. Factsheets produced by the project.

Factsheet	Crop and disease	URL- Appendices
Managing Fusarium diseases in vegetable crops	General – Fusarium	https://www.soilwealth.com.au/resources/fact-sheets/pest-and-disease-management/managing-fusarium-diseases-in-vegetable-crops/ - Appendix 1
Clubroot management in brassica vegetables	Brassicas – *Plasmodiophora brassicae*	https://www.soilwealth.com.au/resources/fact-sheets/pest-and-disease-management/clubroot-management-in-brassica-vegetables/ - Appendix 2
Sclerotinia rot of green beans	Beans - *Sclerotinia sclerotiorum*	https://www.soilwealth.com.au/resources/articles-and-publications/sclerotinia-rot-of-green-beans/ - Appendix 3
Sclerotinia rot in vegetable crops	Lettuce & beans – *Sclerotinia spp.*	https://www.soilwealth.com.au/resources/fact-sheets/pest-and-disease-management/sclerontinia-rot-of-vegetable-crops/ -Appendix 4
Pythium in carrots: Cavity spot and forking in carrots	Carrots - *Pythium*	https://www.soilwealth.com.au/resources/fact-sheets/pest-and-disease-management/pythium-in-carrots-cavity-spot-and-forking-in-carrots/ - Appendix 5
Damping off in spinach	Spinach - *Pythium* spp., *Phytophthora* spp., *Fusarium* spp. and *Rhizoctonia* spp.	https://www.soilwealth.com.au/resources/fact-sheets/pest-and-disease-management/damping-off-in-spinach/ -Appendix 6
Calcium cyanamide	Covers range of crops and	https://www.soilwealth.com.au/resources/fact-

fertiliser; use in vegetables	diseases	sheets/soil-nutrition-and-compost/calcium-cyanamide-fertiliser-use-in-vegetables/ -Appendix 7
Biopesticides in Australia	General	https://www.soilwealth.com.au/resources/fact-sheets/pest-and-disease-management/biopesticides-in-australia/ -Appendix 8
Farm trial design: what to consider	General	https://www.soilwealth.com.au/resources/fact-sheets/crop-management/farm-trial-design-what-to-consider/ -Appendix 9
Use a partial budget to assess practice change on vegetable farms	General	https://www.soilwealth.com.au/resources/fact-sheets/crop-management/use-a-partial-budget-to-assess-practice-change-on-vegetable-farms/ -Appendix 10

Videos

A series of six videos were produced highlighting in-field soil-borne diseases, symptoms and management options (Table 6). A further video was produced in partnership with Soil Wealth – ICP project on experiences from growers following the soil-borne disease masterclass. All videos are housed on the soil-borne diseases page of the Soil Wealth – ICP website (https://www.soilwealth.com.au/my-topic/soilborne-disease/).

Table 6. Soil-borne disease video series.

Video	Crop and disease	URL
Summer root rot	Parsley & carrots - Pythium	https://www.soilwealth.com.au/resources/videos-and-apps/soil-borne-disease-series-summer-root-rot/
Club root	Brassicas - *Plasmodiophora brassicae*	https://www.soilwealth.com.au/resources/videos-and-apps/soil-borne-disease-series-club-root/
Bottom rot	Lettuce - *Rhizoctonia*	https://www.soilwealth.com.au/resources/videos-and-apps/soil-borne-disease-series-bottom-rot/
Black rot	Brassicas - *Xanthomonas campestris*	https://www.soilwealth.com.au/resources/videos-and-apps/soil-borne-disease-series-black-rot/
Big vein	Lettuce – *Olpidium virulentus*	https://www.soilwealth.com.au/resources/videos-and-apps/soil-borne-disease-series-big-vein/
Basel plate rot	Leeks - *Fusarium*	https://www.soilwealth.com.au/resources/videos-and-apps/soil-borne-disease-series-basel-plate-rot/
Soil-borne disease master class for the vegetable industry – Experiences from leading growers	General	https://www.soilwealth.com.au/resources/videos-and-apps/soilborne-disease-master-class-for-the-vegetable-industry-experiences-from-leading-growers/

How-to-guide

A practical guide to identification and control of soil-borne diseases in vegetable crops has been compiled. The guide covers the major vegetable crop families, their symptoms and a summary of disease management options. The guide can be found at https://www.soilwealth.com.au/resources/fact-sheets/pest-and-disease-management/soil-borne-

disease-in-vegetable-crops-a-practical-guide-to-identification-and-control/, and is included as Appendix 11.

Articles

Eight articles were published (Table 7). All factsheets are housed on the soil-borne diseases page of the Soil Wealth – ICP website (https://www.soilwealth.com.au/my-topic/soilborne-disease/

Table 7. Soil-borne disease articles produced by the project.

Article	Crop and disease	Publication	URL
Soil diseases in vegetable under attack in new project	General	ABC rural	https://www.soilwealth.com.au/resources/weblinks/soil-diseases-in-vegetables-under-attack-in-new-project/
A multi-faceted approach to soil-borne disease management	General – Prioritisation	Vegetables Australia	https://www.soilwealth.com.au/resources/articles-and-publications/a-multifaceted-approach-to-soil-borne-disease-management/
Disease management Features at International Spinach Conference, Spain	Spinach – downy mildew	Soil Wealth Website	https://www.soilwealth.com.au/resources/articles-publications-and-case-studies/disease-management-features-at-international-spinach-conference-spain/
Investigating cavity spot and forking in carrots	Carrots – *Pythium* spp.	Vegetables Australia	https://www.soilwealth.com.au/resources/articles-publications-and-case-studies/investigating-cavity-spot-and-forking-in-carrots/
Soil-borne disease management in vegetable crops	General	Soil Wealth Website	https://www.soilwealth.com.au/resources/articles-publications-and-case-studies/soil-borne-disease-management-in-vegetable-crops-with-dr-len-tesoriero/
Managing fungicide resistance	General	Good fruit and vegetables	http://www.goodfruitandvegetables.com.au/story/4716315/fungicide-resistance-needs-management/
Damping off in spinach; Best bet fungicide and biologicals	Spinach - *Pythium* spp., *Phytophthora* spp., *Fusarium* spp. and *Rhizoctonia* spp.	Soil Wealth Website	https://www.soilwealth.com.au/resources/case-studies/damping-off-in-spinach-best-bet-fungicide-and-biologicals-trial-20162017/
The effect of custom made composts on the performance of a carrot crop and soil health	Carrots - *Pythium* spp.,	Soil Wealth Website	https://www.soilwealth.com.au/resources/articles-publications-and-case-studies/the-effect-of-custom-made-composts-on-the-performance-of-a-carrot-crop-and-soil-health/

Delivery - eCommunication

Website

The Soil Wealth and ICP website was upgraded to house all project outputs on the Soil-borne disease page (https://www.soilwealth.com.au/my-topic/soilborne-disease/)

Facebook pages

Where appropriate, Facebook pages were used to help communicate information from project activities including for Giggin, WA, Richmond, Tas, Sydney basin, NSW and Virginia, SA.

Research & Development - Economics

A guide to using a partial budget to assess practice change on vegetable farms was developed to provide a framework for growers to assess the economics of soil-borne disease management options (Table 5).

Where appropriate economics of the management options have been included in each article or report.

Research & Development - Research

Targeted research was undertaken to address gaps in soil-borne disease management information. Research and demonstration reports detail the trial information produced by the project (Table 8). These reports provided the information for a number of factsheets and articles (Table 5 & Table 7) and were also communicated to the research community via six conference presentations (Table 9). The research and demonstration reports and conference publications are included in the Appendices.

Table 8. Research and demonstration trial reports.

Report	Title	Appendix
Research report	Damping off in spinach: Best bet fungicide and biologicals trial	Appendix 12
Research report	Sclerotium rot of chilli: Best bet fungicides and biologicals	Appendix 13
Research report	Effect of planting density on the incidence of soil-borne disease and yield of chillies	Appendix 14
Research report (draft)	Experiments to test management options for damping-off disease of babyleaf spinach	Appendix 15
Research report	Grafting cucumbers to disease resistant rootstocks	Appendix 16
Demonstration report	Soil-borne disease management in capsicums grown under protected cropping	Appendix 17
Demonstration report	The effect of custom made composts on the performance of a carrot crop and soil health	Appendix 18
Demonstration report	Can calcium cyanamide ($CaCN_2$) fertiliser affect Pythium spp. and other soil-borne diseases in carrots – findings of an on-farm demonstration	Appendix 19

Conferences

Six conference papers were present by the project team based on research undertaken during the project (Table 9). The conference papers are also included in the Appendices.

Table 9. Research papers presented at National and International conferences.

Conference - Appendix	Title	Authors	Location
Australasian Soil-borne diseases Symposium - Appendix 20	An integrated research into practice approach to Soil-borne disease threats in the Australian vegetable industry	Kelvin Montagu, Gordon Rogers, Doris Blaesing, Len Tesoriero, Marc Hinderager, Donna Lucas, Kathy Ophel-Keller, Michael Rettke, Julie Finnigan, Carl Larsen & Anne-Marie Boland	Christchurch, November 2016
Australasian Plant Pathology Society Biennial Conference - Appendix 21	Control of Sclerotium rot of chillies in Australia	L Tesoriero, L Spohr, A Harris, K Montagu, & G Rogers	Brisbane, September 2017
Australasian Plant Pathology Society Biennial Conference - Appendix 22	Managing damping off in babyleaf spinach in Australia	L Tesoriero, L Sporr, A Harris, D Lucas, D Blaesing, K Montagu, & G Rogers	Brisbane, September 2017
International Spinach Conference - Appendix 23	Managing damping off in babyleaf spinach in Australia	Len Tesoriero, Fiona Lidbetter, Shannon Mulholland, Lorraine Spohr, John Archer, Ann Harris, Donna Lucas, Doris Blaesing, Kelvin Montagu, & Gordon Rogers	Spain, February 2018
Australasian Soil-borne diseases Symposium - Appendix 24	RD&E prioritisation of soil-borne diseases affecting Australian vegetable	Blaesing D., Lucas D., Tesoriero L., Rogers G	Adelaide, September 2018
National Soil Science Conference - Appendix 25	How do cover crops reduce soil-borne disease in vegetable production, via influence on specific pathogens or changes in general soil microbial communities?	K. Montagu, A. Harber, B. Walker, D. Lucas, R. Tegg, S. Powell, L Tesoriero, M. Rettke, C. Wilson and R. Doyle	Canberra, November 2018

Outcomes

The project had two overarching goals:

1. By 2018, 200 vegetable growers, supported by advisers, adopting, trialling or intending to adopt practices which reduce the risk of soil-borne diseases using existing or new approaches.

2. Demonstrate a 10% improvement in profitability of targeted crops can be achieved by better soil-borne disease management.

We have strong evidence that goal 1 has been achieved during the life of the project. This is provided by the good levels of engagement with the outputs delivered, as detailed below (Table 10). The annual soil-borne disease masterclass provided a “hothouse” for growers, advisers and the project team to integrate cultural, chemical and biological management options and tailor these to specific production systems. Following the masterclass, 80% of respondents had introduced or fine-tuned practices to better manage soil-borne diseases, and more than two-thirds of growers and advisers felt better able to manage soil-borne diseases.

If 80% of the 650 growers and advisers have had introduced or fine-tuned practices to better manage soil-borne diseases, then the project would have achieved goal 1.

The electronic and written resources housed on the Soil Wealth website will continue to provide growers and advisers with a strong framework for developing integrated soil-borne disease management practices on their farms.

The profitability goal is more difficult to assess. Assessment of individual crop economics indicates that a 10% improvement is more than possible under trial conditions. Assessing if this is achieved in commercial operations is more problematic due to the absence of a suitable control and the episodic nature of soil-borne diseases. Despite these limitations two-thirds of participants reported being better able to manage soil-borne diseases and had improved information on the financial assessment of management options.

Monitoring and evaluation

The monitoring and evaluation section uses the key M&E Plan evaluation questions to discuss the impact, effectiveness and appropriateness of the project activities and outputs.

Impact - What has changed or is different as a result of this project?

The project has delivered training and events across the country (Figure 2), and produced a wide range of electronically available information which has already been accessed many times (Table 10).

To get an insight into the impact of the project a follow-up survey of masterclass participants was undertaken. This is a subset of the growers and advisers who were engaged by the project.

Overall there is clear evidence that growers and advisers are changing management practices (Figure 3), with more than two-thirds of growers and advisers feeling better able to manage soil-borne diseases after attending the masterclass (Figure 4).

The 79 masterclass participants were emailed a survey, with 20 response received. Overall, 80% of respondents indicated that they have introduced or fine-tuned practices to better manage soil-borne diseases since the masterclass. Specifically, 45% indicated that they had introduced new practices, with a further 35% indicating that they had fine-tuned existing practices. Twenty percent of respondents indicated that the masterclass reinforced current approaches.

The practices which growers have introduced are summary in Figure 3. Growers were more likely to introduce general practices to improve soil health, such as use of cover crops and compost. This reflects a key message from the masterclass to focus on preventing soil-borne diseases rather than reacting to their presence. Another cultural practice, changing crop rotation, was also reported. The increased use of diagnostic services and biological controls was also reported.

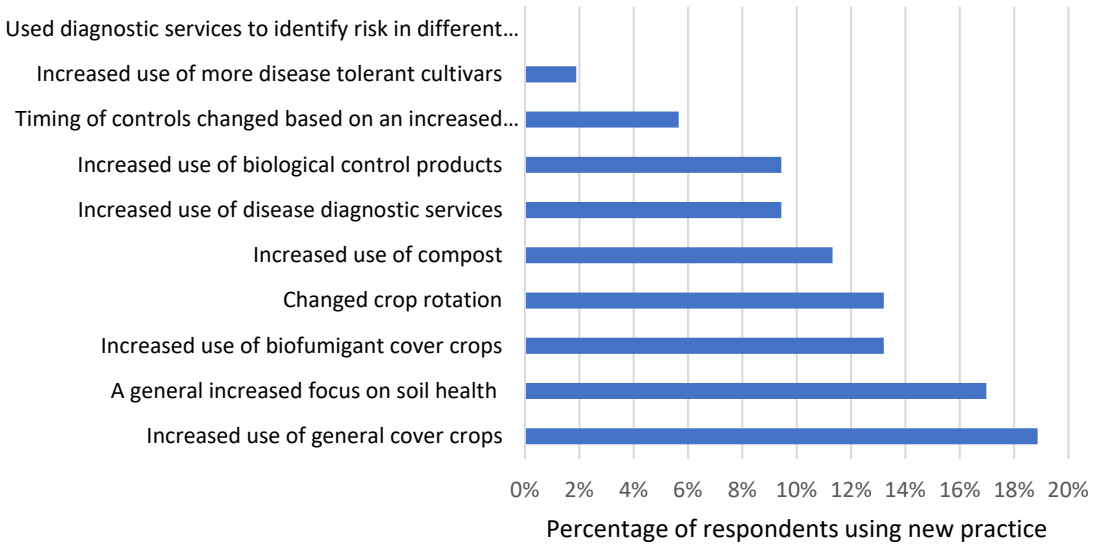


Figure 3. Practice changes made by growers and advisers following the Soil-borne Disease masterclass

More than two-thirds of growers and advisers felt better able to manage soil-borne diseases after attending the masterclass. The remaining third of participants considered that they sometimes felt better able to manage soil-borne diseases (Figure 4).

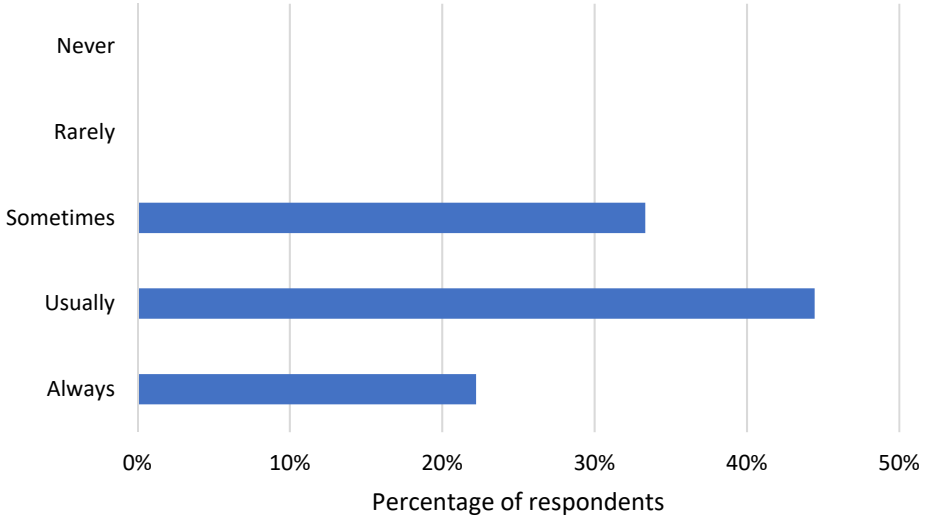


Figure 4. Ability of masterclass participants to better manage soil-borne diseases after attending the masterclass

Effectiveness - *To what extent were the planned activities and measures achieved?*

The program logic details the planned activities and outputs (Figure 1). Focusing on the specific measures in the program logic indicates a high level of project effectiveness. Across the delivery outputs all were delivered at or above that required. In particular, more training events and videos were produced than originally planned due to demand.

The project established three of the planned new demonstration sites. Some growers were wary of highlighting the presence of soil-borne diseases. The project elected to move the resources to deliver a wider program of training, with five more training events to be run around the country.

Only one how-to guide was produced following consultation with growers and advisers. Instead of producing five specific crop and soil-borne diseases how-to guide, a more integrated and comprehensive guide was produced covering all the major vegetable crops including brassicas; capsicum; chilli and eggplant; carrot; celery; parsnip and parsley; green beans and peas; lettuce, endive and artichoke; pumpkin, squash, zucchini and cucumber; spinach, silverbeet and beetroot; spring onions, leek and garlic; Sweet corn.

Table 10. Project performance against deliver outputs, and relevant metrics (as at February 2019).

Delivery output	Delivered	Metrics
5 new demo sites	3 demo sites	
5 upgraded demo sites	5 research sites	
6 webinars	6 webinars (series. Table)	3,759 views
3 masterclasses	3 masterclasses plus 5 other training events (Table 3)	159 participants
Community of practice	Contribution content to CoP	1,257 members
10 farm walks	17 farm walks and industry events (Table 4)	479 participants
10 factsheets	11 factsheets (Table 5)	1,806 views
2 videos	6 videos (Table 6)	2,466 views

5 how-to guides	1 how-to guide	This has just been completed so no user metrics are available
6 articles	8 articles (Table 7)	594 views
Upgrade & update SW-ICP website	Dedicated soil-borne disease page	
Social media	Contribute to relevant Facebook sites and twitter	More than 1,900 followers on twitter

Appropriateness – To what extent has the innovation being tested contributed useful information to address the goals?

The project had two goals:

1. By 2018, 200 vegetable growers, supported by advisers, adopting, trialling or intending to adopt practices which reduce the risk of soil-borne diseases using existing or new approaches.
2. Demonstrate a 10% improvement in profitability of targeted crops can be achieved by better soil-borne disease management.

The metrics for project activities (Table 10) indicates that project activities and outputs were aligned with grower and advisor needs. Training and events held across the country has helped more than 600 people gain a better integrated approach to managing soil-borne disease. As evidenced by the masterclass survey 80% of participants have introduced or fine-tuned practices to better manage soil-borne diseases. If this level of practice change is applied to the more than 650 people who have attended face-to-face events, then it is highly like that the project has achieved its goal of supporting 200 growers to adopt practices to reduce the risk of soil-borne diseases.

Furthermore, the project has a far great reach through the webinars, based on the masterclass, and videos which have already posted more than 6,000 views.

The project outputs will provide a wealth of information as a project legacy, which will be maintained and promoted by the Soil wealth and integrated crop protection project.

The profitability goal is more difficult to assess. Assessment of individual crop economics indicates that a 10% improvement is more than possible under trial conditions. Assessing if this is achieved in commercial operations is more problematic due to the absence of a suitable control and the episodic nature of soil-borne diseases. Despite these limitations the, two-thirds of participants reported being better able to manage soil-borne diseases.

The activity which contributed less than expected to the goals were new demonstration sites. Grower sensitivity to “show casing” their soil-borne disease challenges meant recruitment of commercial demonstration sites was problematic.

Recommendations

Managing soil-borne diseases

A key recommendation of the project is the need to shift to preventative strategic approaches to manage soil-borne diseases. Once a soil-borne disease is in a crop there are few post-plant treatments to prevent its spread or progression for most diseases.

The project recommends growers and advisors:

1. Understand their soil-borne disease. Correctly identifying and understanding the disease life cycle will help target management options most effectively.
2. understand what paddocks and seasons are most susceptible to soil-borne diseases for your key crops. Experience and new soil testing for soil-borne diseases (e.g. Predicta, project VG15009) are available to identify at risk paddocks and seasons.
3. Focus preventative actions during the fallow and planting preparation phase, i.e. setting the soil and crop up to reduce the impact of soil-borne diseases occurs prior to planting.
4. The cultural, biological and chemical management options need to work together to both target vulnerable stages of the soil-borne disease, and to create a soil environment which is not favourable for the disease.

To help growers and advisors build an integrated management approach tailored to their cropping system, risk levels, market requirements, soils and climate, the project developed a wide range of resources. Information on identification and control is summarised in "Soil Bourne Disease in vegetable crops - a practical guide to identification and control". Further detailed information on disease lifecycles and control options are housed on the Soil Wealth – Integrated Crop Protection website (www.soilwealth.com.au/my-topic/soilborne-disease/).

Future needs

All major vegetable crops can be affected by soil-borne diseases. Looking forward the project suggests that the vegetable industry consider investment in the following:

- Growers and advisors require training to build integrated preventative approaches to manage soil-borne diseases. Consideration be given to supporting further delivery of training events such as the Soil-borne Disease Masterclass.
- Cultural practices (rotation, cover crops, compost, nutrition, irrigation, cultivation) are important parts of an integrated preventative approach. Typically research and development into these practices are overlooked due to market failure, with private investment unable to obtain a suitable return. Under these conditions support from industry is required to help ensure that new information is developed on how best to use these cultural practices in managing soil-borne disease.
- Today's marketplace is inundated with biological products that claim to restore healthy soil microbial balance, boost plant defence mechanisms and/or stimulate plant growth. Products with generic statements such as these are not regulated in Australia and can go to market with little or no substantiated data. Their role in managing soil-borne diseases under field conditions is unclear, with few biological products meeting the stringent efficacy requirements to obtain registration and include usage details on the label. Currently, only one product is registered for use in potatoes for the suppression of *Rhizoctonia*, and none for vegetables. While some biological products may have efficacy against soil-borne disease, research is required to understand the best usage pattern, under what conditions they be effective, and how they can best be used in an integrated management approach. While companies will undertake this work if they are seeking registration, there is a clear need for the vegetable industry to understand the potential role of the wider range of biological products in managing soil-borne diseases.

Refereed scientific publications

Kelvin Montagu, Gordon Rogers, Doris Blaesing, Len Tesoriero, Marc Hinderager, Donna Lucas, Kathy Ophel-Keller, Michael Rettke, Julie Finnigan, Carl Larsen & Anne-Marie Boland, 2016. An integrated research into practice approach to Soil-borne disease threats in the Australian vegetable industry. Proceedings of Australasian Soil-borne diseases Symposium. November 2016, Christchurch.

L Tesoriero, L Spohr, A Harris, K Montagu, & G Rogers, 2017. Control of Sclerotium Rot of chillies in Australia. Proceedings of Australasian Plant Pathology Society Biennial Conference. September 2017, Brisbane.

L Tesoriero, L Spohr, A Harris, D Lucas, D Blaesing, K Montagu, & G Rogers, 2017. Managing damping off in baby-leaf spinach in Australia. Proceedings of Australasian Plant Pathology Society Biennial Conference. September 2017, Brisbane.

Len Tesoriero, Fiona Lidbetter, Shannon Mulholland, Lorraine Spohr, John Archer, Ann Harris, Donna Lucas, Doris Blaesing, Kelvin Montagu, & Gordon Rogers, 2018. Managing damping off in baby-leaf spinach in Australia. Proceeding of International Spinach Conference. February 2018, Spain.

Blaesing D., Lucas D., Tesoriero L., Rogers G, 2018. RD&E prioritisation of soil-borne diseases affecting Australian vegetable. Proceedings of Australasian Soil-borne diseases Symposium. September 2018, Adelaide.

K. Montagu, A. Harber, B. Walker, D. Lucas, R. Tegg, S. Powell, L Tesoriero, M. Rettke, C. Wilson and R. Doyle, 2018. How do cover crops reduce soil-borne disease in vegetable production, via influence on specific pathogens or changes in general soil microbial communities? Proceedings of the Australian National Soil Science Conference. November 2018, Canberra

Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report

Acknowledgements

The project team gratefully acknowledge the contributions made by many in the vegetable industry, especially growers who hosted demonstration sites or research trials including

- Austchilli, Queensland
- Houston's Farm, Tasmania
- Harvest Farms, Tasmania
- Center West Exports, Western Australia
- Allen Dale Farm, NSW
- J & Y Boustani Rossmore, NSW
- Lioulous, South Australia

Appendices

Appendix 1 Managing Fusarium diseases in vegetable crops

Appendix 2 Clubroot management in brassica vegetables

Appendix 3 Sclerotinia rot of green beans

Appendix 4 Sclerotinia rot in vegetable crops

Appendix 5 Pythium in carrots: Cavity spot and forking in carrots

Appendix 6 Damping off in spinach

Appendix 7 Calcium Cyanamide Fertiliser; Use in vegetables

Appendix 8 Biopesticides in Australia

Appendix 9 Farm trial design: what to consider

Appendix 10 Use a partial budget to assess practice change on vegetable farms

Appendix 11 Best practice guide to the management of soil-borne diseases in vegetable crops

Appendix 12 Damping off in spinach: Best bet fungicide and biologicals trial

Appendix 13 Sclerotium rot of chilli: Best bet fungicides and biologicals

Appendix 14 Effect of planting density on the incidence of soil-borne disease and yield of chillies

Appendix 15 Experiments to test management options for damping-off disease of baby spinach

Appendix 16 Grafting cucumbers to disease resistant rootstocks

Appendix 17 Soil-borne disease management in capsicums grown under protected cropping

Appendix 18 The effect of custom made composts on the performance of a carrot crop and soil health

Appendix 19 Can calcium cyanamide (CaCN2) fertiliser affect Pythium spp. and other soil-borne diseases in carrots – findings of an on-farm demonstration

Appendix 20 An integrated research into practice approach to Soil-borne disease threats in the Australian vegetable industry. Proceedings of Australasian Soil-borne Diseases Symposium. November 2016, Christchurch.

Appendix 21 Control of Sclerotium Rot of chillies in Australia. Proceedings of Australasian Plant Pathology Society Biennial Conference. September 2017, Brisbane.

Appendix 22 Managing damping off in baby-leaf spinach in Australia. Proceedings of Australasian Plant Pathology Society Biennial Conference. September 2017, Brisbane.

Appendix 23 Managing damping off in baby-leaf spinach in Australia. Proceeding of International Spinach Conference. February 2018, Spain.

Appendix 24 RD&E prioritisation of soil-borne diseases affecting Australian vegetable. Proceedings of Australasian Soil-borne diseases Symposium. September 2018, Adelaide.

Appendix 25 How do cover crops reduce soil-borne disease in vegetable production, via influence on specific pathogens or changes in general soil microbial communities? Proceedings of the Australian National Soil Science Conference. November 2018, Canberra

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SoilWealth NURTURING CROPS

Integrated Crop Protection PROTECTING CROPS

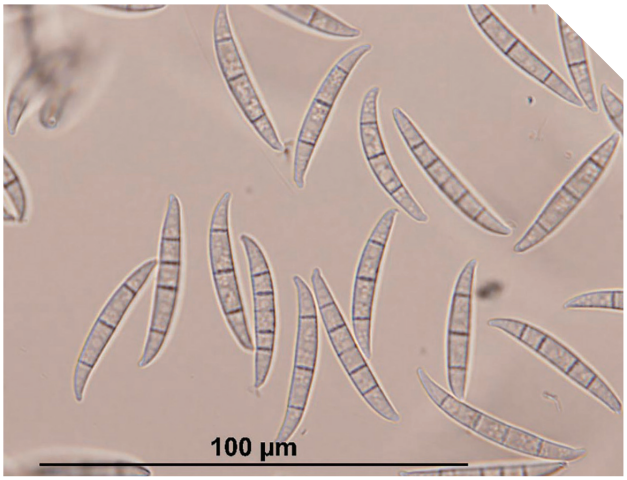
JULY 2018

MANAGING FUSARIUM DISEASES IN VEGETABLE CROPS

Yellowing and wilting cucumbers affected by Fusarium wilt.

INTRODUCTION

Fusarium is a genus of common soil-borne fungi. Most live as saprophytes on decaying plant matter while a few are also important plant pathogens. These plant pathogenic Fusarium fungi are necrotrophs (they feed on dead plant tissue) – which implies they produce enzymes or toxins that kill plant cells as they invade.



Banana-shaped Fusarium spores.

Fusarium pathogens of vegetables produce characteristic banana-shaped spores (macroconidia), as well as other smaller, jellybean-shaped ones (called microconidia) and small resting bodies (chlamydospores and sclerotia). These chlamydospores and sclerotia can survive in soils for several years.

Wilt diseases

While there are many different pathogenic *Fusarium* species, some of the most damaging diseases are caused by strains of one species complex, *Fusarium oxysporum*. They cause vascular wilt diseases by entering the roots and colonising the water-conducting tissue (xylem) and then spreading up into stems where they secrete enzymes and toxins that destroy the surrounding tissue. This causes older leaves to yellow and plants eventually wilt and die.

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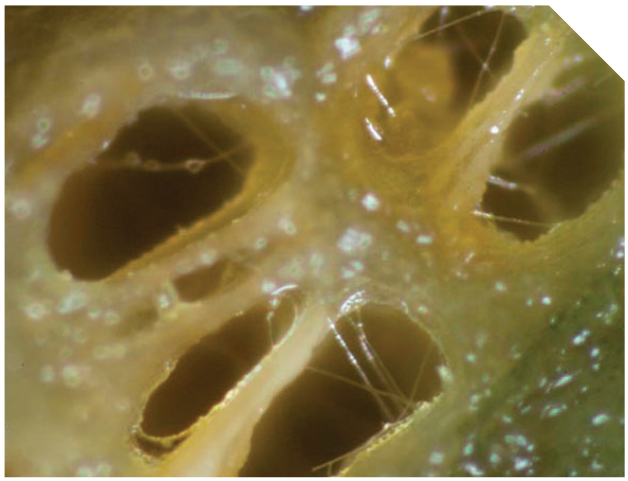

Strands of Fusarium hyphae growing inside cucumber xylem.

F. oxysporum has evolved into host specific sub-species (called formae speciales) and races which may infect some varieties of a plant species and not others. For instance the fungus that causes Fusarium wilt of cucumbers is called *F. oxysporum* f.sp. *cucumerinum* which is different to the fungal strains causing wilt diseases on spinach, watermelons, cauliflowers, tomatoes etc. There are at least three races of *F. oxysporum* f.sp. *cucumerinum* which means there are varieties of cucumbers with genetic resistance to races I and II. Unfortunately, the dominant race causing this disease in Australia is neither of these races and there are no commercial varieties of cucumbers available carrying resistance to this pathogen.

Not all Fusarium wilt pathogens are known to occur in Australia (see Table 1). Similarly, new Fusarium races appear around the world that may attack vegetable varieties that have previously been grown successfully. Therefore they can be biosecurity threats.

Table 1 Fusarium wilt causing strains (*formae speciales*) occurring on vegetables

HOST	f.sp.	AUSTRALIA
Beans	*phaseoli*	?
Brassicas	*conglutinans*	+
Capsicums	*capsici*	-
Celery	*apii*	?
Cucurbits		
Cucumbers	*cucumerinum*	+
	radicis-cucumerinum	-
Melons	*melonis*	+
Watermelons	*niveum*	+
Luffa	*luffae*	-
Bottle gourds	*laginariae*	-
Bitter melon	*momordicae*	-
Winter melon	*benincasae*	-
Eggplants	*melongenae*	-
Lettuce	*lactucae*	-
Onions (Alliums)	*cepae*	?
Peas	*pisi*	+
Radish	*raphani*	?
Snake beans	*tracheiphilum*	+
Spinach	*spinaciae*	+
Tomatoes	*lycopersici*	+
	radicis-lycopersicae	+?

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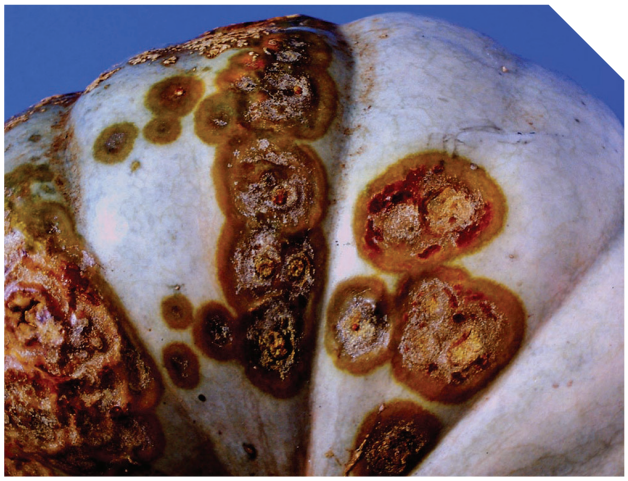

Fusarium rot of pumpkin caused by *F. solani*.

Vegetable diseases caused by other *Fusarium* species or strains

Other strains of *F. oxysporum* cause diseases of certain vegetables; for instance, *F. oxysporum* f.sp. *radicis-cucumerinum* causes a stem and root rot disease of cucumbers overseas. Similarly *F. oxysporum* f.sp. *radicis-lycopersici* causes a stem and root rot of tomatoes. There are also other *Fusarium* species that can cause fruit, stem and root diseases. Examples are: strains of *F. solani* causes fruit and stem rot of capsicums; stem and fruit rots of pumpkins and other cucurbits and beans; *F. lactis* causes internal fruit rot of capsicums overseas; and *F. avenaceum* causes dry rot of carrots; and several species are associated with crown rot of asparagus. Some Fusarium strains can be associated with seedlings damping off and they often form disease complexes with other fungal (e.g. *Rhizoctonia*) or oomycete (e.g. *Pythium* and *Phytophthora*) pathogens.

Source, spread and factors that favour Fusarium diseases

Fusarium spores can be a contaminant on seed and it can spread on seedlings in nurseries. Unfortunately, infected plants can be symptomless until they are transplanted or when the plant matures. The fungi survive for many years in soil and are difficult to eradicate once they have become established on a farm. The Fusarium spores spread with soil and media, water, (Sciarid and Shore) flies, contaminated equipment and workers' hands, footwear and clothing. One important factor favouring Fusarium wilt diseases on many crops is ammonium nitrogen. Potassium deficiency has been shown to favour brassica yellows.

Different Fusarium wilt diseases are favoured by particular temperature ranges – generally higher soil temperatures favour disease, and soil temperatures over 20°C.

Plant stresses caused by imbalances in water, nutrition or heavy fruit load also favour disease development.

Management strategies

- Use resistant varieties – containing race-resistance genes
- Grafting onto resistant rootstocks
- Avoid ammonium (NH_4^+) fertilisers – nitrate fertilisers can suppress disease

Fusarium basal plate rot of leeks (left) and healthy plant (right). The plant on the right was grown in soil following a brassica biofumigant cover crop.

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- Apply calcium supplements
- Avoid overwatering: use less more often; for soilless crops in substrates such as coir or sawdust ensure the medium does not remain saturated overnight, particularly in winter
- Preventative measures – crop and farm hygiene, and biosecurity: e.g. come clean – go clean
- Contaminated irrigation water can be treated by filtration, UV radiation, or with chemical disinfectants
- Control Sciarid flies and soil-borne insect pests – particularly at the seedling stage
- Remove, bury or compost infected plant waste
- Crop rotation (>3 years), cover crops (such as biofumigant mustards or sorghum), organic amendments (such as quality composts) can suppress diseases
- Microbial biocontrol bacteria and fungi, as well as plant defence activator chemicals (such as soluble silicates or chitosan) can suppress soil-borne diseases including Fusarium but are not specifically registered in Australia for disease control in vegetables
- There are no agrichemicals registered in Australia for use during cropping; soil fumigation can be used between crops.

Fusarium wilt of bunching spinach occurs mostly as a disease complex with root rot pathogens such as *Pythium* and *Phytophthora* species and *Rhizoctonia solani*.

Fusarium yellows of cauliflower.

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Integrated Crop Protection PROTECTING CROPS

MAY 2018

CLUBROOT MANAGEMENT IN BRASSICA VEGETABLES

Causal organism: Plasmodiophora brassicae

WHAT IS CLUBROOT?

Clubroot is one of the most potentially devastating soil borne diseases affecting brassica vegetables (e.g. cabbages, cauliflower, broccoli, kale and Brussels sprouts) in Australia. Once plants are infected there are no effective control measures. The pathogen can persist in soil for up to 20 years. It is spread by spores carried by infected seedlings, soil particles and water. This fact sheet details how to identify clubroot as well as some key management strategies to help prevent infection and spread.

Identifying Clubroot

Above Ground
Foliage of plants infected with clubroot may appear wilted; stunted or pale in colour.

Below Ground
Digging up plants infected with clubroot will reveal characteristic stubby swollen roots known as galls. Infected roots have reduced ability for uptake and transport of water and nutrients.

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CLUBROOT MANAGEMENT STRATEGIES

1. Crop and soil management

Soil Amendments

Lime

- Maintaining a soil pH of 7.0 – 7.5 with added lime can reduce the impact of clubroot.
- Reactive lime products (e.g. Quicklime) are often used to raise pH, however the optimum product and amount required will vary between soil types. Seek further advice on rates suitable for soil.
- Apply at least one week prior to transplanting to avoid phytotoxicity[1].

Calcium

- When soil pH is greater than 7 adding soluble calcium salts can reduce clubroot incidence.
- Repeated soil applications of calcium cyanimide can increase soil calcium, pH and beneficial soil microbes, which all help reduce clubroot incidence[3].
- Calcium nitrate has the benefit of also providing a nitrogen source in the form of nitrate which helps protect against clubroot, unlike acidifying ammonium fertilisers[4].
- Banding in rows is an effective and economical application method for calcium products[3].

Boron

- Boron inhibits the infection and development of clubroot and can be applied to the soil in formulation with calcium nitrate fertiliser.
- It can also be applied as boric acid or sodium tetraborate e.g. Granubor. Seek further advice on rates that are suitable for your crop.

Fungicides

- Fungicides will not control established disease however they may provide protectant control.
- The fungicide fluazinam is effective in reducing clubroot infection when applied either as a seedling drench[1] or as a soil drench at transplanting[4,5].

Brassica choice

- Brassica vegetables vary in susceptibility to clubroot (see below) and cultivar choice should be carefully considered in high-risk scenarios.
- Clubroot resistance cultivars should be used as part of an integrated management strategy however repeated planting of resistant cultivars may result in a loss of resistance.

Biocontrol products

- Formulated biocontrol agents (eg. *Bacillus subtilis* and *Gliocladium catenulatum*) applied as a soil drench at transplanting can reduce clubroot infection when disease pressure is low[6].

Soil and irrigation management

- Manage irrigation to prevent over watering.
- Take steps to improve soil structure (e.g. increasing organic matter or adding calcium) to improve drainage and minimise waterlogging.

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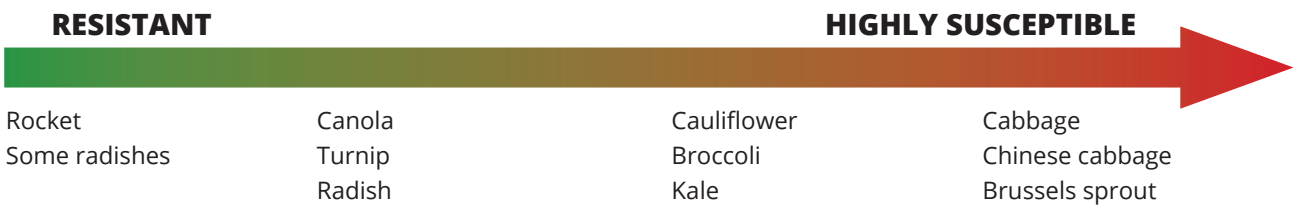
Figure 1. Clubroot susceptibility of brassica vegetables



2. Reduce the disease load in your soil

Rotations

- Rotations of more than 7 years are recommended between brassica crops to reduce resting spore levels.
- When part of an intergated mangement strategy however, a minimum of 2 years between brassica crops may be used.
- Avoid brassica cover crops (eg. Caliente (mustard) or Nemat (rocket).

Clubroot weed hosts

- Control volunteers and weeds which host clubroot such as, Shepherd's purse (*Capsella bursapastoris*) and Wildradish *(Raphanus raphanistrum)* during fallow and non-brassica crop phases.

Fumigation

- Fumigation can be helpful when pathogen load is high. Consideration should be given however to negative impacts on soil health, variable efficacy across different soil types, cost and concerns with user safety.
- Fumigants such as metham sodium and dazomet are effective fumigants for clubroot control[1].

3. Farm biosecurity

Stop soil and plant movement

- Clubroot can only move small distances on its own and spread is mostly through infected seedlings, soil and moving water.
- Follow biosecurity procedures[2] to minimise infected soil and plant movement.
- Quarantine any infected areas/paddocks and reduce surface runoff to stop spore movement.
- If only a small area is infected, dispose of infected plants.
- For small infestations quarantine area, remove plants, roots and attached soil and either burn or dispose of in an industrial landfill.

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CLUBROOT MANAGEMENT IN BRASSICA VEGETABLES

May 2018

SoilWealth NURTURING CROPS

Integrated Crop Protection PROTECTING CROPS

INTEGRATED MANAGEMENT STRATEGIES

As disease pressure increases an integrated approach, combining a number of management strategies is required[4], as shown in Figure 2.

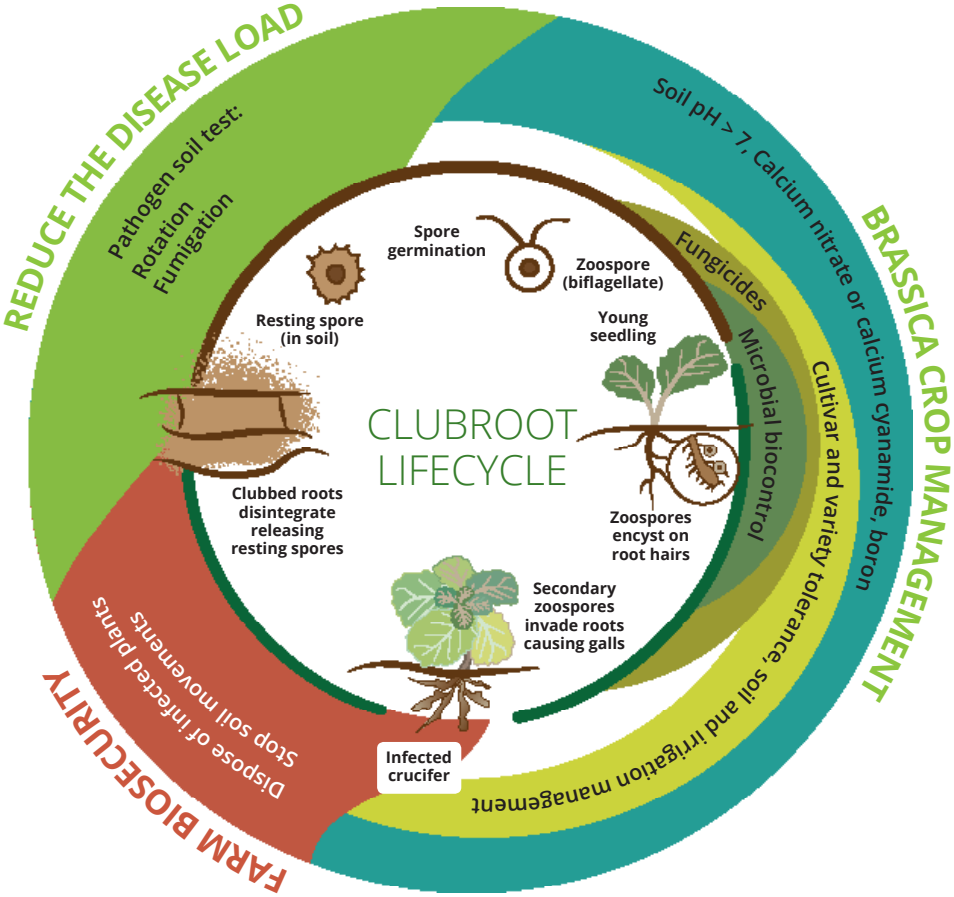

Figure 2. Integrated management options for clubroot management in Brassica vegetables.

Trials conducted in in clubroot-infected soils in Werribee, Victoria showed that integrating soil amendments (calcium nitrate +boron (CaNO3/B), ground-burnt agricultural (GBA) lime) with fungicide (fluazinam) treatment improves marketable yield of cauliflower[1] (See Figure 3).

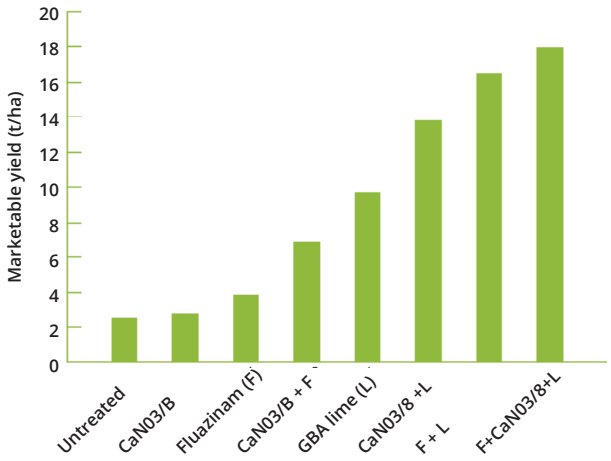

Figure 3. The effect of an integrated approach on marketable yield of cauliflower in a clubroot infected soil[2].

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EVALUATING CLUBROOT RISK

The table below highlights management practices and environmental conditions that either increase or reduce your risk of clubroot infection. This should be used as a guide to help reduce the risk of infection to your crop.

DECREASE CLUBROOT RISK	INCREASE CLUBROOT RISK
Paddock has not grown a brassica crop in the last 7 years or never grown a brassica crop.	Paddock has grown a brassica crop (e.g. cabbage, cauliflower, broccoli, Brussels sprouts) in the past 2 years.
Disease-free seedling.	Choosing a highly susceptible brassica crop e.g. cabbages or Brussels sprout.
Liming soil to maintain pH of 7.0-7.5[1.]	Warm soil temperatures (17-25°c)[5.]
Early application of calcium nitrate and boron[1.]	Poorly drained wet soils and over irrigation.
Applying fungicide seedling or soil drench e.g. fluazinam[1.]	Compacted soils.
Fumigating with metham sodium[1.]	Acidic soils <pH 6
Use of microbial biocontrol agents[6.]	Brassica cover or biofumigation crops.
Raised beds to improve drainage.	Fertilisers containing ammonium fertilisers[4.]

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JUNE 2018

SCLEROTINIA ROT OF GREEN BEANS

Source: The Ohio State University.

Sclerotinia rot, also known as white mould, is one of the major diseases of green beans in Australia. It is caused by the fungus *Sclerotinia sclerotiorum*. Sclerotinia rot can cause significant yield losses during the cropping season as well as post-harvest damage.

Sclerotinia can survive in the soil for more than five years and has a wide host range (e.g. beans, lettuce, carrots, potatoes), which makes control of the disease a challenge.

IDENTIFYING SCLEROTINIA

Sclerotinia can induce a variety of distinctive symptoms including yellowing, water-soaked lesions and collapse of bean pods, followed by the appearance of fluffy white fungal threads studded with black resting bodies of the fungus, called sclerotia (figure 1). Sclerotia are irregular in shape, up to 1–1.5cm long and resemble rat faeces[1].

Sclerotia can also form inside stems, flowers and fruit of affected plants.

Figure 1. (a) Fluffy white fungal growth and (b) black resting bodies (sclerotia) on bean pods infected with sclerotinia. **Source:** John Duff, Qld Primary Industries and Fisheries Primary Industry and Fisheries

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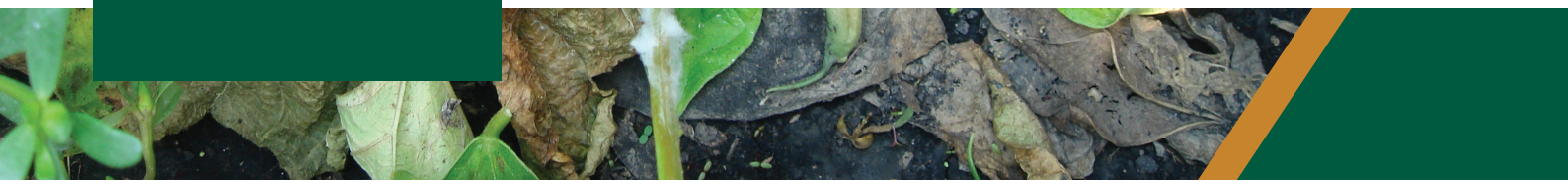

MANAGEMENT OPTIONS

There are a variety of options for Sclerotinia management in green beans including conventional disease control, such as application of fungicide, or cultural control practices – such as crop rotations, that aim to reduce favourable conditions for the disease.

Best practice guidelines for green beans, recommend that a combination of these strategies be used, i.e. integrated pest management approach[1]. When deciding which management strategies to use, consideration should be given to cost, sustainability, e.g. risk of chemical resistance developing, and any adverse effects to the user environment or other crop management systems.

Current options available for Sclerotinia control in green beans include:

Chemical control

- Only fungicides that are registered or have a current permit for use can be used to control Sclerotinia in green beans
- Currently there are limited products available. At the time of printing (April, 2018) Switch™ (cyprodinil + fludioxinil) and Filan™ (boscalid) were registered for Sclerotinia control in green beans, however APVMA (www.apvma.gov.au) should be consulted for the most up-to-date information. Product labels should always be carefully read and followed
- Application timing is critical (see figure 3). Switch™ and Filan™ at flowering have been shown to reduce Sclerotinia by more than 80%[2]
- Relying on the one chemical group can increase the risk of resistance, therefore rotating products that are from different chemical groups is encouraged. Further information on fungicide activity group tables see Crop Life Australia (www.croplife.org.au)
- In situations of extreme disease pressure, application of soil fumigants may be used although consideration should be given to user safety and the negative impacts of soil fumigants, e.g. death of beneficial soil microorganisms.

Cultural control options:

- Increasing plant spacing or selecting varieties with less dense canopies to promote good air circulation around plants and reduce humidity will reduce Sclerotinia risk[2].
- Ensure a break of around four years between susceptible crop species, particularly in paddocks where crops were previously affected by Sclerotinia rot.
- Control broadleaf weeds such as shepherd purse (*Capsella bursa-pastoris*) and variegated thistle (*Silybum marianum*) as they are hosts for *Sclerotinia* and help it survive during fallow periods or crop rotations
- Plant biofumigant cover crops, e.g. mustard species, which release compounds into the soil that inhibit Sclerotinia growth
- Ploughing in cover crops ("green manuring") can increase organic matter which acts as a food source for good soil microbes. Large populations of good soil microbes can outcompete soil pathogens such as Sclerotinia and reduce their numbers in the soil[2]
- Research is continuing into biological products such as *Coniothyrium minitans* (Contans™) or plant derived produces (e.g. ECO-V), which may
- not provide complete control alone but are beneficial when used in integration with conventional control options[2]
- Avoid overirrigating, which can increase disease pressure, while still meeting the crop's water needs (see below for further details)

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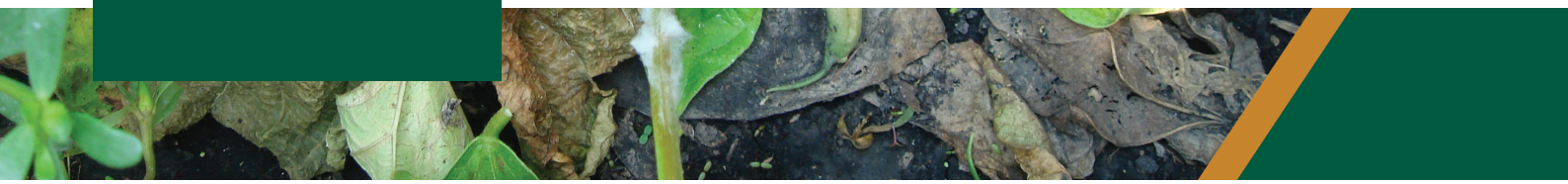
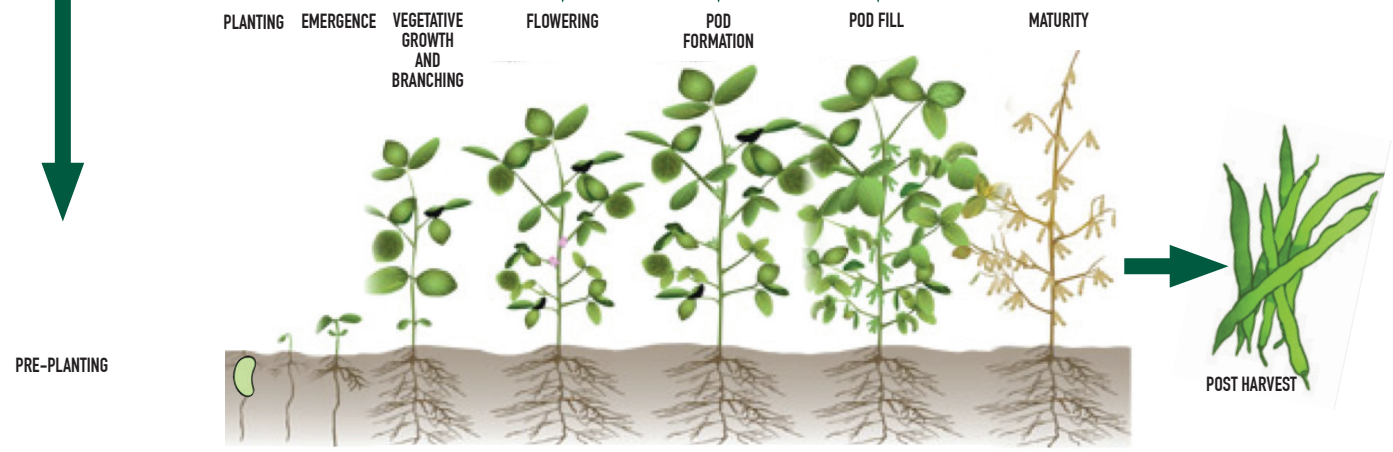
SCLEROTINIA ROT OF GREEN BEANS
June 2018



IMPORTANT IRRIGATION TIMINGS

Consider pre-plant irrigation to ensure adequate soil moisture in the profile. Monitor soil moisture at seedling emergence to ensure healthy even crop establishment. Avoid over-watering.

Water demands may be reduced in flowering and pod fill compared to the vegetative stage, but moisture stress at this time can severely limit yield. Over irrigation however, can increase risk of disease. Use soil moisture monitoring tools to help accurately schedule irrigation.



Soil fumigation pre-planting may be considered to reduce risk in extreme disease potential situations.[1]

HIGH RISK	1st Application	2nd Application	3rd Application
MEDIUM RISK		1st Application	2nd Application

Foliar fungicide applications from early flowering depending on risk of disease. Where multiple applications are required try to rotate the fungicide group used to minimise risk of resistance. Always follow label instructions for application details and withholding periods.

Soil fumigation maybe considered post harvest of a highly diseased crop.[1]

CHEMICAL CONTROL OPTIONS

Figure 2. In-crop management options for control of Sclerotinia in Green Beans

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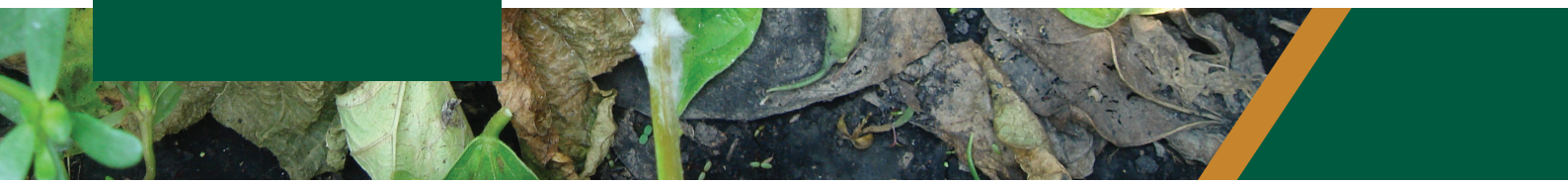

STRATEGIC IRRIGATION FOR SCLEROTINIA CONTROL IN GREEN BEANS

To maximise yield it is critical to ensure the water requirements of a green bean crop are met, particularly when environmental and crop demands (see figure 2) are high. Environmental conditions such as sunshine (length and strength), wind, humidity and temperature will all influence how much water is lost to the air from soil and plants - known as evapotranspiration (ET_o). Useful seven-day forecasts of ET_o are also provided by IrriSAT and The Yield.

ET_o however changes between crops and seasons and information that is relevant to your block– known as ET_c – can be obtained from satellite images which can also be sourced through IrriSAT.

Monitoring soil moisture can also help keep an eye on what is happening in your crop at peak water demand and to allow you to adjust irrigation following in-crop rainfall. Big technological advancements have taken place in this area such as real-time soil moisture data being sent directly to your smartphones or computers e.g. Wildeye.

By taking into consideration crop growth stage, ET_c and soil moisture more informed decision on when to irrigate and exactly how much to deliver can be made. This will ensure adequate water is available to the crop at critical development stages without heightening the risk of Sclerotinia through overirrigation.

Overirrigation may create conditions that increase incidence of Sclerotinia. Extended periods of water droplets on a plant increase the likelihood of infection and consequently the incidence of Sclerotinia is significantly increased when green beans are heavily irrigated[3].

Maintaining adequate plant available water in the top 30cm is particularly important for green beans as 80% of water requirements are extracted from this depth.

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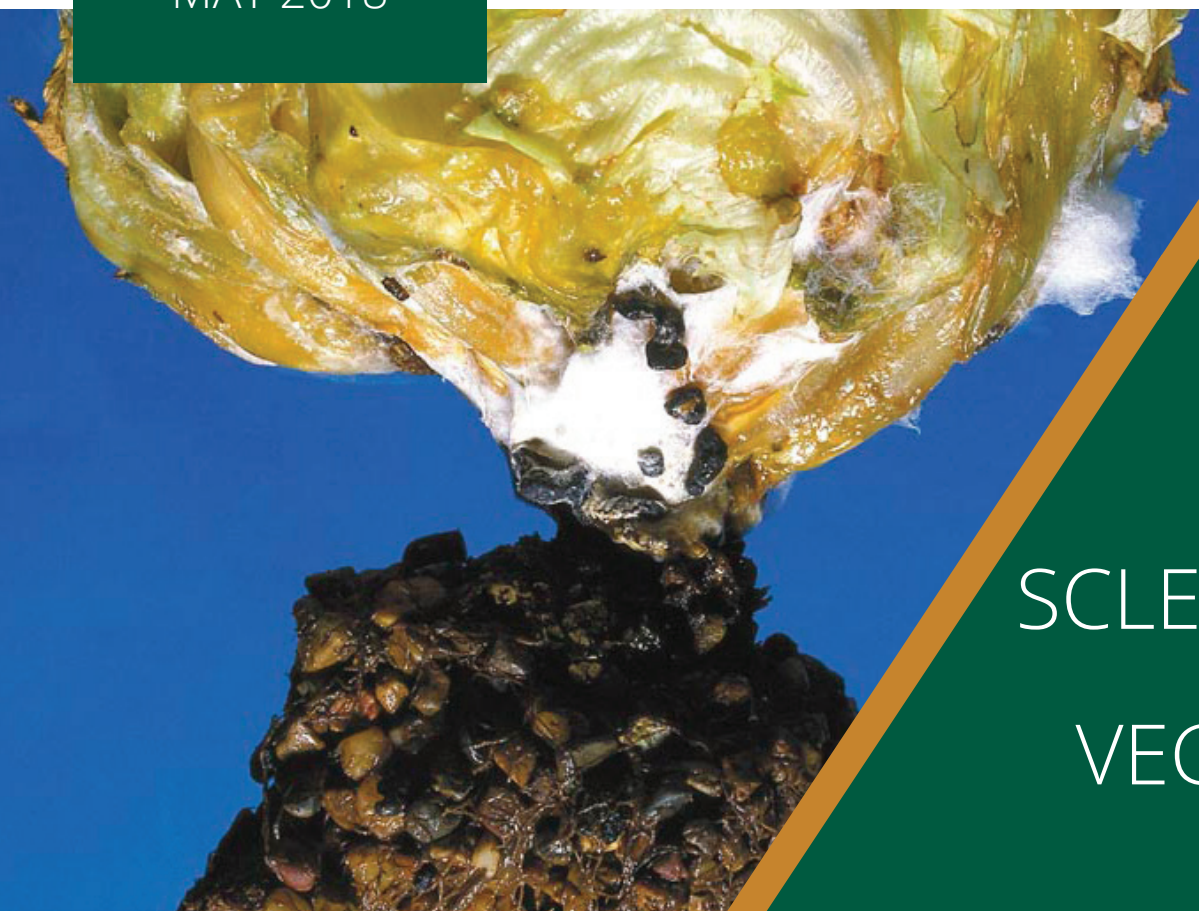
MAY 2018



SCLEROTINIA ROT OF VEGETABLE CROPS

Sclerotinia rot is also known as white mould, cottony rot, drop of lettuce and nesting of beans after harvest. It is caused by pathogenic fungi of two species: *Sclerotinia sclerotiorum* and *S. minor*. A third species, *S. trifoliorum*, was thought to only infect legumes (such as peas and beans) but more recent genetic studies suggest it might also infect other botanical hosts. Overall, these fungal species are an important plant pathogen because of their wide range of hosts – more than 400 different plant species – and they can persist in the soil for many years. Sclerotinia rot can also cause significant yield losses during cropping and as a post-harvest disease.

SYMPTOMS

The Sclerotinia fungi induce a variety of symptoms in the above-ground parts of the crop. Symptoms may include yellowing and collapse of leaves and water-soaked lesions, followed by the appearance of a fluffy white fungal threads studded with black resting bodies (sclerotia) of the fungus (figures 1 & 2).

Figures 1& 2. Sclerotia can also form inside stems, flowers and fruit of affected plants. Sclerotia of *S. sclerotiorum* and *S. trifoliorum* can resemble rat dung and be up to 1–1.5cm long. S. minor has smaller sclerotia about the size of a match-head (1-5mm).

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Figure 3. Saucer-shaped apothecia of *S. sclerotiorum* on the soil surface.

DISPERSAL AND LIFE CYCLE

Sclerotia can survive in soils for long periods (up to five years or more). They germinate and may infect the bases of plants directly or those of *S. sclerotiorum* can also produce small creamy-brown saucer-shaped bodies called apothecia on the soil surface (figure 3). Numerous microscopic spores are ejected into the air from the top surface of these mushroom-like bodies. Their release is triggered by water such as rainfall, dew, fog or irrigation. Spores can be carried in air currents and wind until they land on plant tissue where they germinate and infect under humid and moist conditions. Flower petals are more easily infected than healthy vegetative tissue. Infected flowers lead to infections of developing fruit (figure 4). Damaged or senescing parts of plants are commonly also more infected. Sclerotinia rot is more serious under milder temperatures (15–21°C) and prolonged wet weather conditions. Densely planted crops with poor air circulation favour infection due to the higher humidity surrounding leaves and flowers.

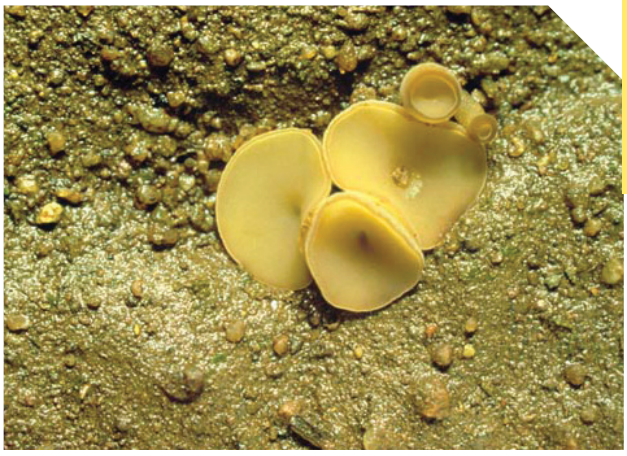

Figure 4. Sclerotinia rot on greenhouse cucumber fruit.

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SCLEROTINIA LIFE CYCLE

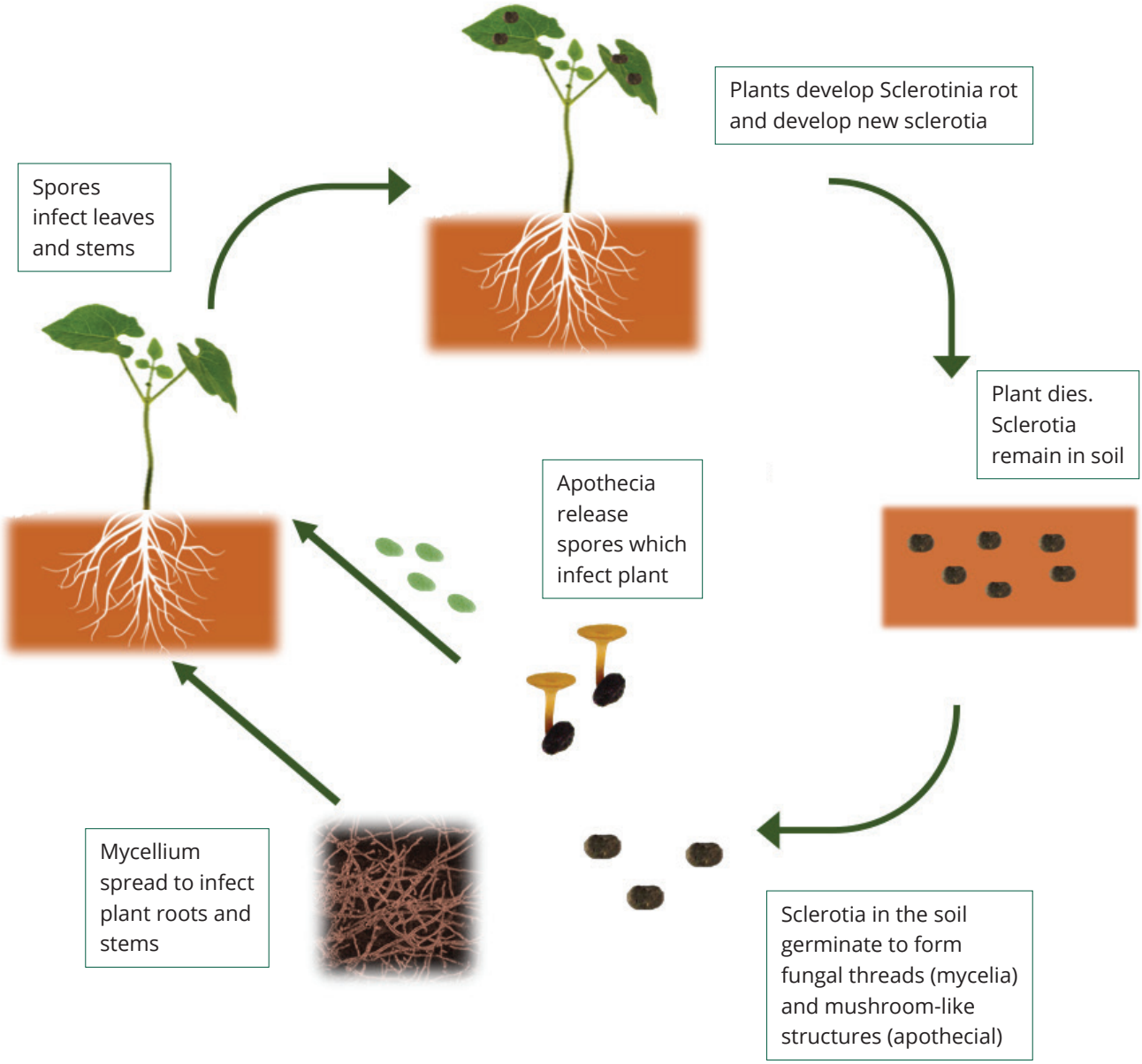

Figure 5. The life cycle of Sclerotinia. Plant dies; Sclerotia survive in soil; Sclerotia germinate to form fungal threads that can directly infect plants at ground level or develop into mushroom-like apothecia that release spores which then infect flowers, and damaged leaves or stems.

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MANAGEMENT OPTIONS

There is a variety of options for Sclerotinia management that involves both, conventional disease control practices such as fungicide application, as well as cultural controls, where the growing situation is amended to reduce favourable conditions for the disease. Current control and management options available for Sclerotinia include:

- Fungicide application with registered protectant and systemic chemicals
- Application of soil fumigants prior to sowing
- Plant crops in well-draining soil
- Increase plant spacing to promote good air circulation around plants
- Crop rotation – ensure a break of around four years between susceptible crop species, particularly in paddocks where crops were previously affected by Sclerotinia rot
- Control broadleaf weeds during crop rotation as many weed species are potential alternative hosts for Sclerotinia fungi
- Amending soil conditions to favour beneficial bacteria and fungi can suppress survival of pathogens
  - Biofumigant and brassica crops release volatile compounds into the soil which can inhibit pathogen growth
  - Application of green manure crops or composted organic matter enhance soil microflora which then compete with soil pathogens
  - There is some current research on the addition of formulated microbial biocontrols (such as products containing the fungi *Trichoderma* or *Coniothyrium* sp.) that can colonise and kill sclerotia of the Sclerotinia fungi in the soil prior to planting. Application of these products to crop residues may also be a useful way to lower sclerotial survival in soil
- Store harvested produce at suitable atmospheric conditions such as low temperature and oxygen levels
- Treat harvested produce with fungicides to prevent post-harvest rots

Pythium in carrots

Cavity spot and forking in carrots

Integrated Crop Protection
PROTECTING CROPS

Soil Wealth
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What causes cavity spot and forking in carrots?

Two *Pythium* species are mostly responsible for forking and cavity spot of carrots in Australia. In most cases, *P. sulcatum* cause the symptoms. In an earlier survey, *P. violae*, has only been identified in South Australia. Further studies are in progress to investigate the spread of *P. violae*.

P. sulcatum, the main pathogen causing cavity spot of carrots in Australia, (Davison and MacKay 2000), mostly affects the carrot family of plants. It also causes severe root rot diseases of parsley and coriander. *P. violae* is the main cause of cavity spot of carrots in most other countries and has a much wider host range that includes plants from several plant families.

Apart from *P. sulcatum* and *P. violae*, other species of *Pythium* or *Rhizoctonia* pathogenic to carrots, nematodes or any other type of early damage to the root tip can cause forking.

***Pythium* spp. survives as resting spores between susceptible crops.**

The primary source of *Pythium* inoculum, causing cavity spot and forking of carrots, are dormant resting spores formed during colonisation of plant tissue. They can survive in the soil for several years.

Figure 1: Forking of carrots. Source: Len Tesoriero

Cavity spot caused by *P. sulcatum* is most severe in summer and autumn harvested crops. In wet soils this species also produces motile spores (zoospores) which are attracted to roots where they encyst and create infection. Although zoospores only survive for a day or so they can increase the population concentration of this pathogen by over 1000-fold, which greatly increases chances of finding roots to infect. This can lead to multiple infection sites on any one carrot.

P. violae does not produce motile spores; it produces spherical swellings which spread with irrigation water. Cavity spot caused by *Pythium violae* is most severe in winter harvested crops.

Factors affecting cavity spot development and management approaches

The main factors affecting cavity spot development are soil temperature, soil pH and soil moisture. Temperatures can be controlled to a degree via site selection and scheduling planting times. Other factors can be controlled by crop management approaches.

Temperatures - The prime growth temperatures for *P sulcatum* are: minimum 2 to 3°C, optimum 20 to 28°C, and maximum 36 to 37°C. The optimum temperature for saprophytic growth of *P. sulcatum* (25°C) is higher than that for *P. violae* (19°C).

Temperatures of 30°C and above are lethal for *P. violae*1[1]. This sensitivity to high temperatures may be a reason for the low number of *P. violae* detections in Australia. The relatively high optimum temperature for *P. sulcatum* may be one reason why it is not a predominant species causing carrot cavity spot in most Northern Hemisphere countries.

Soil moisture – high soil moisture leads to greater incidence and higher severity of *Pythium* infections.

1 Suffert F., M. Guibert. 2006. The ecology of a *Pythium* community in relation to the epidemiology of carrot cavity spot. Applied Soil Ecology 35 (2007) 488–501

Document ICPSW2/057/1704

This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government. This factsheet has been produced as part of VG15010 A multifaceted approach to soilborne disease management.

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Previous work on a *Pythium* species showed that cyclic wetting and drying reduced the in field population in the absence of host plants[2]. Observations by growers confirm that high soil moisture levels support the development of cavity spot. However, the critical crop growth stages, the threshold soil moisture and the period required at that threshold to cause infection with *P. sulcatum* or *P. violae* are still unknown. Recommendations in recent published literature suggest minimising total water inputs at key production times (e.g. < 30 mm/wk for *P. violae* control under UK production conditions). UK research showed that using fungicides early in the season, with at least 15 mm of water applied simultaneously to activate fungal growth, achieved good disease control.

Varieties, genetic tolerance – some varieties are more susceptible than others. Variety selection can greatly help in minimising the occurrence of cavity spot. However, market demands and other production considerations have to be taken into account.

Chemical control – Metalaxyl-M can reduce the incidence and severity of cavity spot disease when applied at or shortly after seeding. However, if it is used too frequently it can lose its effectiveness because of an increase in its rate of breakdown in the soil[3]. Various researchers have demonstrated this effect caused by soil bacteria using the fungicide as a food source. There have been reports where the metalaxyl half-life in sandy soils has been reduced to as little as 1 day. Enhanced breakdown of metalaxyl appears to be a widespread problem; growers should not rely on it for cavity spot control. Overseas work demonstrated that some *Pythium* species have developed resistance to metalaxyl. Metalaxyl leaches from sandy soils.

Metham sodium has failed to control cavity spot[4] in trials in WA. Enhanced breakdown with repeated use has been implicated. Still, Metham sodium is used commercially for carrot production to manage the disease.

Soil pH - In WA, it has been shown that liming soil to increase pH reduces the incidence and severity of cavity spot[5]. The recommended pH range is pH 6.5-7.5 with a target pH of 7.2 or higher (measured in calcium chloride)[6]. The positive effect of lime (calcium carbonate) may be due to inducing a soil microflora that is inhibitory to filamentous fungi like *Pythium*. However, this is not confirmed. The application of lime may also be beneficial in the longer term via positive effects on soil structure and thus aeration as well as increased calcium availability to the crop.

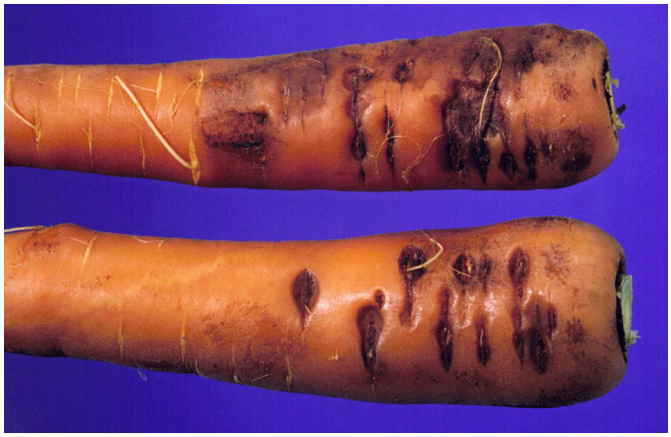

Figure 2: Severe cavity spot on carrots. Source: Len Tesoriero

Nutrition – UK research found that increasing the level of exchangeable calcium above 8 meq/100 g soil decreased the incidence of cavity spot[7]. High inputs of available calcium pre-planting (e.g. 15 t/ha of a product called Limex) also decreased cavity spot incidence. In both cases, *P. violae* was the target organism. There does not appear to be any consistent relationship between cavity spot disease severity and other plant nutrients, although Canadian research experience suggests that moderate mineral fertiliser use overall, compared to their industry standard, reduced this disease.

Calcium (Ca) is known to suppress diseases by the following mechanisms: it is involved with recognition and early defence by the plant when the pathogen contacts the cell membrane; it binds to pectate in the cell walls making them resistant to enzymes secreted by the pathogen to attack the cell wall; Ca also inhibits the pathogen from secreting plant cell degrading enzymes called polygalacturonase; and it inhibits sporangial germination in *Pythium* species.

Rotation – Views on the positive effect of rotation differ in the international literature. Rotation with broccoli has shown promising results in WA where the primary pathogen was *P. sulcatum*. Other research on this pathogen suggests that rotation with lettuce or onions

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may also be beneficial. However, *P. violae* can attack broccoli[8] and using this as a rotational crop may exacerbate cavity spot if *P. violae* is present. In this case, rotation with onions, corn, potatoes or beans may be more beneficial.

Cover crops / biofumigation – Reports on the benefits of cover crops and biofumigants vary. In some instances, good control or reduction of disease incidence were achieved, especially with mustards. In other trials and field experiments by growers, cavity spot incidence or severity were not altered or the disease was worse. It appears that biofumigation or cover crops may not reduce inoculum levels, even in cases where disease expression is reduced. The conclusion is that the effect of cover crops on *P. sulcatum* and *P. violae* is currently not understood well enough to make general or regional recommendations.

Other - Crop hygiene, selection of planting date and crop density, tillage approaches that ensure good soil structure and drainage, crop residue management to foster their breakdown, and timely harvest are some cultural practices that reduce the impact of root diseases.

Some integrated crop protection (ICP) strategies that may help reduce the likelihood of infection in combination with other management practices listed above include: application of the products formulated with the beneficial bacterium, *Bacillus subtilis* or other biopesticides[9], Calcium Cyanamide or the use of silicon (which provokes plant defences). To date, reports on the efficacy of integrated approaches vary.

Conclusions

While some general rules apply, especially the need for managing soil moisture, pH, soil calcium and crop maturity; carrot producers should find their own optimum combination of additional management strategies that fit their production systems and growing conditions.

Figure 3: Moderate cavity spot
Source: Dr Michael Rettke, PIRSA_SARDI

Disease prediction

A substantial research effort has been made to predict *Pythium* inoculum levels and disease risks in vegetable crops, including carrots. So far, most research had a focus on identifying threshold levels of inoculum rather than identifying conditions (e.g. temperature, soil moisture, soil nutrient levels, levels of other diseases or pests) that cause infections to occur in different commercial production systems.

Researchers from the South Australian Research and Development Institute (SARDI) are currently developing soil DNA tests for detecting soil populations of *P. sulcatum* and *P. violae*. Once these have been developed and tested, the next step is to understand the relationship between cultural practices, environmental factors and soil inoculum levels.

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This article has been produced as part of VG15010 - A multifaceted approach to soilborne disease management.

8 Schrandt, J.K., Davis, R.M. and Nuñez, J.J.(1994). Host range and influence of nutrition, temperature and pH on growth of *Pythium violae* from carrot. Plant Disease 78, 335-338.
9 Seaman, Abby, Editor. (2015) Production Guide for Organic Carrots for Processing. Publisher: New York State Integrated Pest Management Program, Cornell University (New York State Agricultural Experiment Station, Geneva, NY).

Damping off in spinach

Integrated Crop Protection
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What causes damping off?

Usually, one or several of the following soil borne fungal pathogens cause damping off in spinach: *Pythium* spp, *Phytophthora* spp, *Fusarium* spp and *Rhizoctonia* spp. If more than one pathogen are involved, pathologists talk about a "damping off complex".

Other fungi such as *Verticillium* spp can cause spinach to wilt and die off, but generally only in older plants such as in seed crops.

What are the signs and symptoms? What conditions favour the disease?

Symptoms include, poor growth, stunted, yellowing plants, death of seedlings (Figure 1 and Figure 2), wilting of older plants, poor germination and brown or black, rotted roots and crowns. Symptoms can depend on which pathogens are involved (Table 1).

Figure 1: Plants wilting and roots rotting 17 days after sowing (typical damping off symptoms). (Source: Donna Lucas)

Figure 2: Damping off root rot complex in spinach. (Source: Dr. Len Tesoriero)

Table 1: Pathogens causing damping off and symptoms (from Ekman, Tesoriero and Grigg, Horticulture Australia, 2014)

PATHOGEN CAUSING DAMPING OFF	SYMPTOMS
Pythium and Phytophthora	Pre-emergence damping off can cause brown, gelatinous rotting within the seed coat. If seeds do germinate, crop emergence is poor. Seedlings are stunted, yellowing and wilted and they tend to fall over or collapse and die. Water soaked lesions appear on the stem below the cotyledons and the upper part of the tap root, near the soil junction. Pythium infections of the root growing tips can result in excess branching of the root system above the infection.
Fusarium spp	General plant wilting and associated yellowing, foliage loses colour and eventually dies. Roots and vascular tissues turn black (called "browning").
Rhizoctonia solani	Dry, sunken cankers with a sharply defined margin develop near the soil junction soon after seedlings emerge. Plants wilt and collapse. More advanced seedlings may send out new shoots from below the diseased area.

Document ICPSW2/056/1703

This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government. This factsheet has been produced as part of VG15010 A multifaceted approach to soilborne disease management.

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In Figure 3 the lettuce plants on the right are infected with *Pythium* in a lab experiment; plants on the left are healthy. Note the difference in roots (colour, number, length and mass). This highlights the importance of assessing roots in the field, rather than just the leaves. Crop leaves might look healthy but be stunted due to root disease.

The conditions that favour damping off can depend on the pathogens causing the disease.

Wet conditions favour damping off caused by *Pythium*, *Phytophthora* and *Rhizoctionia* (Table 2). These fungi produce spores or sclerotia (hard resting structures) that can survive in the soil for extended periods. The fungi can also survive on plant trash.

Acidic soils low in organic matter favour damping off caused by *Fusarium* (Table 2 and Figure 5).

Figure 3: Pythium in lettuce. (Source: Dr. Len Tesoriero)

Table 2: Conditions that favour pathogens causing damping off

CONDITION	PYTHIUM SPP	PHYTOPHTHORA SPP	RHIZOCTONIA SOLANI	FUSARIUM SPP
Wet soil conditions above field capacity for extended periods or periodic wetness	Y	Y	Y	
Wet and cool soils	Y	Y		
Wet and warm soils	Y			
Moist and warm soils e.g. above 15°C			Y	Y
Poor air circulation preventing soil and plant surfaces to dry off	Y	Y	Y	Y
Reduced Tillage			Y	
Acidic soils low in organic matter				Y
Physical damage at soil level e.g. wind, transplanting or insect damage – when combined with wet soil conditions			Y	

Figure 4: Bare patches in spinach, typical of damping off. (Source: Donna Lucas)

How do the fungi spread?

The fungal pathogens associated with damping off are widely distributed in soil and/or water. Both *Pythium* and *Rhizoctonia* are spread by irrigation water, rain, contaminated soil on equipment, and movement of infected plant materials.

Susceptibility and severity

All stages of spinach can be infected but emerging plants and young seedlings are most susceptible. The two main types of damping off are pre-emergence and post-emergence. Damping off can cause stunted growth through to plant death and bare batches in paddock (Figure 4). It can affect a few plants through to large areas within a crop.

Damping off in spinach

Figure 5: Fusarium wilt in spinach. (Source: Dr. Len Tesoriero)

How to diagnose damping off

Seedling plants collapsing or falling over is a typical symptom, often in patches. Each disease has unique symptoms on the roots and root tips. The most accurate diagnosis is by sending a fresh sample to a pathologist. Knowing the causal pathogen can aid selection of effective management and control strategies.

How to manage damping off

1. Get site specific advice.
2. Susceptibility is related to soil and environmental conditions. Damping off typically occurs in wet / compacted / poorly drained soil. Therefore:
   a. Sow in well-drained soil
   b. Avoid risky paddocks (e.g. a known history of damping off, poorly drained soils, poor soil condition) especially for crops grown during the high risk periods.
3. Monitor and manage crop nutrition. Stressed or slow growing crops (especially during establishment) are more susceptible to damping off.
4. Use nitrate forms of N fertiliser for management of *Fusarium*. Ammonium based N fertilisers can foster *Fusarium*.
5. Keep soil pH above 6.5 especially to avoid the risk of *Pythium.*
6. Optimal irrigation scheduling and soil moisture monitoring. Avoid over-watering. Prevent flooding and saturated soil – particularly for *Pythium*.
7. Rotation with a diverse range of species. Consider diversity in cover crop species as well. Preferably 3-4 years between spinach crops.
8. Look after soil health by maintaining good carbon levels, minimising tillage (except for *Rhizoctonia* management) and management of soil moisture and drainage.
9. Testing or disinfection of irrigation water.
10. Use a systems approach – limit crop stress, e.g. from poor nutrition, soil compaction etc.

What to try – if economically viable

- Cover crops and biofumigants.
- Solarisation.
- Microwave treatment.
- Use of good quality organic amendments.
- Use of approaches and inputs that support good crop establishment.
- Good weed control to avoid hosts. When weedy paddocks are prepared for sowing spinach the decomposing organic matter can be a host for Rhizoctonia and Pythium. Avoid decomposing plant tissue.
- Optimise fungicide types, application methods and timing. Use different activity group chemicals for each disease to manage fungicide resistance.
- Seed dressing.
- Farm hygiene and sanitation. Minimise soil, water and equipment movement from infested fields to clean sites.
- Seed quality - It may be worthwhile re-grading seed (gravity table) and sowing the larger seed, especially when conditions are not optimal. Older or physiologically aged seed is slower to germinate and therefore more prone/susceptible to disease.
- Good nursery practices for transplants where seedlings are used rather than direct-seeded crops.
- Enable good drainage (surface drainage and good soil structure).

What to look out for in the future

- Biopesticides (some are registered in USA, some may become available in Australia)
- New fungicides including seed treatments.

For more information

Resources are available on the Soil Wealth – ICP website (http://www.soilwealth.com.au) including:

- **Pests, Diseases and Disorders of Babyleaf Vegetables – a field identification guide**
- **Managing soilborne diseases - fact sheet**
- **How to control *Pythium* in vegetable crops – webinar recording**
- **Summer cover crops - fact sheet**
- **Winter cover crops - fact sheet**
- **Biofumigation - fact sheet**
- **Preharvest effects on the quality of babyleaf spinach - fact sheet.**

Calcium Cyanamide Fertiliser

Use in vegetables

Integrated Crop Protection
PROTECTING CROPS

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What is Calcium Cyanamide Fertiliser?

Calcium Cyanamide Fertiliser, also known as nitrolime, has been used in Germany as a slow release nitrogen and calcium fertiliser with liming effect for over 100 years. It was introduced into Australia by the German manufacturer Alzchemie AG Germany (www.alzchem.com) in 1996.

Growers must not use any unrefined, industrial grades of calcium cyanamide. These non-fertiliser products are not formulated for the safe use on soils and crops; they are not wax coated to suppress dust development. The dust may be a risk to work place safety as it would contain free, carcinogenic carbide, and potentially further toxic substances. Industrial grade products may also lead to crop losses and soil contamination.

Always use fertiliser grade products, follow material safety data sheets (MSDS) and adhere to manufacturers' recommendations.

Image 1: Calcium cyanamide provides control of soil-borne diseases, newly germinated weeds, and assists with organic residue breakdown when applied as a fertiliser

What effect does Calcium Cyanamide Fertiliser have?

Effect on soil borne diseases

Calcium Cyanamide Fertiliser offers proven control of clubroot and some species of *Phytophthora*. Research has shown that other organisms causing soil-borne diseases may also be controlled. A preliminary trial in carrots in Western Australia has shown a decline in soil levels of *Pythium sulcatum*, the pathogen causing cavity spot and forking.

Calcium Cyanamide Fertiliser does not act like a soil fumigant with broad spectrum, destructive effect on all soil life. It is well suited to integrated crop protection, nutrient and soil health management approaches.

Effect on weeds

The hydrogen cyanamide phase of calcium cyanamide acts only in the top 3 to 4 cm of the soil. It therefore affects most of the weeds that have germinated to that depth and even small weeds up to the 4-leaf stage. Weed seeds located at deeper levels, or weeds propagating by rhizomes, are not adequately controlled.

Key messages

Calcium cyanamide can be used:

- **As a non acidifying, slow release nitrogen fertiliser**
- **To reduce soil borne disease pressure**
- **To control weeds that have just germinated**
- **To break down organic matter such as crop residues or compost ingredients.**

This fact sheet explains how Calcium Cyanamide Fertiliser works, how to use it in vegetables and how to handle and store it safely.

ICPSW4/053/1702

This project has been funded by Hort Innovation using the vegetable research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture. This factsheet has been produced as part of VG15010 A multifaceted approach to soilborne disease management.

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Calcium Cyanamide Fertiliser use in vegetables

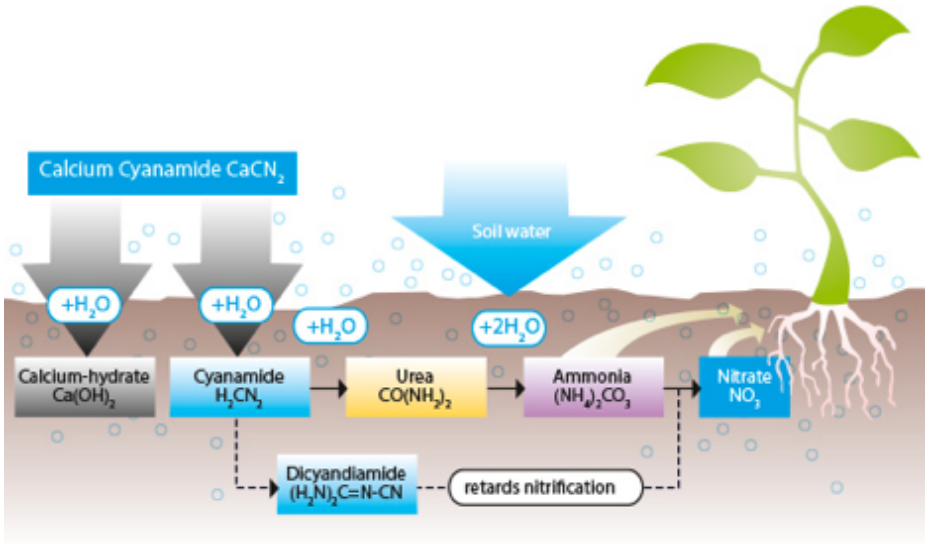

Figure 1: An illustration of calcium cyanamide's reactions within the soil. (Image from https://www.alzchem.com/en/agriculture/calcium-cyanamide-perlka/effect)

Breakdown of crop residues

Calcium Cyanamide Fertiliser can be used to accelerate the breakdown of crop residues or organic matter including materials for composting because it supplies nitrogen and has a liming effect; it's sanitising effect helps suppress weeds and diseases.

How Calcium Cyanamide Fertiliser works

A few hours after the fertiliser has been applied to the soil, the soil water reacts with calcium cyanamide to form calcium dihydroxide and hydrogen cyanamide (not cyanide). Hydrogen cyanamide is toxic to plants, and has strong fungicidal properties. It can inhibit the growth and sporulation of pathogenic fungi, and unlike cyanide, does not form poisonous gases in the presence of moisture.

Hydrogen cyanamide is completely converted to urea in 7–14 days and, to a certain extent, to dicyandiamide, which is a nitrification inhibitor. Urea in the soil is further converted to ammonium, however the dicyandiamide hinders further breakdown of ammonium to nitrate.

The calcium dihydroxide has a liming effect, and this leads to an accumulation of ammonium nitrogen in the soil before the ammonium can be absorbed by clay minerals, temporarily immobilised by soil microflora or taken up by plants.

This means calcium cyanamide is a slow release form of nitrogen for the crop, and is eventually converted to nitrate (refer to https://www.alzchem.com/en/agriculture/calcium-cyanamide-perlka/effect or http://www.aamo.com.au/ for further information).

Properties

Table 1: Chemical properties

CHEMICAL PROPERTIES	CALCIUM CYANAMIDE
Total nitrogen	19.8%
Nitrate nitrogen	1.8%
Cyanamide nitrogen	>15%
Dicyandiamide nitrogen	approx. 0.5%
Neutralising value (CAO)	>50%

Table 2: Physical properties

PHYSICAL PROPERTIES	CALCIUM CYANAMIDE
Appearance and composition	Grey-black granulate
Pouring density	1000 kg/m^3
Grain size	0.8 - 3.5 mm

Liming value

The so-called liming value specifies the effect of a nitrogen fertiliser on the lime balance of a soil. If a fertiliser provides more lime than is required to neutralise the acids that are produced when nitrogen is converted in the soil, its lime value is positive. In the opposite case its lime value is negative, which means it reduces the soil's pH. Liming values of different fertilisers is provided in Table 3.

Table 3: Liming values of various nitrogen fertilisers including calcium cyanamide

FERTILISER	LIMING VALUE (KG CaO)	
	PER 100 KG CALCIUM CYANAMIDE	PER 100 KG N
Calcium cyanamide 19.8% N	+ 30	+ 152
CAN calcium ammonium nitrate, 27% N	- 16	- 58
Urea 46% N	- 46	- 100
NPK, e.g. 13-13-21	- 13	- 100
Ammonium sulphate nitrate	- 51	- 196
DAP 18-46	- 37	- 205
Ammonium sulphate 21%	- 63	- 300

Use in vegetable crops

Calcium Cyanamide Fertiliser must always be used as part of a complete fertiliser and integrated crop protection program. It is high in nitrogen (19.8%) and high in calcium and therefore cannot be just added to existing nutrition programs.

In addition to the general use guides below, the wax coated Calcium Cyanamide Fertiliser may be band placed or blended with other compatible products. Three grades of coated Calcium Cyanamide Fertiliser are available in Australia to meet specific needs. Correct use is vital to achieving the desired results and avoiding crop damage. For further information on specialised uses please contact the supplier (http://www.aamo.com.au/) or a nutrition adviser who is familiar with the product, relevant research and specific applications suited to your crops, soils and climate.

Table 4: Brassica Crops

WHEN TO APPLY	APPLICATION RATE (KG/HA)	IMPORTANT NOTES
Clubroot infested areas		
Two weeks before sowing or transplanting; to be repeated if necessary	400 - 500	Apply accurately across soil surface by drop or disc spreader. Irrigate immediately to a depth of 10cm or soil field capacity. If possible incorporate to a depth of 5-15cm by rotary hoe or by bed forming operation (adapted from *Perlka® Fertiliser Beats Clubroot* factsheet from Lefroy Valley)
Two to three weeks after sowing or transplanting	400 - 500*	Only on well-established brassica plants or sown brassica 10 to 15cm high, foliage must be dry (no dew!)
Clubroot-free areas		
Two to three weeks after planting	400 - 500*	Side-dress when plants are dry; the soil should be moist

* with cauliflower not more than 300 kg/ha, with Chinese cabbage no top dressing.

Table 5: Leeks

WHEN TO APPLY	APPLICATION RATE (KG/HA)	IMPORTANT NOTES
Direct seeded		
Application before seeding	300 - 350	Observe waiting period of 8-14 days
Transplanted		
Before planting	300 - 350	Observe waiting period of 8-14 days; possibly work into the soil to a shallow depth
Top dressing	300 - 400	Approximately 14 days after planting ; calcium cyanamide grains should not be allowed to contact the roots at transplanting. When using row application equipment, calcium cyanamide can also be applied later

Table 6: Lettuce

WHEN TO APPLY	APPLICATION RATE (KG/HA)	IMPORTANT NOTES
Before planting	300 - 350	Observe the following waiting periods: in spring: 2 - 2.5 weeks in summer: 1 - 1.5 weeks

Table 7: Asparagus

Spread on moist soil and on dry plants. Always spread ***before*** leaflets have formed.

WHEN TO APPLY	APPLICATION RATE (KG/HA)	IMPORTANT NOTES
In the first year after planting		
Crop stage: between planting and emerging	200	Use a harrow to flatten off the steep slopes of the beds into gentle waves
Crop stage: plants that are one hand high, before they branch out	200	Spread on dry plants but the soil should be moist
In the second year after planting		
After ploughing	300 - 500	Weeds should be growing but not beyond the 4-leaf stage, because in this stage they are particulary sensitive
In the third year after planting and beyond		
After ploughing	300 - 350	Weeds should be growing but not beyond the 4-leaf stage, because in this stage they are not sensitive

Image 2: To ensure the efficacy of Calcium Cyanamide Fertiliser, make sure that you follow the guidelines specific to the crop that you are growing

Photo RMCG: SoilWealth soil amendment trial with carrots, Forthside Vegetable Research Station, Tasmania, with Spencer Gibbs, Cradle Coast NRM

Other crops

Table 8: Calcium Cyanamide application to other crops

CROP	APPLICATION RATE (KG/HA)	WHEN TO USE
Peas	200 - 300	1 - 2 weeks before sowing or in the period from when the tips break through until the plant is approx. 10cm tall
Broad Beans	200 - 300	1 - 2 weeks before sowing or after sowing until shortly before the plants emerge
Bush Beans	300 - 400	Before plants emerge
Carrots	300 - 400	2 - 3 weeks before sowing
Spinach	300 - 400	2 - 3 weeks before sowing
Radishes	300 - 500	2 - 3 weeks before sowing
Cucumbers	300 - 500	2 - 3 weeks before laying or planting
Celery	300 - 500	3 weeks before planting
Tomatoes	300 - 500	3 weeks before planting
Rhubarb	300 - 500	Before sprouting in spring

General application rules

Table 9: Application guide

ITEM	RECOMMENDATIONS
Soil moisture at application	Conversion from calcium cyanamide to urea and then ammonium will only happen when soil conditions are moist i.e. just below or at field capacity
Incorporation depth and method	Normal cultivation depth, can be applied to the top of soil but then nitrogen losses may occur and the effect on diseases and weeds lessened
Conversion and witholding time before seeding & impact of soil organic matter	Conversion usually takes: 2–3 days per 100 kg/ha 6–9 days for 300 kg/ha Calcium cyanamide 8–12 days for 400 kg/ha Calcium cyanamide 10–15 days for 500 kg/ha Calcium cyanamide Use longer withholding periods in light soils, especially if organic matter levels are low
Soil moisture after application	Soil must be kept moist to incorporation depth during the conversion time. If the crop is sown after more days than it takes to convert it (e.g. 2 weeks), keep soil moist for the duration of conversion only
Adjacent crop safety	If there are crops close by that are in a sensitive development stage (e.g. establishment to 5-leaf for carrots), then ensure the crop does not get covered by calcium cyanamide dust
Adjust the N fertiliser program	As with any nitrogen fertiliser, the application rate of calcium cyanamide may depend on the nitrogen requirements of the crop and the nitrogen supply from the soil (residual N from crops or cover crops and mineralisation from organic matter) Calcium cyanamide contains 19.8 % N An application of 300 kg/ha supplies 59.4 kg N/ha 500 kg/ha supply 99 kg N/ha
Adjust liming	Calcium cyanamide has a liming effect – refer to the liming value table above
Environmental	Even where chemical pesticides must be omitted in part or entirely, calcium cyanamide may still be used to take advantage of its phytosanitary effects in addition to its effect as fertiliser. In light soils, N may be washed through the root zone – monitoring is recommended
Health and safety	Breathing protection with a fine particle filter must be worn and other precautions applied as per the manufacturers MSDS

Mixing

Calcium cyanamide can be mixed with other products, but note the following:

- Do not mix it with fertilisers containing ammonium nitrate! This could set off chemical reactions that could make the mixture greasy and result in ammonia loss
- All mixtures should always be stored dry! Cover loose goods with a tarpaulin
- Mixtures with hygroscopic-acting fertilisers should be spread as quickly as possible to avoid lumping
- To ensure an even distribution when spreading a mixture make sure that the mixture components have roughly the same grain sizes and specific gravities.

Storage

- Calcium cyanamide must be stored dry and protected from damp in a clean area
- Do not store it together with highly flammable and combustible materials and substances
- Store it separately away from fertilisers containing nitrates, and away from substances that are acid and alkaline
- Calcium cyanamide (ground) may only be stored together with ammonium- and ammonium nitrate-containing fertilisers when it is adequately separated from them. Adequately separated means:
  - A minimum distance of 5m when stored loose outdoors
  - A minimum distance of 2.5m when stored loose in a storage room
  - A minimum distance of 1m for packaged products in a storage room
  (non-reactive substances can be stored in between)
- With loose calcium cyanamide and packaged calcium cyanamide there are no material-related storage problems since the product does not corrode wood, concrete, plastics or steel
- When storing in flat stores the usual precautions for loose storage of mineral fertilisers should be observed (cover with PE film)
- Storage in tower silos is straightforward; as long as damp is prevented from getting in, there should be no bridging and caking
- Transport and interim storage in sloped-bottom containers is also straightforward.

Biopesticides in Australia

January 2018

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WHAT ARE BIOPESTICIDES?

Biopesticides are a diverse group of pest control products based on naturally occurring biochemicals, minerals and microbes. They generally have very low toxicity to humans and are sustainable with minimal environmental impacts. Many can be used in organic production.

Biopesticides often require a good understanding of pests and diseases to be used effectively. They help to manage, rather than completely control pests. For example, protective products need thorough crop coverage with repeated applications, often starting before symptoms appear. Biopesticides are therefore best used in an integrated approach rather than as simple replacements for conventional pesticides.

PLANT EXTRACTS

A range of products and oils derived directly from natural botanical materials.

While products such as garlic and chilli have a long history of traditional use against insects, pyrethrin is perhaps the most well known botanical insecticide. Other plant extracts include derivatives from tea tree, canola and neem as well as essential oils from herbs such as rosemary, mint, thyme, geranium, lemongrass, cinnamon and rosemary.

Pyrethrins, normally derived from *Chrysanthemum cinerariifolium*, are highly effective insecticides but generally less toxic to mammals than synthetic pyrethroids. They also break down more quickly than pyrethroids when exposed to sunlight, so are relatively short-lived in the environment. Pyrethrins kill insects on contact at high doses, and are repellent at lower concentrations. Unfortunately they are not pest specific, so kill bees and beneficial insects and are toxic to aquatic organisms through runoff.

Some oils derived from plants are also insect repellent. Tea tree oil is one example. Other plant based oils have a physical effect, smothering small insects by blocking their breathing holes. There have been many studies on the use of essential oils, with several having been shown to reduce spore germination and fungal growth. However, no essential oil products are currently registered for use on vegetables.

MICROBIAL PESTICIDES

Products in which a living microorganism (bacteria, fungus, virus or protozoa), or an extract of that microorganism, is the active ingredient.

Some microbial insecticides are very selective, so specific pests may be controlled with no effect on non-target organisms. For example, the nuclear polyhedrosis virus which infects *Helicoverpa* spp. is specific to this family. Others, such as the bacteria *Bacillus thuringiensis* subsp. *kurstaki*, has wider effects, affecting all insects within the family Lepidoptera. Least specific are products such as spinosad. However, as it must be eaten to be toxic, predatory beneficial insects are only minimally affected.

Microbial fungicides include both fungi and bacteria and are generally non-specific. Their mode of action is not always clear, but they may activate plant defences, act directly against the fungal pathogen, or simply occupy – thereby blocking – an ecological niche. Some claim to simply improve nutrient uptake and plant health, thereby making the crop generally more resistant to diseases.

Formulations of the nuclear polyhedral virus affecting *Helicoverpa* spp. are specific to Heliothis larvae and highly effective.

ICP1/067/1709

This project has been funded by Hort Innovation using the vegetable research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

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NATURAL CHEMICALS / MINERALS

Includes a wide range of elements, mined materials and clays.

Natural compounds may be simply extracted. However others have been heated, chemically reacted, or mixed with surfactants in order to transform them into their active form. Some of these types of products could be considered synthetics; the definition of what constitutes a biopesticide is not always easily defined.

Minerals such as kaolin clay, copper compounds and sulphur are widely used in crop protection. Other naturally ocurring chemicals include iron phosphate, potassium bicarbonate, silicon and phosphites. These products may either control the organism directly or work by strengthening plant defences. For example:

- Phosphite can both suppress growth of certain fungi (particularly oomycetes such as *Phytophthora* spp. and *Pythium* spp.) and stimulate plant defences.
- Copper compounds and sulphur protect plants by preventing spores from germinating
- Silicon has been shown to stimulate plant defences
- Kaolin is normally applied to prevent sunburn, but can also help protect plants from some insect pests.

Koalin clay is used to prevent sunburn, but can also help protect plants from some insect pests.

While such compounds have benefits, they can be damaging to the plant and environment if used incorrectly. For example, if copper sprays are applied at low pH, the release of copper ions is increased and effects can easily become phytotoxic. Some plants are extremely sensitive to sulphur, possibly due to its acidifying effects. Moreover, accumulation of products such as copper or phosphites can degrade soils, reducing microbial activity.

The male attractant Cuelure, combined with an insecticide, is used to attract and kill male Queensland fruit flies *Bactrocera tryoni.*

BIOCHEMICALS

These are chemicals that are either produced naturally by insects or microbes, or are analogues of these manufactured in the laboratory.

Spinetoram®, a modified version of the bacterial extract spinosad, is an example of a biochemical often included within the broader definition of biopesticides. Produced in a laboratory, spinetoram is designed to resist degradation by sunlight, and has been demonstrated to be more effective against insect pests than natural spinosad.

Some biochemicals control pests indirectly. For example, pheromones or parapheromones (male lures) can be used to either “attract and kill” or disrupt mating of insect pests. The parapheromone cuelure is used to attract male Queensland fruit flies (*Bactrocera tryoni*), while trimedlure has a similar effect on medfly (*Ceratitis capitata*). Another example is the use of synthetic analogues of insect growth regulators (IGRs), which can prevent eggs from hatching and larvae from developing into adults.

BIOPESTICIDES CURRENTLY AVAILABLE IN AUSTRALIA

The following table lists biopesticide products registered for use on Australian vegetable crops. Every effort has been made to ensure this information is correct at the time of publication. However, growers should consider customer requirements (especially for export) as well as ensure that all chemicals are applied in accordance with state legislation.

Information is available through the APVMA PubCRIS site portal.apvma.gov.au and Growcom at infopest.com.au.

DISEASE MANAGEMENT

	NAME	ACTIVE CONSTITUENT	CROPS	DISEASE/ BENEFIT	LABEL NAME/ COMPANY	NOTES
PLANT	**Tea tree oil**	Plant extract from *Melaleuca alternifolia*	Cucurbits, tomatoes, capsicums	Powdery Mildew	**Timorex Gold** by Biomor	May have adverse effects on beneficial insects
MICROBIAL	***Aureo-basidium pullulans***	Bacteria – *Aureobasidium pullulans* strains DSM 14940 and DSM14941	Grapes	Grey mould (*Botrytis cinerea*)	**Botector** by Nufarm	Under consideration by APVMA for registration on vegetables
	Mycorrhiza	Fungi – Endo and ecto-arbuscular mycorrhizal fungi	Seed treatment / soil amendment*	Improved nutrient uptake and root growth Improved soil health	Various	Not effective for brassica crops
	Pseudomonas	Bacteria – *Pseudomonas fluorescens*	Various	Various soil-borne diseases Improved plant health	**Sudo-Shield** by Nutri-Tech Solutions	Thought to enhance natural plant defences
	Streptomyces lydicus	Bacteria – *Streptomyces lydicus* strain WYEC 108	Carrots, fruiting vegetables	Powdery mildew	**Actinovate** AG by Novozymes BioAg Inc.	Best applied protectively, before disease develops
			Tomato	*Phytophthora*, *Fusarium* sp.		
			Vegetable seed treatment	*Fusarium, Rhizoctonia, Pythium*		
	***Trichoderma* sp.**	Fungi – *Trichoderma harzianum, T. lignorum* and *T. koningii*	Various – Soil amendment*	Wide range of soil-borne diseases Improved nutrient uptake and root growth	Various	Products often contain a range of beneficial bacteria and fungi

	NAME	ACTIVE CONSTITUENT	CROPS	DISEASE/ BENEFIT	LABEL NAME/ COMPANY	NOTES
	Copper	Copper hydroxide, copper ammonia complex	Legumes, cucurbits, brassicas, capsicums, carrots, lettuce, spinach	Downy mildew, bacterial spots, crown rot, blights	Various	Protective - thorough coverage is essential
	Silicon	Plant available silicon	Various	Improved disease resistance	Various	Thought to enhance natural plant defences
	Sulphur	Elemental sulphur	Vegetables, including fruiting vegetables (except certain cucurbits)	Powdery mildew, rust, black spot	Various	Protective - thorough coverage is essential Acidic, and must not be applied during hot weather

INSECT MANAGEMENT

	NAME	ACTIVE INGREDIENT	CROPS	INSECT	LABEL NAME/ COMPANY	NOTES
PLANT EXTRACTS	**Eco-Oil**	Emulsified plant based oil	Tomatoes, cucumbers, capsicums	Two-spotted mites, aphids, greenhouse white fly	**Eco-Oil** by Organic Crop Protectants	Works by smothering, also contains compounds designed to attract beneficial insects
PLANT EXTRACTS	**Pyrethrum**	Plant extract from *Chrysanthemum cinerariifolium* or *C. coccineum*; Pyrethrin	Various	Various	Various	Pyrethrins are less environmentally persistent and toxic to humans than synthetic pyrethroids but can kill bees and other beneficials
MICROBIALS	**Bt**	Bacteria – *Bacillus thuringiensis* subsp. *aizawai*	Brassica vegetables	Lepidopteran caterpillars	Various	Kills when ingested; thorough coverage is essential

Biocontrol products in Australia

	NAME	ACTIVE INGREDIENT	CROPS	INSECT	LABEL NAME/ COMPANY	NOTES
MICROBIALS	**Bt**	Bacteria – *Bacillus thuringiensis* subsp. *kurstaki*	Various	Lepidopteran caterpillars	Various	Best used within an integrated pest management program, especially early in the season when pest pressure is moderate
	Bt	Bacteria – *Bacillus thuringiensis* subsp. *israelensis*	Labelled for application to salt and fresh water Permits for use within protected cropping structures	Mosquito larvae and certain other fly larvae; non-plant pests	Various	Granules applied directly to standing pools of water
	Fruit fly bait	Spinosad – Extract from the bacteria *Saccharopoly-spora spinosa*	Fruiting vegetables	Fruit flies, including: Queensland fruit fly (*Bactrocera tryoni*) & Mediterranean fruit fly (*Ceratitis capitata*)	**Naturalure** by Dow	Bait which includes protein and feeding attractants Most effective when freshly applied, most attractive to immature female flies, needs to be combined with other strategies
	Muscardine fungus	Fungus – *Beauveria bassiana*	Vegetables under protected cropping	Thrips, whitefly, aphids and mites	**Broadband OD** by BASF Australia	Fungus infects insects, causing white muscardine disease
	Nuclear polyhedrosis virus	Virus – specific to *Helicoverpa* sp.	Fruiting vegetables leafy vegetables, legumes, sweet corn	Heliothis larvae (*Helicoverpa armigera, H. punctigera*)	Various	Best applied with high water rates, most effective when combined with natural predators
BIOCHEM	**Spinetoram**	Spinetoram – Fermentation product derived from the bacteria *Saccharopoly-spora spinosa*	Various	Various, including caterpillars, some fly larvae, thrips and certain psyllids	**Radiant** and **Success Neo** by Dow	Modified version of Spinosad with improved UV stability and field effectiveness

	NAME	ACTIVE INGREDIENT	CROPS	INSECT	LABEL NAME/ COMPANY	NOTES
BIOCHEM	**Insect growth regulator**	Pyriproxyfen	Cucurbits and other fruiting vegetables, lettuce, sweet potatoes Permits for use in some brassicas, beans and herbs	Silverleaf whitefly, greenhouse whitefly and scales	**Admiral Advance** by Sumitomo	Mimics insect juvenile hormone, reducing egg hatch and preventing larvae progressing to the adult lifestage
NATURAL CHEMICALS	**Soap insecticide**	Potassium salts of fatty acids	Various	Aphids, thrips, mealybug, two spotted mite, Spider-mite, whiteflies	**Hitman** by Vicchem, **Natrasoap** by AgroBest, **BugGuard** by Mulitcrop	No withholding period when used as directed
	White oil	Petrolium oil @ 815-851g/L	Various	Aphids, green mirid, green vegetable bug grey cluster bug leafhoppers, mites, rutherglen bug and thrips	Various	Available for vegetable crops by minor use permits e.g. PER12221 V3

WEED MANAGEMENT

Biocontrol products that act as herbicides include a range of oils, acids and salts. These products control weeds by destroying the leaf cuticle or damaging cell walls. This allows the contents of the cells to leak out, killing these parts of the plant.

Examples include vinegar (acetic acid), citric acid and salt (sodium chloride), and combinations of all three. Although not registered for use in vegetable crops, commercial products are available for spot spraying weeds in paths, driveways, around sheds etc. Note that USDA data indicates that >10% acetic acid is needed to reliably control certain annual weeds, but household vinegar contains around 5% acetic acid. Also, acids and salts affect soil health.

Unfortunately these herbicides can only kill the above ground parts of the plant, so don't provide long-term control of weeds with extensive root systems or underground storage structures such as rhizomes, tubers, or bulbs. However, they can still be effective against small, annual weeds.

Other tips to improve efficacy are to apply during ideal growing conditions, thoroughly cover the foliage, and consider adjuvants to buffer the pH of water (prior to mixing acids), and wetters (non-ionic surfactants) for penetrating waxy, hairy leaf surfaces.

Result of spraying grass weed with 7% acetic acid solution 24 hours prior. Only the flat leaves directly contacted by the spray have been killed. Photo by R. Pavlis.

DEVELOPMENTS IN BIOPESTICIDES

Biopesticides are really nothing new. After all, the anti-fungal properties of sulphur and copper have been known for thousands of years. Other biopesticides are more recent discoveries. All are now benefitting from research and development to understand how they work and optimise their effects.

The development of biopesticides is increasing worldwide. Most major crop protection companies are developing and marketing products that contain non-synthetic ingredients derived from plants, microbes or minerals. Drivers include the difficulty of registering new chemistry, customer pressure to minimise residues, resistance to existing products and the need to improve safety for both agricultural workers and the environment.

In contrast with conventional pesticides, many biopesticide products include more than one active ingredient. For example, microbial products often include several strains of bacteria and/or fungi, designed to work together to improve overall plant health.

Seed treatments and soil amendments are a major growth area for biopesticide development. Small amounts of beneficial fungi or bacteria can readily be incorporated with seeds or seedlings to reduce seed rots, damping off, and other soil-borne diseases. They may also reduce development of seed-borne pathogens. Other products can stimulate the defences of emerging seedlings, helping the young plants resist pests and diseases, and encouraging early establishment and growth.

Even though biopesticides are based on naturally ocurring products, they still need to be registered. This is because they are sold to control a pest and are released into the environment. Like conventional pesticides, biological products are often initially targeted at broadacre crops. Registration for use on horticultural crops may occur later, once the product is established in the marketplace.

Many biopesticides are environmentally benign, as well as potentially safer for the spray operator than conventional pesticides.

This is one reason the range of products available is still relatively limited; various strains of *Bacillus thuringiensis* account for over 90% of commercially available microbial biopesticides.

Preparations of *Bacillus thuringiensis* (Bt), used to control Lepidopteran caterpillars such as this cluster caterpillar (*Spodoptera litura*), are by far the most widely used microbial biopesticide.

CHALLENGES

- **Microbe survival** – The limited shelf life of microbial products that involve living fungi or bacteria is a clear challenge. Shelf-life is highly dependent on the product, its formulation and the storage environment. Storage life may be as little as a month, while other products may remain active for up to two years.
- **Environment** – Whereas conventional pesticides are relatively unaffected by weather conditions, temperature and humidity can greatly influence biopesticide effectiveness, especially if the product is a microbial preparation. Presence or absence of predatory species and competitors also influences how well some products work under field conditions.
- **Timing** – Many biofungicides (e.g. copper, sulphur) are protective against infection. Once infection has ocurred they have little impact on the spread of disease.
- **Management** – Most biopesticides can help manage a pest or disease, but do not necessarily control it. Biopesticides often need to be combined with other strategies to maximise effectiveness; they cannot simply replace a conventional pesticide. This means application requires greater forward planning, increasing the complexity of the crop management system.

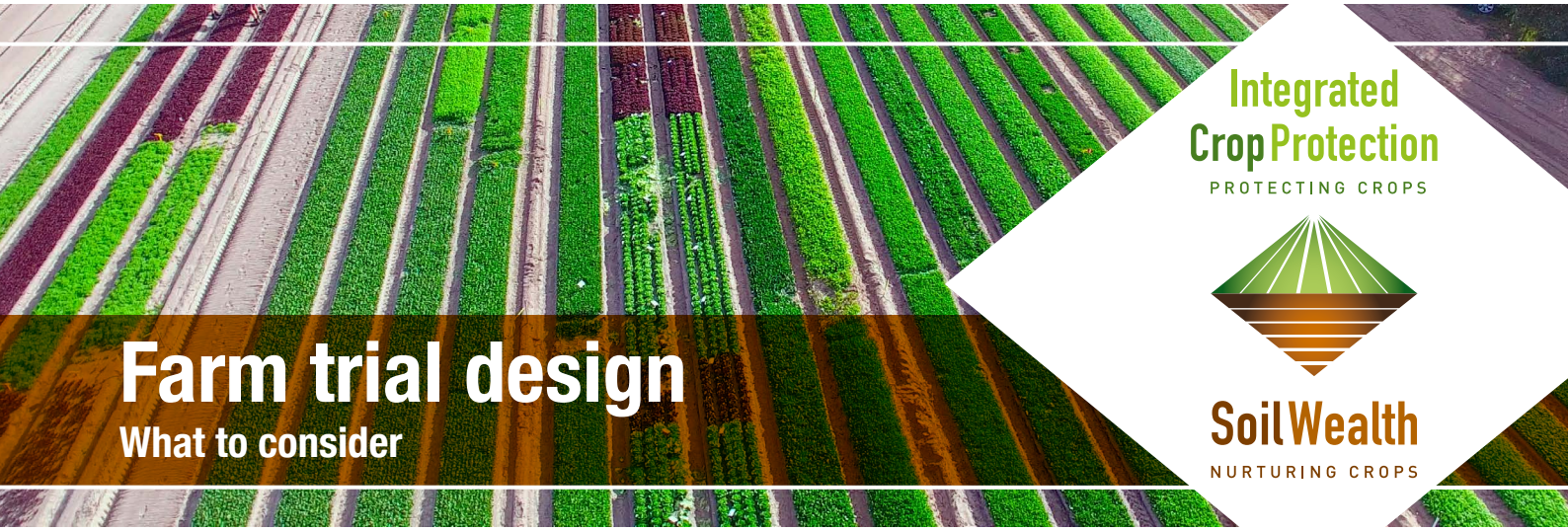
ADVANTAGES

- **Reduced risk** – many biopesticides have relatively short persistence in the environment and/or are envionmentally benign. Use of products with low toxicity to humans reduces potential risk to farm staff applying sprays, as well as minimising or avoiding residues potentially affecting consumers.
- **IPM compatible** – Biopesticides can be useful components of an IPM strategy, especially if pest pressure is low. Many have very low or nil toxicity to beneficial insects and microbes, and may even increase the activity of these natural control agents.
- **Resistance management** – The complex modes of action of many biopesticides can make it difficult for pests to develop resistance. This can mean biopesticides can provide a sustainable, long term approach for pest management. Biopesticides can also provide a useful rotation with conventional pesticides as needed, reducing opportunity for resistance to develop.
- **Organic** – Some, although not all, biopesticides are permitted under organic certification.

DISADVANTAGES

- **Speed** – It can take several days for the effect of some biopesticides to become apparent, compared to the rapid knockdown that may be achieved with conventional products. This can potentially allow crop damage to continue.
- **Variable effects** – The effectiveness of biopesticides can be hard to predict, especially for microbial preparations and for products that work by stimulating plant defences.
- **Doesn't kill all pests** – In the case of insecticides, even if the biopesticide reduces the population below the economic threshold, customer specifications for "no live insects" can make this result unacceptable.
- **Photodegradation** – Many plant-based products are rapidly degraded by UV light, limiting their effectiveness in the environment.
- **Cost** – Biocontrol products can be more expensive than synthetic pesticides. They may also require special storage conditions, and need to be applied more often.

Fourth instar whitefly larvae (*Bemisia tabaci*), showing normal scales (left) and scales infected by an entomopathogenic fungus (right) Photographs by L.S. Osborne, University of Florida.



Farm trial design

What to consider

Integrated Crop Protection
PROTECTING CROPS

SoilWealth
NURTURING CROPS

What is the question? What is your goal?

Be clear about what actually is your question. Ask how it fits into your long-term goals and plans and what the gains or learnings could mean in that context.

Research your question, ask others you trust for input. Then narrow down your question to just one or two variables, or treatments. For example, does this cover crop provide improved saleable yield gains, is this variety better than the one I have been using, does the new equipment save time and fuel costs? You may want to find out about multiple benefits but have a clear, priority research question that you write down.

Planning

It is worth spending extra time planning to ensure a better final outcome. Badly planned trials usually fail and are a waste of time and money. Put somebody in charge of the trial and allow for sufficient time to run it well.

Start planning preferably half a year before you need to start the trial. Things to be considered include – extra time needed to set up and look after the trial, which blocks/strips or bays are suitable, what data you will collect and who will do it, what inputs or equipment you need to have on site in time.

Strive to only have one or two variables that you are testing. This is especially important if you plan to only have one or 2 replicates for each treatment. Results from split paddock trials can be misleading, if conditions are not the same.

You will need extra time for data collection. You will need to check the trial throughout the growing season and record your observations and measurements. You will also need to record weather events such as hail, frost, excessive heat and humidity. Time will be particularly important at harvest as you should harvest and asses all the trial plots on the same day. Data collection could require harvesting, sorting (by size and quality) and weighing the product from smaller sub-plots for each individual treatment area at the trial sites or harvest large plots or entire treatments and running the product from each over the grading line separately to get yield and quality data. Load cells on harvesters can be used to obtain total yield data but it will be important to still determine saleable yield for each quality grade.

Example plot design

	BLOCK 1		BLOCK 2			BLOCK 3		Dimensions	
	Bed 1	Bed 2	Bed 3		Bed 4	Bed 5	Bed 6		
	Buffer		Buffer			Buffer		7.5 m	
	Treatment 1		Control			Treatment 3		20 m	
	Buffer		Buffer			Buffer		5 m	
	Treatment 2		Treatment 3			Control		20 m	
Buffer	Buffer	Buffer	Buffer	Sprinkler row	Buffer	Buffer	Buffer	5 m	110 m
	Treatment 3		Treatment 1			Treatment 2		20 m	
	Buffer		Buffer			Buffer		5 m	
	Control		Treatment 2			Treatment 1		20 m	
	Buffer					Buffer		7.5 m	

July 2018 v1

This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government. This factsheet has been produced as part of VG15010 A multifaceted approach to soilborne disease management.

Hort Innovation

ahr applied horticultural research

RMCG

Knowing market prices and production cost will then allow you to estimate profitability of a new technique or product you trialled.

It may be worth considering:

- conducting a trial in collaboration with others in your area
- involving research or extension specialists or advisers during planning and data analysis
- discussing the trial with your peers, they may want to run the same trial for comparison
- asking company reps about possible trial inputs, markers, sample packs or contributions such as soil or plant analyses.

Factor in the difference in cost estimates between the control and the treatment.

If you want to be able to confirm differences between treatments mathematically, you need to involve somebody who understands statistical analyses in trial planning.

Choosing sites

Rules for designing a good field trial are:

- include an untreated control plot, which is managed 'as usual'
- use accurate measurements or visual/photographic assessment that are repeatable, document them
- use several trial plots with the same treatment, especially if soil conditions are not identical across the trial
- do not include paddock edges, headlands or any obviously different areas
- allow for buffers between plots to ensure treatments do not overlap e.g. when using sprays or fertilisers.

The untreated control site gives you a baseline to compare your treatment to. It allows you to determine if the treatment has had a measurable effect. As far as possible, the only difference between the control sites and the treated site should be the trial treatment you are testing. Timing and application of any other treatments, including irrigation, should be the same as practicable. Variety, soil, cropping history, topology, etc., should also be as uniform as possible. By minimising the differences, you are ensuring that any difference in result is solely due to the treatment.

Create a diagram of the trial - show trial plot layouts, including allowing for edge effects.

Data / what should you measure?

Measurements should relate to marketable yield and quality i.e. number of heads, bunches, cartons or tonnes per hectare sored by quality (grade 1, 2, processing, waste). Record/photgraph what defects were found that downgraded the product. If your treatment is directed towards pest and disease incidence, it may be worth monitoring for differences in target pests or diseases. Use visual asssments of incidence and severity in each treatment. Take samples and send to a dignostic lab (patholgy or entomolgy) if you need to confirm the type of disease or pest present. If the trial is aimed at crop nutrition, consider taking soil and plant samples for analysis to confirm differences.

Visual assessment may not be particularly reliable unless they are well described and repeatable e.g. incidence = number or % of plants per small plot or transect affected and severity = % leaf area diseases or damed on affected plants.

Each treatment needs to be assesesd at the same time using the same method. Photos taken of permanent observation plots may be useful.

While there may appear to be a difference between the results from your control and your treated plots, it may not actually be due to anything other than trial set up; i.e. the differences are due to differences in soil, nutrients or irrigation, not treatment. You will only see yield differences if they are above 20%. If you want to be sure about differences, you need to repeat each treatment and control at least four times using a randomised design. Then, given data is collected for each treated area (plot) seperately, you could do, or ask somebody for, a statistical analysis. If that is what you are aiming at, involve the specialist in the trial planning phase.

Sharing your results

Consider sharing your results with other growers.

Resources

Search for 'on farm trial design' for further information.

Example Farm Trial Protocol / Checklist

1 Version number and date

Keep the protocol up to date, both while it is being revised during planning and when details change during implementation.

2 Author(s)

3 Crop(s)

4 Farm Location

5 Trial Reference or Number

Introduce a unique reference or number for each trial. Needed to keep track of each one and not confuse it with others with similar names.

6 Trial Name/Title

Choose a short, memorable title that people quickly learn relates to your trial.

7 Investigators

7.1 Responsible Investigator

Remember the PI is the person responsible for the design and implementation, recording and analysis of the work.

7.2 Team members

As applicable

8 Background and Justification

In each of the following sections you must make it clear:

8.1 The problem to be addressed

8.2 How your trial will help solve the problem

8.3 What is the next step (when this trial is concluded) expected to be

8.4 Cost estimate

Actual $ needed for consumables or capital items plus time (hours) you think you will spend. Attach details if required

8.5 Summary of what is already known

What is known about the problem and possible solutions e.g. from literature? Past trials by you and others in this area.

8.6 Links to other trials

Describe how this trial links to other activities, such as other trials or training activities.

8.7 Trial hypotheses

Trial Hypotheses: statements which you believe to be true and when this is to be confirmed by the trial allow the work to progress.

8.8 Potential Impact

If the work goes as planned and hypotheses are confirmed (or not), what will the effect be? Who will benefit? How will they benefit and by how much? How sustainable will the impact be?

9 Trial Objectives

The trial design and the protocol depends on the objectives. List them clearly, completely to leave no doubts about any aspect of the trial later. You may want to include a description of who the resulting information is aimed at.

The objectives must be consistent with each other and capable of being met with a single trial.

Your team or others may need to get involved in deciding the objectives, If that has not yet been done it is probably too early to write a detailed protocol.

10 Methods

Give enough detail here for the protocol to be useful for:

- Anyone to see what you plan to do, so that suggestions for improvement can be made.
- As the permanent record of what should be done, to be referred to during implementation, recording and analysis. It should be good enough for this even if the Responsible Investigator leaves.

10.1 Trial type

E.g. pruning nutrition, irrigation etc.

10.2 Duration

Be realistic! The start date must be far enough in advance to make proper preparations. The trial must be long enough to get results) but short enough to keep everyone interested. The appropriate length will depend on the objectives.

10.3 Trial location on farm

Block

10.4 Treatments

Describe both the treatments to be compared and the method of arriving at these. If "current practice" is included as a control treatment make it clear exactly how this is defined.

10.5 Layout, Trial plan

Describe where the treatments will be applied and how these are chosen. Describe trial area location and how it is marked within a farm. Include block/plot layout and sizes, as well as method of allocating treatments to plots.

10.6 Inputs

Describe what inputs (e.g. seeds, chemical, fertiliser) are needed and how, by whom these will be supplied

10.7 Trial Management

Who is responsible for deciding on management activities (e.g. planting, weeding, spraying, harvesting)? Who is responsible for carrying them out? List each management decision and who is making it. Distinguish decisions about the management (e.g. how many times to weed) from carrying out the work (e.g. doing the weeding)

10.8 Non-experimental Variables / Risks

Describe key variables or risks that could have an influence but are out of your hands

10.9 Data collection

Describe sampling schemes, sample sizes and measurement unist (plants, kg, plot.) and times e.g. by growth stage

Data may be collected on 'response variables' such as

- agronomic performance parameters
- economic performance parameters
- Visual assessments
- Off-site impact
- Observations (recorded)…

Describe the monitoring process (eg how will you collect data planned data collection)

10.10 Data Management

Describe who will be collecting and managing the data. Explain how this will be organised and if any training is necessary. Describe how and where data will be looked after / recorded electronically. Who will have access to it? How and where will it be archived?

10.11 Communication

Who is looking after team communication and communication of results? In which format will they be communicated?

10.12 Data analysis, reporting and feedback

Describe methods to be used for analysing, interpreting and reporting the data. Who will do it and when.

11 Outputs

List tangible outputs e.g. a report, a presentation

12 References

As required

Use a partial budget

to assess practice change on vegetable farms

Integrated Crop Protection
PROTECTING CROPS

Soil Wealth
NURTURING CROPS

Will a potential change to soil management increase profit?

How do we assess whether a change we've already made was profitable?

One way to answer these questions is to use a 'partial budget'. A partial budget assesses:

- **Additional revenue and reduced revenue**
- **Additional costs and reduced costs**

to work out the net change in profit.

A partial budget only includes items that change.

Figure 1: Post-harvest sorting of produce

Some things to consider in assessment of changing soil management

- Post-harvest costs can change as a result of practice change. For example, if produce quality is improved, labour costs can potentially be reduced e.g. to remove outer leaves; or packing and grading costs may potentially be reduced. Consider if post-harvest losses have/will change and how this may affect costs (e.g. storage costs) or income (sales) in your business.
- Machinery costs may either increase or decrease depending on our situation. If you need to purchase additional equipment e.g. a roller or mulcher, then work out the additional cost (see example later). Some producers have found that using cover crops, compost or other 'Soil Wealth' practices result in improved soil structure and therefore smaller tractors can be used for tillage or the number of tillage passes can be reduced. This represents a potential cost saving i.e. lower purchase price for smaller tractors, in addition to the savings from fewer tillage passes, fuel usage etc.
- Unpaid labour (your time) may also change. If the reduced (or increased) work load impacts your life, value this increase or decrease to your work schedule on an hourly rate basis.
- Multi-year gross margin assessment may be the most appropriate way to estimate the net change in profit. In this case, estimate the changes in costs and revenue over a whole rotation.

Market considerations

Consider any benefits such as keeping customers happy through delivering consistently good quality produce or being able to supply earlier or later in the season.

ICPSW5/062/1706

This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government.

How does it fit with your farm and business objectives?

You also need to think about non-economic factors. Consider how changes fit for you, your farm and farming system. Will you enjoy it? Does it make life easier?

What are the risks? How can they be managed?

Are there any risks associated with making this change? For example, if we are thinking about using cover crops, what if there are delays in terminating the cover crop? Do we need to mow or mulch the cover crop so that there is not too much bulk at termination? How long will we need to allow between cover crop termination and sowing/ planting the cash crop? Do we know the pest and disease risks for our situation? It can be helpful to talk to other growers in a similar situation.

Consider longer term benefits

Longer term benefits can be difficult to estimate. They still need to be considered though. For example, if soil structure will be improved, this could provide risk management benefits as well as cost savings. If a soil is well structured, it is less likely to erode during high rainfall or flood events; and it will not remain waterlogged for long. Costs saved might be costs of re-forming beds and you may avoid complete loss of a crop. Consider how often these events occur in your region e.g. is it a one-year-in-ten event? Experience from growers has shown that changing soil management or using cover crops can reduce fertiliser and irrigation costs. Often pest and disease management needs to change.

Consider saleable yields over the longer term

Will they be maintained or increased over the longer term? How does this compare to your current yield trends and expectations?

Sensitivity analysis

It is often worthwhile repeating the calculation using different assumptions and scenarios.

Limitations of partial budgets

- Partial budgets are suitable for small or incremental changes. They are not suitable for large or complex changes that require more detailed analysis such as a full gross margin assessment.
- A partial budget is useful for estimating the profit, but it does not guarantee the results. The correct management still needs to occur in the paddock.
- Partial budgets do not tell us the cash flow implications of making a change.
- Results are not additive. For example, if you evaluate two or more potential practice changes (e.g. cover crops, compost and minimum tillage), and implement more than one of these changes, the result will often be less than the sum of the individual results.

Using cover crops – an example partial budget

This example considers using a cover crop instead of a fallow. In the cash crop (that follows the cover crop), saleable yield is improved and post-harvest labour costs are reduced due to improved crop quality. Additional equipment (a mulcher) is purchased. The figures are calculated per hectare.

Note that the profit will vary with each situation and will depend on a range of factors including, but not limited to: soil type and soil condition, climate, crop type/ variety, current yield, potential yield, current practices, fluctuations in market prices and crop health factors (e.g. disease pressure).

An excel calculator is available on the Soil Wealth – Integrated Crop Protection website: http://www.soilwealth.com.au/resources/fact-sheets/crop-management/use-a-partial-budget-to-assess-practice-change-on-vegetable-farms/.
This includes a printable blank worksheet for calculating by hand.

$/ha

ADDITIONAL REVENUE	Area or number	Yield or units	$/unit	
Additional revenue (after packaging costs) per ha				$1,500
				$
				$
				$
A. Sub-total				$1,500
Less REDUCED REVENUE	**Area or number**	**Yield or units**	**$/unit**	
e.g. if a cover crop replaces a cash crop				$
				$
				$
				$
B. Sub-total				$0
Net change in revenue				$1,500
Less ADDITIONAL COSTS	**Area or number**	**Yield or units**	**$/unit**	
e.g. cover crop seed, sowing				$150
e.g. termination costs				$50
Depreciation on additional equipment (see note below)				$19
				$
				$
C. Sub-total				$219
Add REDUCED COSTS	**Area or number**	**Yield or units**	**$/unit**	
e.g. post-harvest labour saved (5 hours / ha @ $28/hr)		5.00	28.00	$140
				$
				$
				$
				$
D. Sub-total				$140
Net change in costs				$79
Net change in profit (A-B-C+D)				**$1,421**

*Depreciation in this example was calculated as follows:

Additional machinery $10,000 market value
x 15% depreciation rate
= $1,500 depreciation for the year
divided by 80ha
= $19/ha

Figure 2: Roller-crimping a ryecorn cover crop and direct seeding in one pass. Photo courtesy of Rodale Institute.

2019

SOIL BORNE DISEASE IN VEGETABLE CROPS

A practical guide to identification and control

ahr applied horticultural research

Hort Innovation

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BRASSICA FAMILY

Includes cabbages, cauliflower, broccoli, kale, mustards and Brussels sprouts

Black leg	Clubroot	Damping-off/ Wirestem	Fusarium wilt (yellows)
Page #	Page #	Page #	Page #
			

Root knot nematode	Sclerotinia rot	Verticillium wilt	White blister rust
Page #	Page #	Page #	Page #
			

BLACK LEG

Leptosphaeria maculans

WHAT SHOULD I LOOK FOR?

Black leg lesion on leaf showing characteristic black dots (pycnidia) and hole in the middle.

L. Tesoriero, NSW DPI_Crop Doc

Long stem lesion often seen near the soil line that may choke the stem. A brown to black rot develops and root sytsem may be destroyed leading to plant death.

L.Tesoriero NSW DPI_Crop Doc

WHERE WILL I SEE SYMPTOMS?

STEM

LEAVES

FAVOURABLE CONDITIONS

WET

WARM

WINDY

• 15-20ºc

DISTRIBUTION IN THE FIELD

SCATTERED

Individual/small patches of infected plants

HOW DOES IT SPREAD?

FREE WATER

WIND

MOVEMENT OF CONTAMINATED SOIL

MOVEMENT OF CONTAMINATED SOIL

SURVIVES IN SOIL AS : Mycellium/pseudothecia

HOW DO I CONTROL IT?

FALLOW

HOST-FREE ZONE

Control volunteer host plants and weeds

FARM HYGIENE

Stop movement of contaminated soil, water, plant and equipment

PLANTING PREPARATION

CROP ROTATION

Select non-host rotation or cover crops

CHEMICAL TREATMENT

Use registered soil drench fungicides at planting

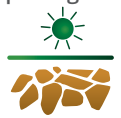
- Consult APVMA or InfoPest website for current registered products.

DRAINAGE

Plant on raised beds or well-draining soil

SOIL SOLARISATION

Cover soil with a tarp to temperature and kill harmful pathogens



POST-PLANT

AVOID OVER IRRIGATION

Saturated soils favour disease development and spread.

HOST RANGE

Other brassicas including cabbage, Chinese cabbage, kale, broccoli, cauliflower, mustards, radish, turnip, shepherds purse etc.

CLUBROOT

Plasmodiophora brassicae

WHAT SHOULD I LOOK FOR?

Digging up wilted plants reveals knot-like swelling (galls) on the root sytsem *S. Grigg*

Scattered areas of wilted plants may be seen across the field. *S. Grigg*

WHERE WILL I SEE SYMPTOMS?

WHOLE PLANT

ROOTS

FAVOURABLE CONDITIONS

WARM

WET

pH<7 ACIDIC SOIL

- 20-26°c

DISTRIBUTION IN THE FIELD

SCATTERED

Individual/small patches of infected plants

HOW DOES IT SPREAD?

WIND

FREE WATER

MOVEMENT OF CONTAMINATED SOIL

SURVIVES IN SOIL AS : Resting spores (zoospores)

HOW DO I CONTROL IT?

FALLOW

FARM HYGIENE

Stop movement of contaminated soil, water, plant and equipment

HOST-FREE ZONE

Control volunteer host plants and weeds

PLANTING PREPARATION

CROP ROTATION

Select non-host rotation or cover crops

DRAINAGE

Plant on raised beds or well-draining soil

CROP SELECTION

Choose a less susceptible/resistant cultivar

SOIL PH

Use amendments to adjust soil pH

CHEMICAL FUMIGATION

Always use chemical fumigants with care and as per label.

- Consult APVMA or InfoPest website for current registered products.

IMPROVE SOIL HEALTH

Add organic matter or amendments to boost beneficial microbes

POST-PLANT

AVOID OVER IRRIGATION

Saturated soils favour disease development and spread.

MAY BE CONFUSED WITH

Root-knot nematode

HOST RANGE

Other brassicas including cabbage, Chinese cabbage, kale, broccoli, cauliflower, mustards, radish, turnip, shepherds purse etc.

DAMPING-OFF / WIRESTEM

Pythium spp / Rhizoctonia solani

WHAT SHOULD I LOOK FOR?

Brassica seedlings showing symptoms of wilting and death caused by damping-off *B. Winter*

Stem dicolouration and rot can be seen at that base of stem, in this case caused by Rhizoctonia spp. Stem eventually collapses leading to wilt and plant death

L. Tesoriero, NSW DPI _Crop Doc

WHERE WILL I SEE SYMPTOMS?

STEM BASE

ROOTS

FAVOURABLE CONDITIONS

COOL

WATERLOGGED SOIL

- 13-15°c

DISTRIBUTION IN THE FIELD

LARGE AREAS

Large areas of infected plants clearly visible

HOW DOES IT SPREAD?

WIND

FREE WATER

MOVEMENT OF CONTAMINATED SOIL

SURVIVES IN SOIL AS : Resting spores (oospores)

HOW DO I CONTROL IT?

FALLOW

CROP ROTATION

Select non-host rotation or cover crops

HOST-FREE ZONE

Control volunteer host plants and weeds

FARM HYGIENE

Stop movement of contaminated soil, water, plant and equipment

CHEMICAL FUMIGATION

Always use chemical fumigants with care and as per label.

- Consult APVMA or InfoPest website for current registered products.

PLANTING PREPARATION

DRAINAGE

Plant on raised beds or well-draining soil

TRANSPLANTS

Use seedling transplants - not direct seeding

POST-PLANT

AVOID OVER IRRIGATION

Saturated soils favour disease development and spread.

HOST RANGE

All brassicas, and a wide range of other vegetables

SoilWealth
NURTURING CROPS

Integrated
Crop Protection
PROTECTING CROPS

VG15010 Research Report

Damping off in Spinach: Best bet fungicide and biologicals Trial 2016/2017

Len Tesoriero & Donna Lucas

May 2017

RMCG

ahr applied horticultural research

Hort Innovation Strategic levy investment | VEGETABLE FUND

This project has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

VG 15010 A multi-faceted approach to soilborne disease management

'A multi-faceted approach to soilborne disease management' (Project VG15010) *is a three-year project (2015-2018) providing Australian vegetable growers with the tools and resources they need to manage the risk of crop losses due to soil-borne diseases.*

VG15010 delivers new information and resources about soilborne diseases to the vegetable industry through the established Soil Wealth and Integrated Crop Protection framework.

This project is a strategic levy investment under the Hort Innovation Vegetable Fund.

1 Contents

Summary

A preliminary field trial was conducted to evaluate the efficacy of chemical and biological control treatments for damping off pathogens in spinach. We demonstrated that three fungicide treatments significantly reduced the area of diseased plants, however, they did not significantly increase spinach yield compared to untreated controls. This is most likely due to other variables affecting plant growth in the trial area.

Soil baiting and bioassays from the trial site taken prior to the experiment revealed two *Pythium* species: *P. irregulare* and *P. ultimum* var *ultimum*, both of which are known to cause damping off diseases of a range of crop hosts including spinach. These results were supported by molecular tests of soil samples taken at sowing and at harvest. Consultation with crop protection companies (Syngenta and Bayer) assisted in the final choice of products with efficacy against *Pythium* spp. Suggested fungicide treatments were propamocarb + fosetyl-Al (Bayer; registered for vegetable seedlings in Europe) and metalaxyl-M + azoxystrobin (Syngenta; registered for seedling *Rhizoctonia* and *Pythium* control on cereals in Australia and similar formulations for vegetable crops in the USA).

A microbial biocontrol product containing a strain of the bacterium, *Bacillus subtilis* was chosen as a stand-alone treatment and in combination with aforementioned fungicides. Although the chemical interventions in this trial were designed primarily for *Pythium* disease control, both chemical treatments contained actives that should suppress *Rhizoctonia* spp. (namely, fosetyl-Al and azoxystrobin).

During crop assessments, *Rhizoctonia solani* was detected causing spinach damping off and collar rot in the trial. The pathogen was confirmed by DNA analysis of soil samples taken at sowing and harvest. Two sub-species relevant to vegetable crops were determined from these soil molecular assays: *R. solani* AG2-1 and AG2-2 which can both affect a wide range of crops. AG2-2 is known to cause damping off of spinach.

Introduction

Baby-leaf spinach is an increasingly important crop nationally. Damping off is a major issue in spinach and other crops across all regions of Australia. Apart from crop losses it can cause problems with postharvest crop quality and shelf life as leaves from harvested diseased plants are physiologically stressed. Previous diagnostic pathology studies conducted by Dr Tesoriero have determined that spinach damping off, wilt, collar and root rots are caused by any one or a combination of several soil-borne pathogens (**Table 1**). The suite of pathogens can change with geography, cropping history, soil type and season. Therefore, any preventative chemical or biological treatments must have a wide spectrum of activity to protect seedlings from any or all of these pathogens.

Table 1: Key plant pathogens associated with spinach damping off, wilt, root and collar rot in Australia

Pathogen	Critical comment
Pythium aphanidermatum	A warm temperature and very aggressive pathogen that can grow at 40°C
Pythium ultimum var. *ultimum*	A cooler to moderate temperature pathogen that can cause seed decay & damping off
Pythium irregulare	A cooler to moderate temperature pathogen that can cause seed decay & damping off
Phytophthora cryptogea *P. drechsleri*	Cause damping off but not seed decay
Rhizoctonia solani	There are different strains of this fungus which is favoured by a warm and wet soil surface
Fusarium oxysporum f.sp. *spinaciae*	This strain causes a vascular wilt disease and to date is only currently confirmed in Victoria

The objectives of the study were:

- To assess biological and chemical products for the control/suppression of damping off in baby leaf spinach.
- To assess the incidence and severity of damping off in spinach crops grown at Richmond, Tasmania in summer 2016-17 and quantify the impact on yield.
- To identify pathogens associated with disease symptoms which will help to inform future research and control measures.

The Trial

The trial was established at Harvest Farms at Richmond, Tasmania.

Trial design was a Latin square with six treatments and six replicates. Each plot was a 10m length of bed.

Trial treatments were:

1. Control (6 L water/treatment unit)
2. Previcur® @ 2.6 L/ha + Aliette® @ 1.2 kg/ha
3. Serenade Prime® @ 7 L/ha
4. Uniform® (Metalaxyl-M 124 g/L + azoxystrobin 322 g/L) @ 400 mL/ha
5. Uniform® + Serenade Prime®@ 7 L/ha
6. Previcur® @ 2.6 L/ha + Alliette® @ 1.2 kg/ha + Serenade Prime®@ 7 L/ha

Information about each product:

- Propamocarb (Previcur® is registered in Australia for control *Pythium* in ornamental plants)
- Fosetyl-Aluminium (Aliette®) is registered for control of *Pythium* and *Phytophthora spp* in perennial tree crops and ornamental crops. It is equivalent to phosphonic (=phosphorous) acid which also initiates a broad-spectrum plant defence response.
- Metalaxyl-M 124 g/L + azoxystrobin (Uniform®) is registered for suppression of *Rhizoctonia* and control of *Pythium* in wheat and barley crops. Metalaxyl also has Australian permits for *Pythium* control on various vegetables while axoxystrobin has wider efficacy to a range of soil and foliar pathogens.
- *Bacillus subtilis* (QST 713 strain as Serenade Prime®) can both stimulate plant growth and suppress plant pathogens.

The spinach was sown on 19th December 2016. The seed variety was 2157. Seed was dressed with Thiram and the effective sowing rate was 1,795 seeds / linear metre (1,600 seed / linear metre x 0.9 field factor[1]). The width of the sowing bed was approximately 1.5m.

Trial treatments were applied as a soil drench using watering cans after sowing on the same day.

Paddock history was as follows:

- Winter 2016 - a 'sparse' rye corn cover crop (<10-15 plants / m^2). This was established by broadcasting and harrowing. It was established late due to autumn cropping and wet weather.
- The cover crop was killed with glyphosate, previous beds were deep ripped, ground was spring-tine harrowed to level the beds, new beds were formed with a stone burying bed-former to invert trash and clods. (Note that beds were reformed in new positions as part of the installation of a new solid set irrigation system)
- October 2016 – a spinach crop was grown.
- 19th December 2016 – spinach crop sown (this trial).
- 19th January 2017 – spinach harvested using a commercial harvester (this trial).

Note that in addition to baby-leaf spinach, lettuce and brassicas are also grown at this farm in rotation with winter cover crops.

Sampling and data collection comprised:

- Soil samples taken on 19th December (sowing date) for:
  - standard pathology assessment

[1] 'Field Factor' is a correction based on expected losses in the field for the species.

  - DNA assays (linkage to Hort Innovation project VG15009 test conducted by The South Australian Research and Development Institute (SARDI
- Weekly observations
- Plant samples assessed by Dr Len Tesoriero to identify pathogens present
- NDVI image of trial site 12th January 2017
- At harvest, 19th January 2017:
  - Assessment of area of disease patches (bare patches). A disease patch was defined as a 10cm circular bare patch of ground. The number of disease patched in each plot was counted (2 assessors) and recorded.
  - Harvested weight per plot (a 9 m length of bed was harvested from each plot)
  - DNA assays from soil samples from 12 out of 36 plots

Results

Soil Pythium and Rhizoctionia solani levels at sowing

At sowing, levels of *Pythium* clade I and *Rhizoctionia solani* in the soil were high

Soil samples taken prior to and at sowing were used in direct baiting and bioassays for pathogenic fungi. The two species of Pythium: *P. ultimum var ultimum* (Figure 1) and *P. irregulare* were detected and caused root rot symptoms on spinach plants (Figures 2 & 3).

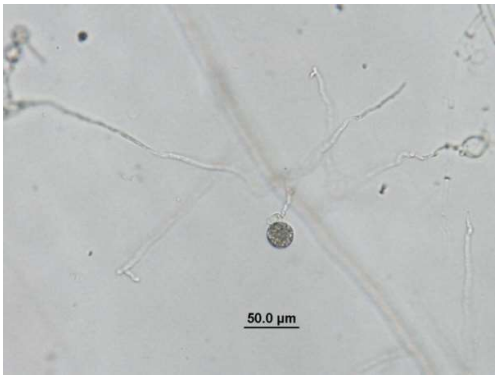


Figure 1 Photomicrograph of *P. ultimum* var. *ultimum* forming sexual structures in culture

Figure 2 Spinach roots from soil bioassay with root rot symptoms caused by *P. ultimum*

Figure 3 Spinach plants affected by *P. ultimum* in soil bioassay

DNA-based tests at sowing

One soil sample was taken from across the trial site for a DNA-based soil test. This test is still under development for vegetable crops and therefore data should be interpreted with care. Work to date has focussed on developing the test for carrots and brassicas rather than baby leaf crops. So not all species relevant for lettuce or baby-leaf crops are included in the suite of pathogens tested.

Rhizoctonia solani AG2.1 and AG2.2 (Figure 4) and *Pythium* Clade F and Clade I (Figure 5) were detected at the sowing date tests. This shows that there were high levels of *Pythium* clade I. This test does tell us which *Pythium* species were present and if they are pathogenic but given the morphological taxonomy and bioassays we can assume that the Clade F detection includes *P. irregulare* and the Clade I includes *P. ultimum* of which some were shown to be pathogenic to spinach. Interestingly, other DNA tests from Tasmanian soils have also detected *Pythium* clade I (Michael Rettke, PIRSA, pers. comm.).

Out of the other species tested for, the following were detected:

- *Plasmodiophora brassicae* was detected at low levels, 1,228 Copies/g.
- *Macrophomina phaseolina* was detected at low levels, 1,323 Copies/g.

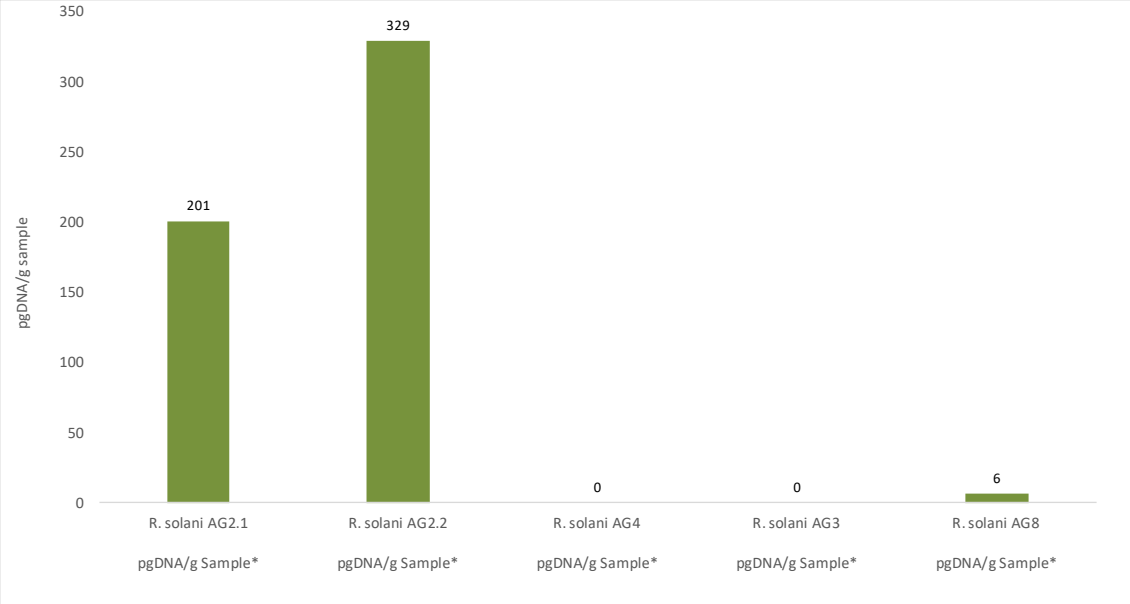


Figure 4. *Rhizoctonia solani* AG2.1 and AG2.2 detected at sowing date

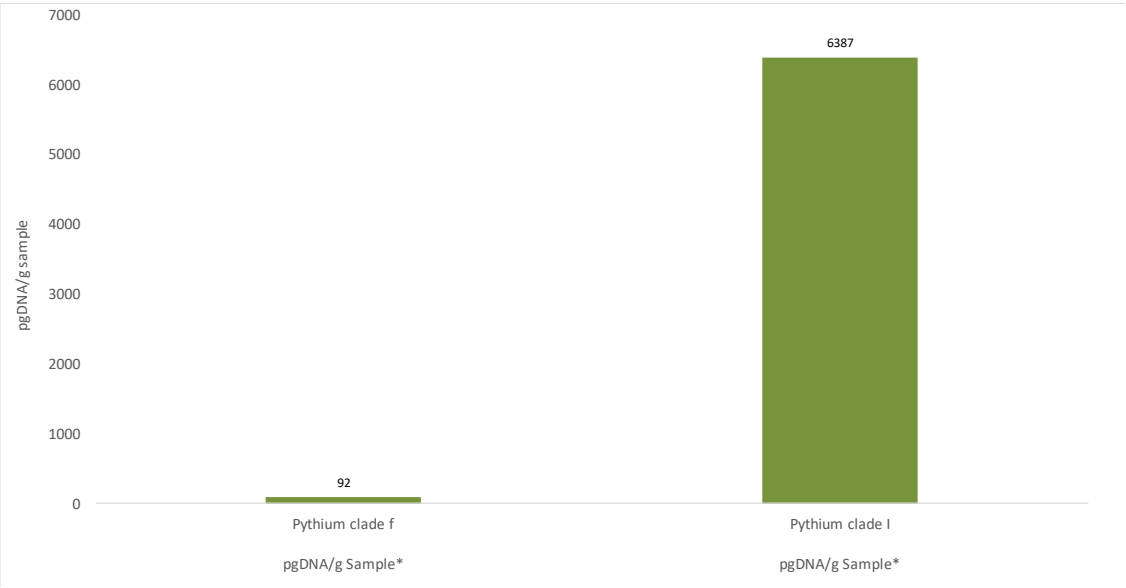


Figure 5. Pythium species detected at sowing date (data shown as pgDNA/g sample).

Field observations and identification of plant pathogens:

Diseased plants were observed which showed typical symptoms of damping off. At early stages of plant development, individual plants were found to be wilting, dying or dead (Figure 6, 17 days after sowing). Then, as the crop developed, bare patches became evident, which is typical of damping off caused by *Rhizoctonia* spp. (Figure 7, 24 days after sowing). *R. solani* and *P. ultimum* were isolated when affected plants were sampled and plated.

Figure 6. Plants wilting and roots rotting (typical damping off symptoms) (17days after sowing).

Figure 7. Bare patches where plants have died (24 days after sowing).

Some plants were observed with symptoms that looked slightly different to typical damping off disease. Plants were stunted and yellowing but roots did not exhibit typical damping off rotting (Figure 8). *Colletotrichum* was isolated from leaves of these plants. Therefore, it was most likely Anthracnose disease that caused the symptoms. These were observed in two or three small patches, but *Colletotrichum* may have also occurred in other areas within the trial that were not examined or tested in detail.

Figure 8. Plants wilting, yellowing and dying (17 days after sowing).

Disease patches

There was a significant treatment effect on the number of diseased (bare) patches. There were fewer bare patches in treatments 4, 5 and 6 compared to the control (Figure 9).

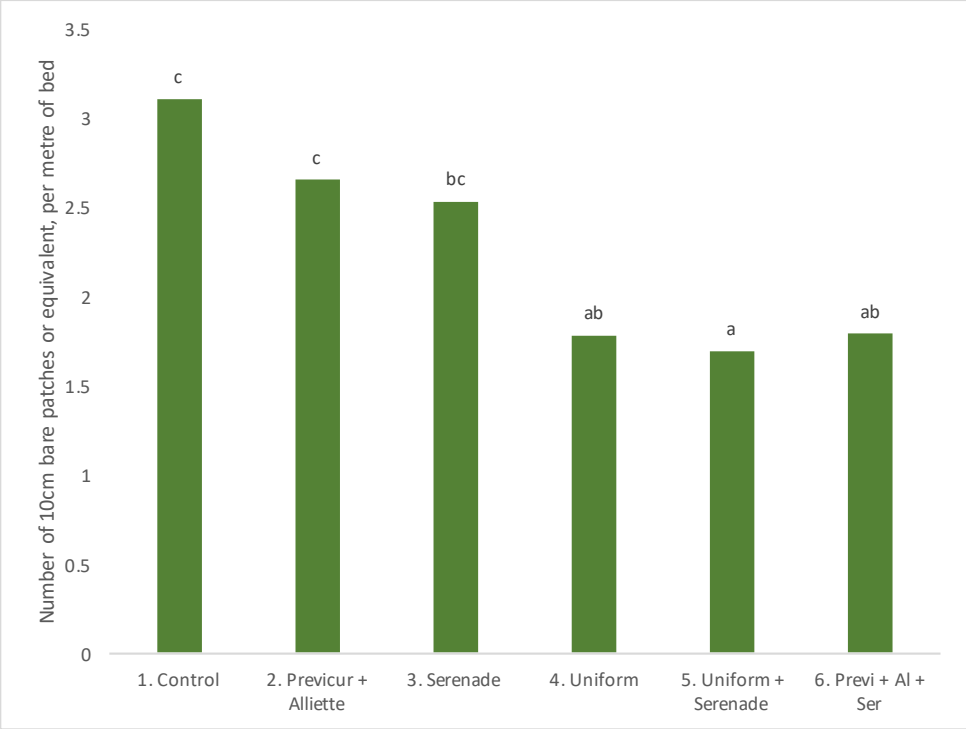


Figure 9. Number of 10 cm disease diameter patches per metre of bed.

Crop Yield

Yield and disease occurrence were very variable across the site. This may be due to variability in: soil structure (e.g. soil depth, compaction and drainage), irrigation coverage/uniformity and background variation in soil biology and pathogens present.

This variability is highlighted in the NDVI image (Figure 10).

There were no significant treatment effects on spinach yields. The average yield across all treatments was 2.5 kg per metre of bed. Data for each plot ranged from 1.6 to 3.9 kg per metre of bed.

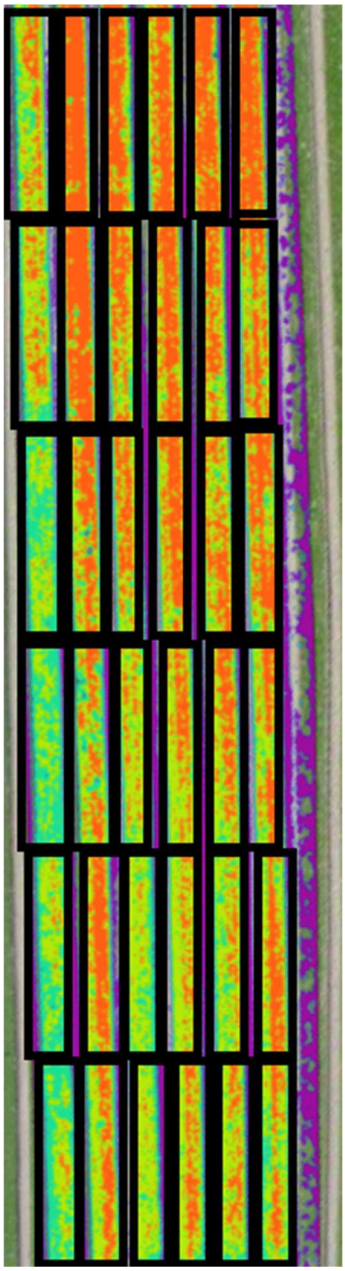


Figure 10. NDVI image and photograph (12th January 2017). In the NDVI image, purple indicates bare soil, red indicates denser growth, green indicates less dense growth.

Soil pathogen DNA levels at harvest

At harvest, 12 soil samples were collected for DNA-based testing; one sample for each of plots 1 to 6 and 31 to 36. These 12 plots were from the two outer beds of the trial which represented the areas that appeared to be more severely affected by disease. Data for *R. solani* and *Pythium* is shown in Table 2 (refer to Appendix 1 for full data set). The data cannot be compared directly to results from the 19th December (sowing date) because of different sampling strategies. However, it appears that inoculum levels may have dropped. There is no apparent or obvious difference between treatments, but it may be difficult to

detect any treatment differences with a small number of tests (i.e. two plots for each treatment).

Table 2. DNA-based tests for *Rhizoctionia solani* and *Pythium* Clade F and Clade I (refer to Appendix 1 for full data set).

		R. solani AG2.1 pgDNA/g Sample*	R. solani AG2.2 pgDNA/g Sample*	R. solani AG4 pgDNA/g Sample*	R. solani AG3 pgDNA/g Sample*	R. solani AG8 pgDNA/g Sample*	Pythium clade f pgDNA/g Sample*	Pythium clade I pgDNA/g Sample*
At sowing, 19th December 2016								
		201	*329*	*0*	*0*	*6*	*92*	*6387*
At harvest, 19th January 2017								
Treatment	***Plot***							
1	*1*	*2*	*16*	*0*	*0*	*1*	*80*	*1508*
1	*36*	*2*	*0*	*0*	*0*	*0*	*122*	*2914*
2	*6*	*14*	*25*	*0*	*0*	*0*	*140*	*1311*
2	*35*	*4*	*0*	*0*	*0*	*0*	*131*	*2022*
3	*5*	*1*	*7*	*0*	*0*	*0*	*136*	*1669*
3	*31*	*4*	*121*	*0*	*0*	*7*	*111*	*1737*
4	*3*	*0*	*1*	*0*	*0*	*15*	*113*	*1008*
4	*32*	*3*	*6*	*0*	*0*	*0*	*119*	*1647*
5	*2*	*1*	*0*	*0*	*0*	*14*	*112*	*773*
5	*34*	*0*	*32*	*0*	*0*	*1*	*151*	*2035*
6	*4*	*12*	*46*	*0*	*0*	*1*	*119*	*1050*
6	*33*	*14*	*9*	*0*	*0*	*7*	*254*	*2154*

Discussion and implications

The wet conditions before sowing and just after sowing most likely worsened the occurrence of disease. These wet conditions made tillage and other operations difficult and as a result the soil in some areas within the trial was more cloddy than typical at sowing. Soil condition may also have influenced the occurrence and distribution of disease.

The variability in yields per plot was most likely affected by site variability including: irrigation and water application (irrigation affected by wind), soil structure, depth of top soil and natural spatial variability in abundance of soil pathogens. Compaction was evident at a depth of about 20 cm but was not consistent across the site or across beds. This may relate to variation in depth of top soil or due to beds being relocated on top of previous wheel tracks. Compaction can cause drainage issues which can make soil-borne diseases worse.

The treatment effect on disease bare patches is promising. However, further work is required to confirm this effect under different conditions. In both of the treatments that included Uniform®, there were fewer disease patches than in the control. The Previcur® +Alliette® + Serenade® treatment also had fewer disease patches than the control suggesting there may have been a positive interaction between these products given that treatments of Previcur® + Alliette® alone or Serenade alone did not have significantly fewer diseased patches than the control.

Conclusions and recommendations

It is promising that some of the products / product combinations examined in this trial reduced the bare patches in the crop.

This trial was conducted as a preliminary trial. Fungicide trials take considerable time and effort and require assessment under a range of conditions of not only efficacy but also different application rates, split applications and placement as well as other health and environmental aspects for registration purposes.

Future research should consider additional fungicide active ingredients and also consider results from current pot trials using seed treatments for spinach.

Next steps are to compile research from this and other trials to prioritise future research needs.

Seed treatment is preferable to soil drenches to reduce the number of operations in the field.

Following in Table 3 are some fungicide options that are being used on other crops (some as seed dressings) for control of *Rhizoctonia, Pythium, Phytophthora* and *Fusarium*. Given issues with resistance development and enhanced biodegradation experienced with various fungicides such as metalaxyl and azoxystrobin it might be prudent for the spinach industry

to look at further options so that chemical seed dressings can be rotated. Note that some of these chemicals may not be appropriate for spinach diseases but this table can serve as a starting point in discussions with crop protection companies.

Table 3. Potential alternative agrichemicals for spinach diseases

Chemical active *Company* *Trade name*	*Activity group*	*Target(s)*	*Critical comment*
Fluopyram *Bayer* *Luna®*	*Gp7 SDHI*	*Rhizoctonia, Fusarium & Sclerotinia*	*Different binding site from other Gp 7 fungicides therefore lacks cross-resistance shown in other group members*
Penthiopyrad *Dupont* *Fontelis®*	*Gp7 SDHI*	*Rhizoctonia, Fusarium & Sclerotinia*	
Fluxapyroxad *BASF* *Imbrex®*	*Gp7 SDHI*	*Rhizoctonia, Fusarium & Sclerotinia*	
Flutolanil *Certis Aust.* *Monstar®*	*Gp7 SDHI*	*Rhizoctonia, Fusarium & Sclerotinia*	
Isopyrazam *Syngenta* *Reflect®*	*Gp7 SDHI*	*Sclerotinia*	
Mandipropamid *Syngenta* *Revus®*	*Gp 40 Carboxylic acid amide*	*Pythium? Downy mildew*	
Fluopicolide *Bayer* *Infinito®*	*Gp 43 Benzamides*	*Pythium, Phytophthora*	*Systemic in xylem*
Ametoctradin *BASF* *Zampro®* *formulated with Dimethomorph*	*Gp 45 Pyrimidylamines (QoSI)* *Gp 40* *Carboxylic acid amides*	*Phytophthora*	
Oxathiapiprolin *Dupont* *Zorvec®*	*New group* *Piperidinyl thiazole isoxazoline*	*Pythium? & Phytophthora*	*Translocates in both directions* *Seed dress*
GST-100 *ProBio Safeguard™*	*?*	*Damping off pathogens*	*Non-biological spinach seed treatment – establishes a barrier on roots*

Acknowledgements

This trial was conducted by project VG15010 'Multi-faceted approach to soil-borne disease management'. The project is funded by Horticulture Innovation Australia Limited using the vegetable industry research and development levy and funds from the Australian Government.

Soil DNA assays were conducted by SARDI, as part of Hort Innovation project VG15009.

The authors would like to acknowledge the team at Harvest Farms for sowing, managing and harvesting the trial.

Appendix 1. DNA-based soil tests

RDTS Samples				SARDI Plant & Soil Health Gate 2B, Hartley Gr. URRBRAE SA 5064																					
					Note: Results are now reported as raw values only, and have not been log																				
SampleNo	Notes	Farmer		Paddock	R. solani AG2.1 pgDNA/g Sample*	R. solani AG2.2 pgDNA/g Sample*	R. solani AG4 pgDNA/g Sample*	R. solani AG3 pgDNA/g Sample*	R. solani AG8 pgDNA/g Sample*	Aphanomyces euteiches pgDNA/g Sample*	Colletotrichum coccodes pgDNA/g Sample*	Blackleg pgDNA/g Sample*	Common Scab pgDNA/g Sample*	Macrophomina phaseolina Copies / g soil	Plasmodiophora brassicae Copies / g sample	Pratylenchus crenatus nematodes/g soil	Pratylenchus neglectus nematodes /g soil	Pratylenchus thornei nematodes/g soil	Paul Copies / g sample	Pratylenchus penetrans nematodes /g soil	Pratylenchus zeae Copies / g sample	Pythium clade f pgDNA/g Sample*	Pythium clade l pgDNA/g Sample*	Meloi yne fa pgDN Samp
BB44234	19/12/2016 Harvest Farms, Richmond, Tasmania				201	329	0	0	6	0	0	0	0	1323	1228	0.0	0.0	0.0	0	0.0	0	92	6387	0	
BB52581	RCMG - supplied by D Lucas	Richmond	1	Plot 1	2	16	0	0	1	0	0	0	0	812	0	0.0	0.0	0.0	109	0.0	0	80	1508	0	
BB52592	RCMG - supplied by D Lucas	Richmond	1	Plot 36	2	0	0	0	0	0	0	0	0	2080	0	0.0	0.0	0.0	0	0.0	0	122	2914	0	
BB52586	RCMG - supplied by D Lucas	Richmond	2	Plot 6	14	25	0	0	0	0	0	0	0	903	0	0.0	0.0	0.0	0	0.0	0	140	1311	0	
BB52591	RCMG - supplied by D Lucas	Richmond	2	Plot 35	4	0	0	0	0	0	0	0	0	1094	0	0.0	0.0	0.0	0	0.0	0	131	2022	0	
BB52585	RCMG - supplied by D Lucas	Richmond	3	Plot 5	1	7	0	0	0	0	0	0	0	558	0	0.0	0.0	0.0	0	0.0	0	136	1669	0	
BB52587	RCMG - supplied by D Lucas	Richmond	3	Plot 31	4	121	0	0	7	0	0	0	0	716	0	0.0	0.0	0.0	0	0.0	0	111	1737	0	
BB52583	RCMG - supplied by D Lucas	Richmond	4	Plot 3	0	1	0	0	15	0	0	0	0	302	0	0.0	0.0	0.0	0	0.0	0	113	1008	0	
BB52588	RCMG - supplied by D Lucas	Richmond	4	Plot 32	3	6	0	0	0	0	0	0	0	1450	0	0.0	0.0	0.0	0	0.0	0	119	1647	0	
BB52582	RCMG - supplied by D Lucas	Richmond	5	Plot 2	1	0	0	0	14	0	0	0	2	682	0	0.0	0.0	0.0	0	0.0	0	112	773	0	
BB52590	RCMG - supplied by D Lucas	Richmond	5	Plot 34	0	32	0	0	1	0	0	0	0	1159	0	0.0	0.0	0.0	0	0.0	0	151	2035	0	
BB52584	RCMG - supplied by D Lucas	Richmond	6	Plot 4	12	46	0	0	1	0	0	0	0	507	0	0.0	0.0	0.0	0	0.0	0	119	1050	0	
BB52589	RCMG - supplied by D Lucas	Richmond	6	Plot 33	14	9	0	0	7	0	1	0	0	627	0	0.0	0.0	0.0	0	0.0	0	254	2154	0	

NOTES:

1. This data should be interpreted with care as the tests are still under development. Further, the tests have not been specially designed for lettuce or baby-leaf crops and therefore not all relevant pathogens are tested for.
2. Note that some data is reported in pgDNA/g sample and some is reported as Copes/g sample.

SoilWealth
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VG15010 Research Report

Sclerotium rot of Chilli:
Best bet fungicides and biological:
Trials 2016-2017

L Tesoriero, L Spohr, A Harris, S Mulholland, J Archer, F Lidbetter, J Coulombe, K Montagu, & G Rogers

24 October 2017

RMCG

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Hort Innovation Strategic levy investment | VEGETABLE FUND

This project has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

VG 15010 A multi-faceted approach to soilborne disease management

'A multi-faceted approach to soilborne disease management' (Project VG15010) *is a three-year project (2015-2018) providing Australian vegetable growers with the tools and resources they need to manage the risk of crop losses due to soil-borne diseases.*

VG15010 delivers new information and resources about soilborne diseases to the vegetable industry through the established Soil Wealth and Integrated Crop Protection framework.

This project is a strategic levy investment under the Hort Innovation Vegetable Fund.

Disclaimer:

Contents

Summary

Capsicum and chilli production in Australia are currently valued at $136M annually. Summer crops in NSW and year-round production in Queensland can be affected by Sclerotium Rot caused by the basidiomycete *Athelia rolfsii* (asexual state = *Sclerotium rolfsii*). This fungus is favoured by soil temperatures above 30°C. Affected plants develop a characteristic basal stem and crown rot causing them to wilt and die at any stage during their development. Losses are progressive and plant death can account for more than a quarter of total plants by their harvest date. Fruit from wilting plants are unacceptable for fresh markets and only a few producers have a secondary processing market.

We conducted two preliminary field experiments in the summer of 2016-7 on chillies (cv. Rio de Oro) to evaluate chemical and biological controls for Sclerotium Rot. A first trial was located on a commercial property in Bundaberg, Queensland in a field known to have a *S. rolfsii* infestation. The second experiment was established at a NSW DPI field station at Somersby on the NSW Central Coast where *S. rolfsii* inoculum was uniformly applied.

Untreated control treatments were compared with four chemical or biological control treatments. The active ingredients of fungicide drenches were: pyraclostrobin or a combined formulation of cyprodinil and fludioxonil. Drenches were applied around the base of plants at three-weekly intervals commencing at seedling transplanting. Another chemical treatment alternated these products in six applications over a 15-week period. The biological control treatment consisted of similar drenches of a product containing isolates of undisclosed species. The trial at the Somersby site used only a commercial formulation containing an isolate of *Pseudomonas fluorescens* and three *Trichoderma* species isolates. Plots were rated for disease severity at three growth stages with the final assessment at harvest. Yield data was collected at the Bundaberg site only.

Individual chemical treatments significantly reduced Sclerotium Rot at both sites. At Bundaberg infection potential was sustained after single product drenches had ceased and plant infection continued until harvest. In contrast the treatment with six fungicide applications remained significantly less diseased. The microbial biocontrol treatment at the Somersby trial also significantly reduced diseased plants whereas the microbial formulation at Bundaberg was ineffective and possibly deleterious to plant health. These trials demonstrate that there are potential chemical and biological control options for Sclerotium Rot on chillies. Further studies are also addressing potential cultural controls such as plant spacing and irrigation scheduling.

Introduction

Sclerotium Rot affects many different crops in warm humid regions of the world. In the USA it is referred to as Southern Blight. The fungus responsible for this disease is *Athelia rolfsii* which is more commonly known as its asexual state, *Sclerotium rolfsii*. It can infect more than 500 plant species in over 100 different plant families. Many of these host plants are common vegetable, grain and ornamental crops.

The fungus survives in soil as sclerotia which are small brown spherical structures that resemble radish or cabbage seeds. These resting bodies can survive in soil for several months in a dormant state. They germinate in response from volatile chemicals released by decomposing plant material and are capable of rapid growth near the surface of warm and moist soil. The fungal threads generally infect plant roots and stems near the soil surface by producing an enzyme that deteriorates the outer cell layers. Infected tissue can become covered in white fungal threads or may appear brown and papery. Sclerotia eventually develop on the surface of infected material. Affected plants turn yellow, wilt a turn brown within a few days.

There are several management options for this disease and an integrated approach would be most likely to provide effective and sustainable control. This study focused on potential chemical and biological options.

Chemicals were chosen for their known efficacy to *Sclerotium rolsii*. The fungicide Pyraclostrobium is a member of the Group 11 strobilurins with low systemic activity. This group of fungicides is considered by the international fungicide advisory body - the Fungicide Resistance Action Committee (FRAC) - to have a 'high risk' for resistance developing in target pathogen populations. This rating may apply more to target foliar pathogens (such as the mildew fungi) than to soil-borne pathogens such as *S. rolfsii*. Another candidate chemical, Fludioxonil, is a member of the Group 12 phenylpyrroles which also has low systemic activity. It has a 'low to medium' risk of resistance developing according to FRAC.

Combining or alternating soil drenches of these products may effectively reduce disease losses without significant residues in harvested fruit while maintaining a strategy to reduce the risk fungicide resistance developing. Unfortunately, the only product available containing Fludioxonil for field use (Switch®) is a formulation with the fungicide Cyprodinil, a Group 9 fungicide which has good activity against several fungi such as *Sclerotinia* but with unknown effectiveness against *Sclerotium*. It is also systemic in xylem so may leave detectable residues in fruit. A resistance management strategy that does not use either produce more than three times in a crop or where Switch® is used earlier in production may be the best way to reduce undesirable chemical residues in fruit.

Biological controls for Sclerotium Rot are mostly based on fungi that can parasitise sclerotia thereby reducing the inoculum potential in soil. Several species of the hyperparasite *Trichoderma* are commercially available which could be evaluated in this study. Another

product which contains the bacterium *Pseudomonas fluorescens* is also potentially useful for this pathogen. Certain species of *Pseudomonas* are known to secrete phenylpyrrole chemicals which may have similar activity to Fludioxonil mentioned above.

The objectives of the study were:

- To assess the incidence and severity of Sclerotium Rot of chilli crops grown at Bundaberg, Queensland in the summer of 2016-17 and quantify the impact on yield.
- To assess biological and chemical products for the control/suppression of Sclerotium Rot of chilli.
- Identify future research needs and potential for effective integrated management strategies

Materials and Methods

Trial 1

A summary of the Bundaberg chilli trial methods is presented in Table 1

Table 1 Summary of trial design and methodology – Bundaberg trial

Trial Name/Number	Sclerotium rolfsii "best bet fungicide & biologicals" #1
Site	Bundaberg Qld. 4670
Crop/Variety	Chilli variety Rio de Oro
Paddock History	Sclerotium rolfsii has been a major issue in this block
Pathogen(s)	Sclerotium rolfsii confirmed
APVMA Permit	The trial is covered under PER 7250 http://permits.apvma.gov.au/PER7250.PDF
Design	Latin Square (5 treatments x 5 replications)
Treatments	1. Control (6 L water/treatment unit) 2. Switch® @ 4g/L applied as 3 x 3-weekly drench applications* 3. Cabrio® @ 1g/m^2 applied as 3 x 3 weekly drench applications 4. Switch® @ 4g/L applied as 3 x 3-weekly then Cabrio® @ 1g/m^2 applied as 3 x 3 weekly drench applications 5.Standard grower biologicals applied as 6 x 3 weekly drench applications *1st application at transplanting Drench treatments were applied in total water volume of 1 L/m^2 with watering cans
Planting Date	12th December 2016
Planting Rate	33 000 chili seedlings /ha
Plot size/Total trial size	Each plot comprised a 15metre length of a bed (approximately 90 plants) Total trial area was 5 beds x 75 m (5 treatments x 15m) Total plants in trial approximately 2,275 plants Buffers 0.5m at each end of each plot.
Data collection	**Plant health** Laboratory diagnostics confirmation of S. rolfsii was associated with wilted plants. Plots were assessed for sick and dead plants on 3 occasions; 3/2/2017 - 7 weeks after planting 19/2/2017 – 9 weeks after planting

	17/3/2017 - 13 weeks after planting Yields were determined at harvest. **Yield** Two assessments of yield were undertaken **Fresh market 17/3/2017** Hand harvest where commercial pickers first picked "Good greens" ie chillies which were suitable for the fresh market – this is **marketable yield**. This was followed by a strip pick of the remaining chillies (reject greens). These were added together to produce a **Total yield**. **Puree market 4/4/2017** An additional pick was undertaken – this mimicked a machine pick for the puree market (i.e. plants were stripped by hand). Chillies from diseased plants would not have been harvested in the fresh market pick (17/3).
Statistical analysis	ANOVA was used with Genstat 18. The numbers of sick and dead plants were combined to give a total number of diseased plants. Diseased plants were counted on 3/2 and 19/2 and the binomial data were analysed separately for each time, using generalized linear modelling (GLM). Means were separated using Fisher's protected LSD method

Trial 2

A summary of the Somersby chilli trial methods is presented in

Table 2

Table 2 Summary of trial design and methodology – Somersby trial

Trial Name/Number	Sclerotium rolfsii "best bet fungicide & biologicals" #2
Site	Somersby NSW
Crop/Variety	Chilli variety Rio de Oro
Paddock History	No cropping for several years. Previously citrus orchard.
Pathogen(s)	Sclerotium rolfsii inoculated into soil around transplants (except nil control)
APVMA Permit	The trial is covered under PER 7250 http://permits.apvma.gov.au/PER7250.PDF
Design	Replicated complete block with 14 replicates of a single plant
Treatments	1. Nil Control (6 L water/treatment unit) 2. Sclerotium rolfsii inoculated positive control 3. Switch® @ 1g/L applied as 3 x 3-weekly drench applications 4. Cabrio® @ 0.23mL/L applied as 3 x 3 weekly drench applications 5. Biologicals – Tricho-Shield® (Trichoderma harzianum, T. lignorum & T. koningii) @ 0.5g/plant + Sudo Shield® (Pseudomonas fluorescens) @ 4.5mg/plant Drench treatments were applied in total water volume of 100 mL/plant
Transplanting Date	24/1/2017
Planting Rate	Beds with 2 rows and plants 0.5 metres apart
Irrigation/Fertiliser	Drip as required; side dressed with complete fertiliser
Trial layout	Single plant treatments with 14 replications
Data collection	**Plant health** Mature plants were observed and scored for disease symptoms. The final scores were made on the 29th April 2017. The following disease rating system was used: 0 = healthy plant 1= yellowing / slight wilt 2= wilted 3= permanently wilted

	Laboratory diagnostics confirmed S. rolfsii was associated with wilted plants.
Statistical analysis	ANOVA was used with Genstat 18. The numbers of sick and dead plants were combined to give a total number of diseased plants. Diseased plants were counted on 3/2 and 19/2 and the binomial data were analysed separately for each time, using generalized linear modelling (GLM) Means were separated using Fisher's protected LSD method

Results

In the Bundaberg trial there was no significant difference between any yield data for treatments although the alternated fungicide treatment gave the greatest 'fresh market green' and 'total yields' (data not shown). There were significant differences between certain treatments for proportions of diseased plants at both the scoring dates. These data are presented in Figure 1.

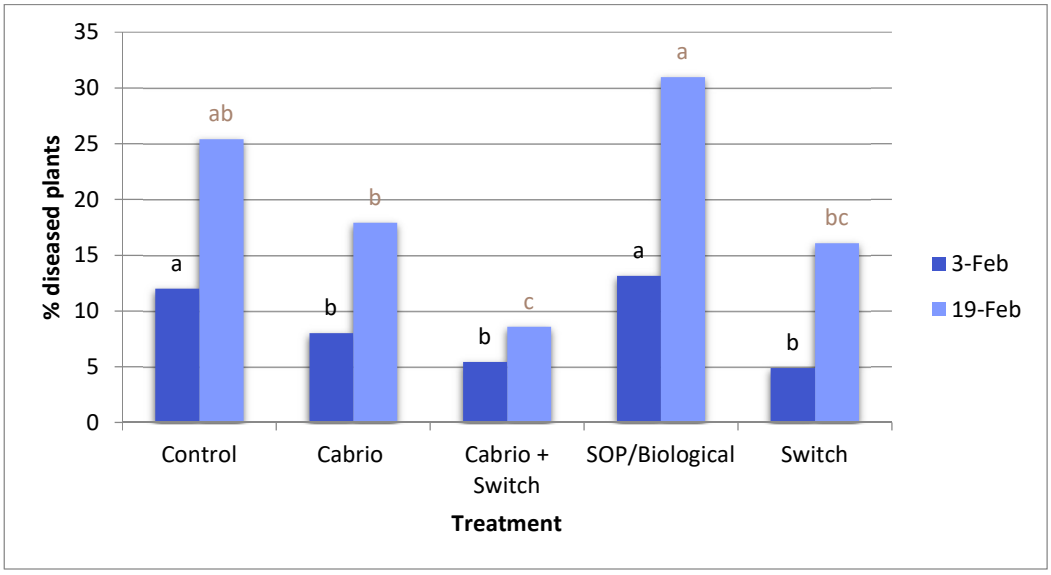

Figure 1. Percent of diseased plants scored at two dates at the Bundaberg. Bars with different letters are significant at P=0.05.

All chemical and biological treatments significantly reduced disease rating scores at the Somersby site. Data is presented in Figure 2.

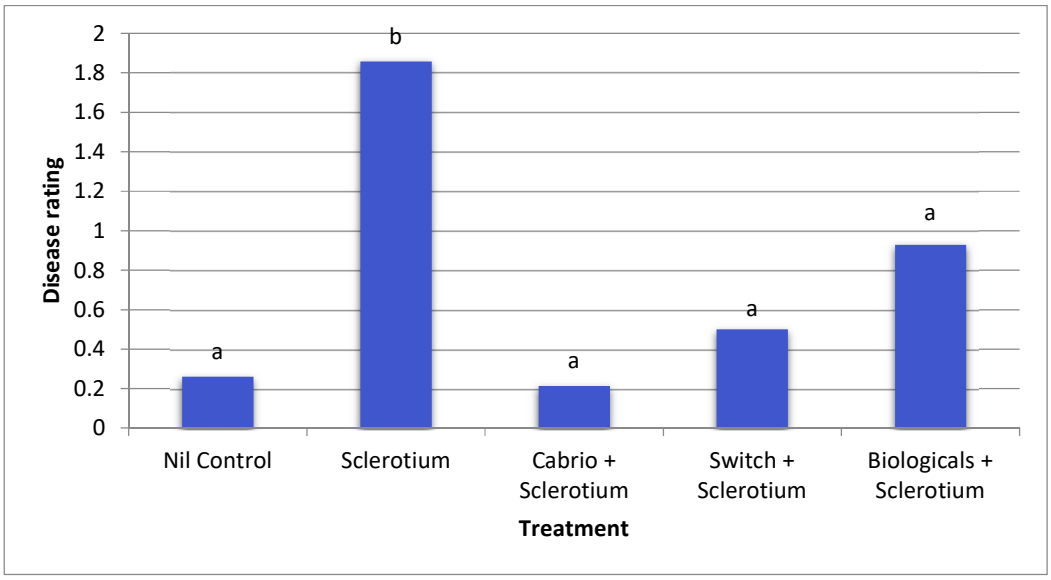

Figure 2. Retransformed means for disease rating of chemical and biological treatments at the Somersby trial site. Bars with different letters are significant at P=0.05.

Figure 3. Wilting plant affected by Sclerotium Rot in the Trial at Somersby, NSW.

Figure 4. Chilli basal stem rot with white fungal treads of *Sclerotium rolsii*

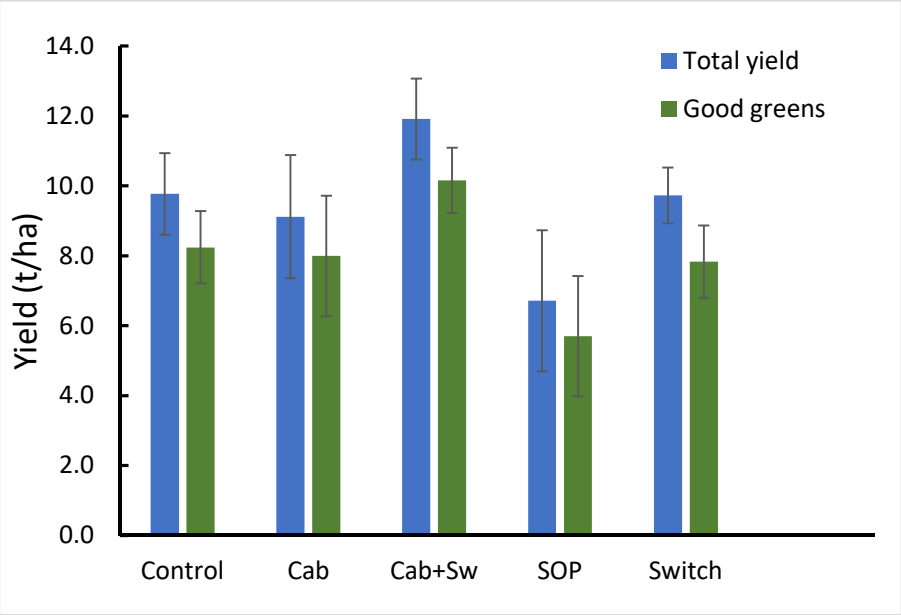

Figure 5. Fresh market chilli yield following chemical and biological treatments at Bundaberg. Bars are means with standard errors.

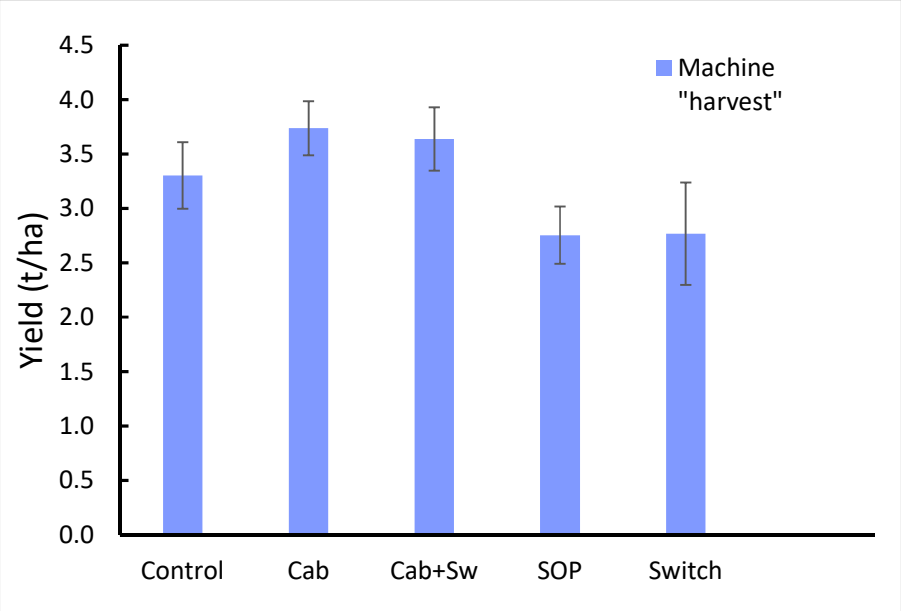

Figure 6. Puree chilli yield (Hand stripped to approximate machine harvest) following chemical and biological treatments at Bundaberg. Bars are means with standard errors.

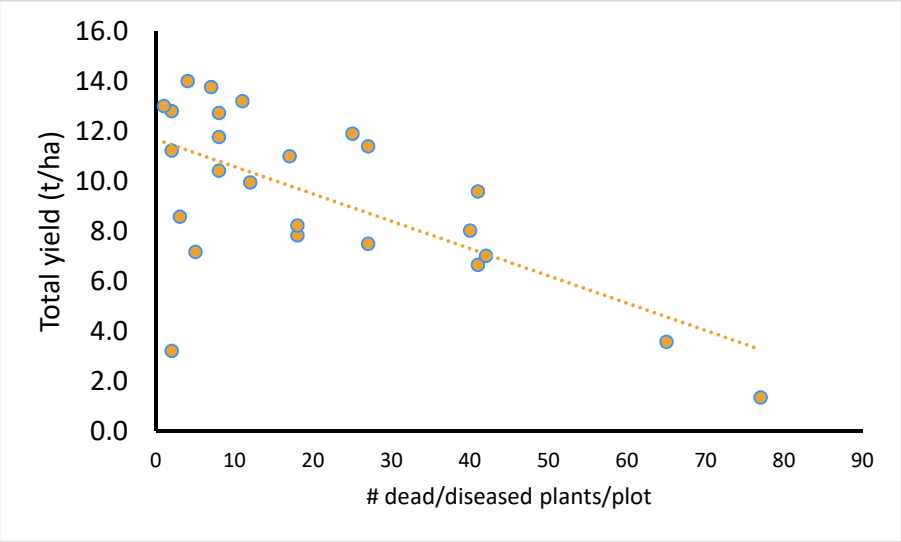

Figure 7. Relationship between disease incidence and total fresh market yield at Bundaberg.

Discussion & Conclusions

Both fungicides reduced Sclerotium Rot of chillies. At Bundaberg the best treatment was where these fungicides were Cabrio and Switch were alternated over a longer period of cropping. This suggests that disease pressure continued for the full duration of cropping even with regular fungicide applications. The SOP (Standard operating procedure) performed poorly in the Bundaberg trial, with higher disease incidence and lower yield.

There was no statistically significant fresh market yield increase from fungicide applications, likely due to spatial variation in *Sclerotium* inoculum and potential for growth compensation of remaining plants neighbouring diseased ones. However, there was a strong positive trend where the mean total and 'markerable green' yield from the alternating fungicide treatment was 22% greater than the control and 77-78% greater than the standard biological treatment (Figure 5). Differences in yield were measured three weeks later when all green chillies were stripped by hand, with the SOP having the lowest yield and the Cabrio and Cabrio + Switch having the highest yield (Figure 6).

The negative impact of dead and disease plants on yield was clear (Figure 7). Even when chemical and fungicide treatments difference on fresh yield could not be statistically determined, due to large variations across treatments probably due to inoculum level variation.

At Somersby fungicide drenches again significantly reduced disease severity as did the mixture of microbial biocontrol products.

There are several other management options that should be considered for effective and sustainable management of Sclerotium Rot of chillies. Following are some suggested strategies that could be evaluated on-farm at the Bundaberg site:

- It is known that lower plant densities where neighbouring canopies are not touching can reduce humidity and soil-surface moisture that favours fungal growth and infection.
- Sclerotium rot is favoured in acidic soils so liming or other strategies that increase soil pH could reduce disease prevalence. Addition of calcium is also known to help plants resist diseases.
- An ammonium form of nitrogen fertiliser has been shown to reduce Sclerotium Rot so its use in preference to the nitrate form may be useful. Note that ammonium fertiliser also decreases soil pH which favours disease so this effect must also be considered with other soil pH amendments.
- Scheduling crops to avoid periods of wet and warm weather – such as during the late summer period.
- Organic amendments or cover crops can promote beneficial microbes that are antagonistic to S. rolfsii however care needs to be taken as this pathogen can also live as a saprophyte on decaying organic matter.
- There are other potential chemicals that could be used as alternative or combined treatments to the ones used in this study. They are Group 7 products that inhibit the respiratory enzyme succinate dehydrogenase. These products are listed in Table 3. It should be noted that this fungicide group also has a high risk of resistance developing according to FRAC so a resistance management strategy needs to be considered and developed.

Table 3. Further potential alternative agrichemicals from Gp7 SDHI for Sclerotium Rot of chilli

Chemical active **Company** **Trade name**	**Product name**	**Company**
Fluopyram	Luna®	Bayer
Penthiopyrad	Fontelis®	Dupont
Fluxapyroxad	Imbrex®	BASF
Flutolanil	Monstar®	Certis Aust.
Isopyrazam	Reflect®	Syngenta

Acknowledgements

This trial was conducted by project VG15010 'Multi-faceted approach to soil-borne disease management'. The project is funded by Horticulture Innovation Australia Limited using the

vegetable industry research and development levy and funds from the Australian Government.

The authors would like to acknowledge the production team at Austchilli Ltd for managing and harvesting the trial.

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VG15010 Research Report

Effect of planting density on the incidence of soilborne disease and yield of chillies

Kelvin Montagu, Len Tesoriero, John Coulombe & Gordon Rogers

August 2017

RMCG

ahr applied horticultural research

Hort Innovation Strategic levy investment | VEGETABLE FUND

This project has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

VG 15010 A multi-faceted approach to soil-borne disease management

The three-year project is providing Australian vegetable growers with the tools and solutions they need to manage the risk of crop losses due to soil-borne diseases in the major vegetable growing regions of Australia.

VG15010 delivers new information and resources about soilborne diseases to the vegetable industry through the established Soil Wealth and Integrated Crop Protection framework.

The project will increase the number of growers, supported by advisors, to adopt practices which reduce the risk of soilborne diseases using existing or new approaches.

1 Contents

1 Summary

Intensive chilli production systems are susceptible to soilborne diseases, such as *Sclerotium rolfsii*, especially during the summer months. This trial, in summer 2017 examined if reducing plant density can reduce soilborne disease incidence and/or improve marketable yields in chilli crops. Three spacing treatments were test, current commercial spacing (100%; 33,500 plants/ha), 75% and 50% of current spacing, replicated four time.

During the trial, there was a low level of soilborne disease incidence. As a result, the influence of plant spacing on *Sclerotium rolfsii* incidence, and soilborne diseases in general, could not be reliably assessed. The trial provided useful information on spacing and yield. The 75% spacing treatment yielding 33% more fresh market red chillies, compared to the 100% current practice, while the 50% spacing treatment yielded 16% more. Big increases in the amount of fruit per plant were behind the maintenance or increase in yield as the planting density decreased. Differences in soil moisture under the spacing treatments may have also played an important role in the yield differences.

Care is required in interpreting the spacing treatments due to: 1. differences in soil moisture across the planting densities, and 2. the summer growing season when rapid growth by individual plants was possible allowing big increases in yield per plant.

Further operational scale trials of the 75% spacing treatment are warranted given the higher yields, reduced costs and possible reduction in soilborne diseases. Any future trial should aim to reduce the influence of irrigation on crop growth and yield so that spacing alone can be assessed.

2 Introduction

Over the last 20 years Austchilli has developed as Australia's leading fresh chilli producer. The focus on chilli production has been associated with intensive soil cultivation. The production system has used compost additions ad cover crops to counter the intensity of cultivation and long fallows under plastic. Intensive chilli production systems are susceptible to soilborne diseases, such as *Sclerotium rolfsii*, especially during the summer months. The disease can cause considerable losses and appears to spread between plants over the growing season.

Despite these soil management practices used by Austchilli an increase in *Sclerotium rolfsii* incidence, especially in transplants in spring, have been observed over the years. In some paddocks 10-20% of plants die with death occurring when plants are quite advanced.

Sclerotium rolfsii overwinters as sclerotia and mycelia in or on infected plants and debris. After winter, sclerotia germinate and hyphal growth resumes. Ideal temperatures for mycelial growth ranges from 8°C to 40°C, and the optimal temperature for sclerotia production is between 27°C and 35°C. Both sclerotia germination and mycelial growth favour water-saturated soils with high temperatures. Susceptible plant tissues, lower stems, roots, and fruit can be directly penetrated by hyphae contact under ideal conditions.

Sclerotium rolfsii is a difficult soilborne disease to control because the fungus has a broad host range that includes over 500 plant species, and sclerotia can survive for several years in

soil. The aim of this trial is to examine if reducing plant density, and hence increasing the distance between plants, can slow the lateral spread of the disease and reduce soilborne disease incidence and/or improve marketable yields in chilli crops.

3 Methods & Materials

3.1 Crop establishment and management

Prior to planting five tonnes/ha of compost was applied and incorporated with a rotary hoe. Beds were formed, sub-surface drip irrigation installed at x cm depth (single line per bed) and plastic laid.

The trial block (Brian's 8) was planted on 11th January 2017 with *Capsicum spp* variety ??? transplants using a water wheel transplanter.

The crop was fertilised and irrigated according to commercial practices based on the 100% spacing treatment.

3.2 Trial design and treatment

The trial was a randomised block with four replicates with three treatments:

1. 100% - standard practice - double off-set rows with 0.35m between plants (6.1 plants/m of bed)

2. 75% - double off-set rows with 0.47m between plants (4.5 plants/m of bed)

3. 50% - single row with 0.35m between plants (3.2plants/m of bed)

Trial layout is provided in

Appendix 1, with each plot (bed) 200 m long. Wheel track to wheel track was 1.5m.

3.3 Measurements

3.3.1 Soilborne diseases

Soil were taken and soilborne pathogens identified using standard pathology assessment by Len Tesoriero.

Plant disease assessment of each plot was undertaken at 14 (4/2/17), 57 (9/3/17), 103 (24/4/17) and 118 (9/5/17) days after planting using the following visual assessment; No disease symptoms, Plants stunted and wilted or dead. Plant health was assessed on 40m subplots within each treatment.

The number of plants lodged was also assessed at 118 days after planting.

Plant samples from plants displaying disease symptoms were sent to determine causal pathogens.

3.3.2 Soil Moisture

Volumetric soil moisture content was monitored in the three spacing treatments using Wildeye moisture sensors (Decagon GS1 frequency domain sensors; probe length 35mm). Two units per treatment were installed in Blocks B and C (see

Appendix 1 for locations), with probes installed at 15 and 50 cm soil depth.

Soil moisture was measured every 30 minutes between 10 February 2017 (22 Days after planting) and 16 April 2017 (87 Days after planting).

3.3.3 Harvest

Two yield assessments were done on subplots within the three spacing treatments.

Strip pick (machine harvest) 16/4/17

Total chilli yield was measured on a 10m subplot, 87 days after planting. For each plot hand pickers stripped all chillies to mimic a machine harvest and provide total yield. No in-field grading was undertaken by the pickers.

Fresh market and puree pick (9/5/17)

A graded pick was undertaken on a 5m subplot, 118 days after planting. For each plot experienced pickers harvested red chillies suitable for the fresh market. Following this harvest, pickers returned and stripped all red chillies suitable for the puree market.

For the three spacing treatments of 50, 75 and 100% of current practices 12, 17 and 24 plants were harvested and measured, respectively.

4 Results

4.1 Crop yield

The total yield of chillies, measured 87 days after planting did not vary (P=0.12) between the three spacing treatments (Table 1). This was because yield per plant increased (P<0.01) as planting density decreased, with plants in the 50% treatment yielding 39% more per plant than plants in the 100% spacing.

Table 1. Chilli total yield 87 days after planting. Transplanted seedlings were established at current practice spacing (100%) or at 75% and 50% of current practice spacing. Values are the plot means ± standard errors.

Treatment	Yield	
	t/ha	*kg/plant*
100%	38.7 ±2.0	1.16 ±0.06
75%	39.4 ±3.6	1.40 ±0.13
50%	34.5 ±3.0	1.61 ±0.14

The harvest at 118 days after planting showed differences between spacing treatments (P=0.045). The 100% spacing treatment produced the lowest yield of fresh market red chillies, with the yield 33 or 16% lower than the 75 and 50% spacings, respectively (Figure 1). The lower grade puree red chilli yield did not vary between spacing treatments (Figure 2), and represented a constant 23% of total yield across all spacing treatments. The highest total yield was measured in the 75% spacing treatment (P=0.028) (Figure 3).

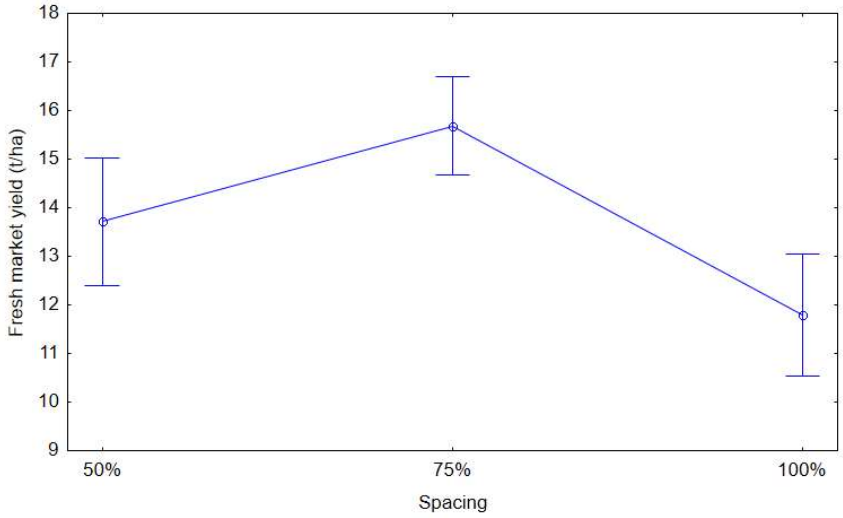

Figure 1. Fresh market chilli reds yield from three spacing treatments. Transplanted seedlings were established at current practice spacing (100%) or at 75% and 50% of current practice spacing. Values are the plot means ± standard errors.

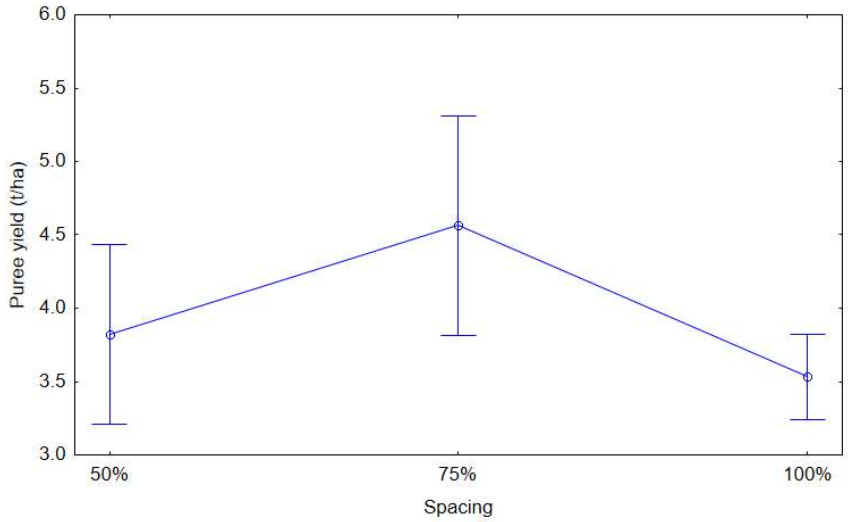

Figure 2. Puree grade chilli reds yield from three spacing treatments. Transplanted seedlings were established at current practice spacing (100%) or at 75% and 50% of current practice spacing. Values are the plot means ± standard errors.

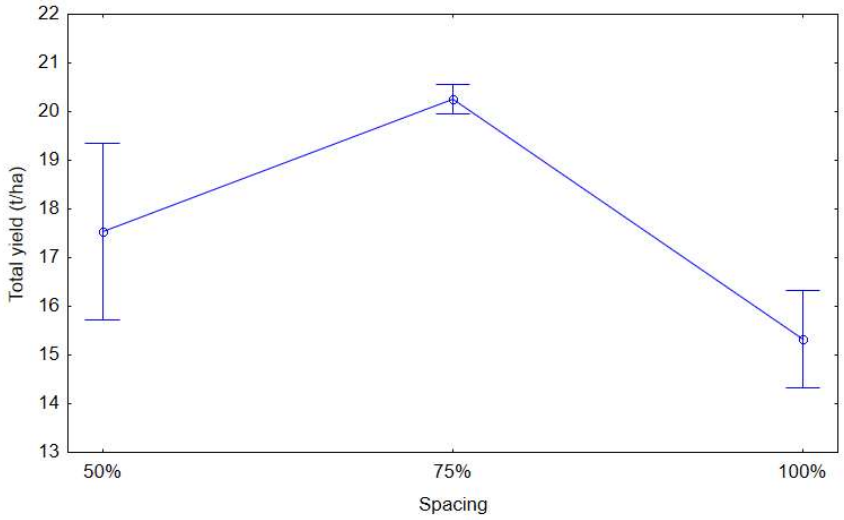

Figure 3 Total chilli yield from three spacing treatments. Transplanted seedlings were established at current practice spacing (100%) or at 75% and 50% of current practice spacing. Values are the plot means ± standard errors.

Plant number varied from 33,500 plants/ha, in the 100% spacing treatment, to 28,475 and 16,750 plants/ha in the 75% and 50% spacing treatments, respectively. The chilli yield was not related to plant number due to large changes in yield per plant (**Figure 4** & **Figure 5**). As planting density decreased from 100% to 50% there was a more than 120% increase in the fresh market reds and total yield per plant.

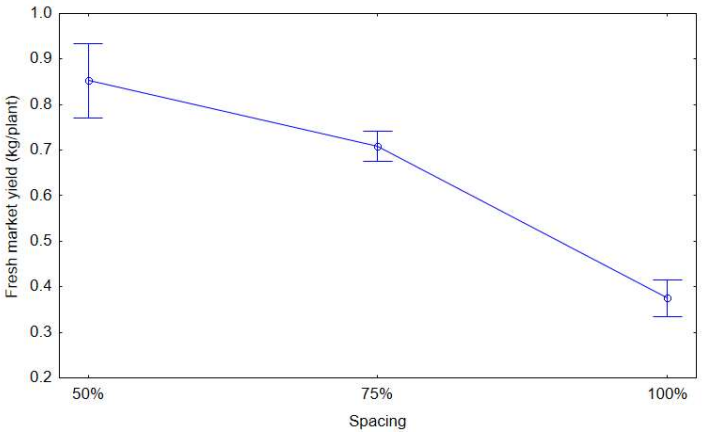

Figure 4. Changes in yield per plant of fresh market chilli reds from three spacing treatments. Transplanted seedlings were established at current practice spacing (100%) or at 75% and 50% of current practice spacing. Values are the plot means ± standard errors.

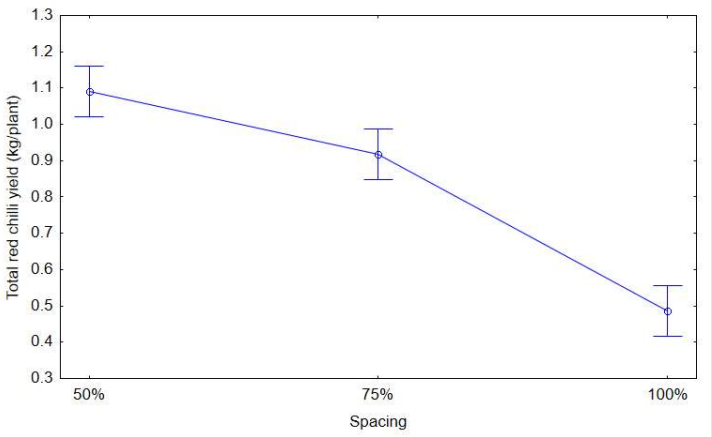

Figure 5. Changes in yield per plant of Total chilli reds from three spacing treatments. Transplanted seedlings were established at current practice spacing (100%) or at 75% and 50% of current practice spacing. Values are the plot means ± standard errors.

4.2 Soilborne diseases

4.2.1 Soil samples

Soil samples taken from Brian's paddock contained five species of Pythium; *Pythium aphanidermatum*, *P. irregulare*, *P. spinosum, P. ultimum*, and *P. vexans*, but no *Sclerotium rolfsii* was detected in the soil sample.

4.2.2 Crop observations and plant diseases

The disease incidence was low with only a maximum of 2% of plants diseased or dead at the end of the growing season. Although disease incidence was low, there were differences between the spacing treatment (P=0.002), with disease incidence lowest in the 50% spacing treatment, and highest in the 100% spacing treatment (Figure 6).

The pathogens responsible for the diseased plants were identified as *Pythium aphanidermatum*, *Rhizoctonia- Ceratobasidium*, and *Fusarium oxysporum*.

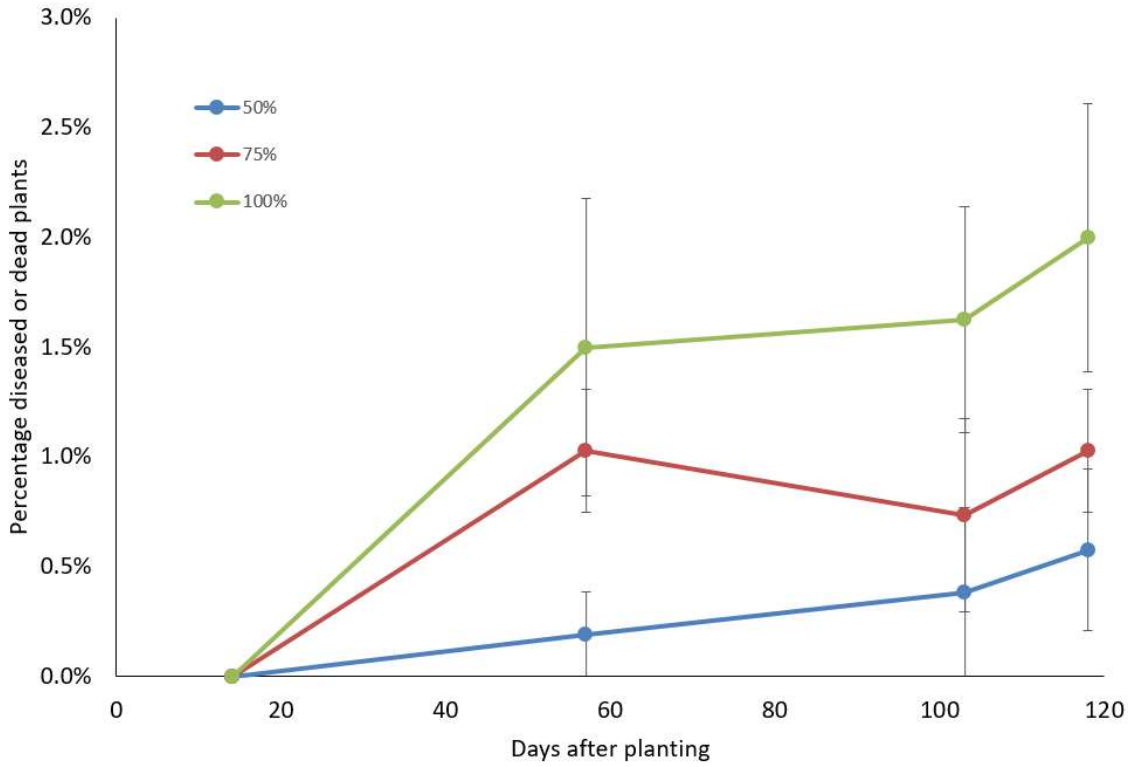

Figure 6. Changes in the percentage of diseased or dead chilli plants in the three spacing treatments.

4.3 Soil moisture

Prior to Cyclone Deb, which delivered 154 mm of rain 63 days after planting, the soil moisture content was greater under the 50 and 75% spacing treatments, compared to the 100% spacing treatment (Figure 7, Figure 8, Figure 9). Overall, the soil moisture content to 50cm was estimated to be 15 and 40% greater in the 50 and 75% spacing treatments, compared to the 100% spacing treatment, with the soil moisture average prior to Cyclone Deb being 94, 77 and 67 mm/50cm, respectively. The differences in soil moisture between the spacing treatments was mainly due to moisture topsoil's in the 50 and 75%, compared to the 100% (Figure 7, Figure 8, Figure 9).

After Cyclone Deb, differences in topsoil moisture levels were less pronounced between the spacing treatments (Figure 7, Figure 8, Figure 9), but differences in soil water extraction were evident. After allowing for drainage the plant water use from the top 30cm was estimated to be 6.4, 5.3 and 4.3 mm/day for 100, 75 and 50% spacing treatments respectively, between 2 and 9th April, (67-74 days after planting).

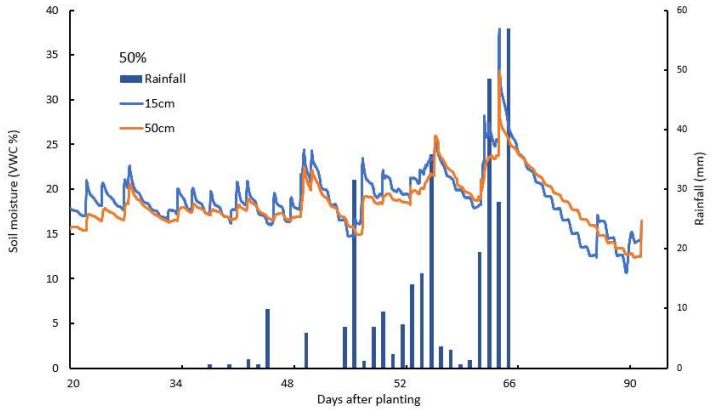

Figure 7. Volumetric soil moisture content at 15 and 50cm in the 50% spacing treatment, and rainfall during part of the trial.

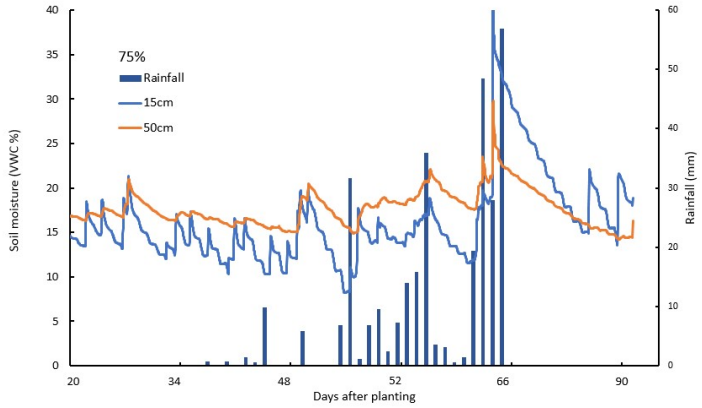

Figure 8. Volumetric soil moisture content at 15 and 50cm in the 75% spacing treatment, and rainfall during part of the trial.

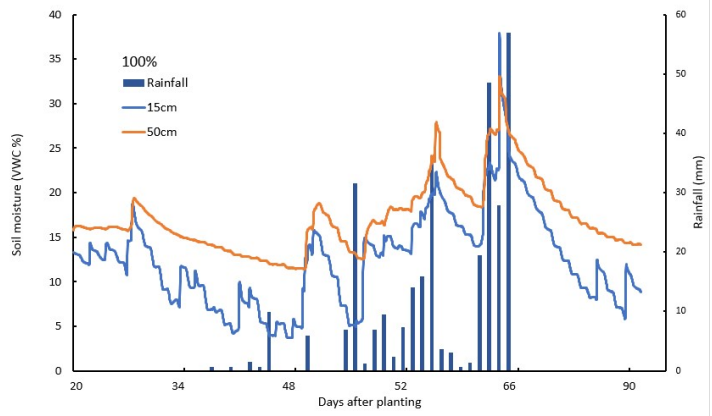

Figure 9. Volumetric soil moisture content at 15 and 50cm in the 100% spacing treatment, and rainfall during part of the trial.

5 Discussion

5.1 Soilborne disease incidence

During the trial, there was a low level of soilborne disease incidence (Figure 6). As a result, the influence of plant spacing on *Sclerotium rolfsii* incidence, and soilborne diseases in general, could not be reliably assessed.

While the soilborne disease incidence was low, the 100% spacing treatment had a higher disease incidence, reaching over 2% of plants diseased or dead by the final harvest, compared with less than 1% in the 50 and 75% spacing treatments. Of the plants assayed for diseases none were infected with *Sclerotium rolfsii,* with *Pythium aphanidermatum*, *Rhizoctonia- Ceratobasidium*, and *Fusarium oxysporum* identified from diseased samples.

5.2 Influence of spacing on yield

The trial provided useful information on spacing and yield, with the 75% spacing treatment giving the highest yield of fresh market red chillies. The results showed the ability of chilli plants to respond to the greater space, and increase growth and yield. This suggested that there may be benefits, not related to soilborne disease management, to reducing seedling planting density and hence cost.

The highest yield of fresh market red chillies was obtained from the 75% spacing treatment, with yield 33% higher than the current practice (100%; Figure 1). Surprisingly, even the single row 50% spacing, which had half the number of plants (16,750 plants/ha) yielded a similar amount to the 100% spacing treatment.

A possible consequence of reducing spacing is an increase in sunburnt fruit (Russco 1991). However, we observed no increase in puree grade puree grade fruit as planting density decreased (Figure 2) with all treatments having a similar proportion of puree grade.

Big increases in the amount of fruit per plant were behind the maintenance or increase in yield as the number of plants decreased (Figure 4). Single row spacings have previously been found to produce higher yields than double row arrangements for bell peppers (Kahn & Leskovar 2006), with Russco (1991) reporting yield increases in three out of four trials when within row spacing was increased from 31 to 46 cm between plants.

Differences in soil moisture under the spacing treatments may have played an important role in the observed yield differences. Commercial irrigation management practices applied to the 100% spacing treatment were used across all three spacing treatments. While the same amount of irrigation was applied it is likely that differences in canopy cover, and hence water use, would have occurred in the early crop stages. With a higher planting density, the canopy of the 100% treatment would have established earlier than the other two treatments and potentially used more water. This is consistent with the soil moisture data where the topsoil of the 100% spacing treatment is consistently drier than the 50% treatment during the first eight weeks of the crop (Figures 7-9). The more rapid drying of the soil may have stressed the chilli plants and reduced their yield potential. By contrast, soil moisture was greater in the lower planting density which would have resulted in the plants being less water stressed.

Differences in crop water use were also observed after Cyclone Deb. After allowing for drainage the plant water use from the top 30cm was estimated to be 6.4, 5.3 and 4.3 mm/day for 100, 75 and 50% spacing treatments respectively, between 2 and 9th April. The high daily water use by the 100% spacing would drive the crop into water stress earlier than the other 2 treatments and may have been responsible for the yield differences.

Care is required in interpreting the spacing treatments due to differences in soil moisture across the planting densities, and also the summer growing season when rapid growth by individual plants was possible.

Soil moisture levels in the 100% spacing treatment were consistently lower in the first 8 weeks, probably due to higher plant water use associated with the greater crop canopy. The potential water stress may have reduced the yield potential of the 100% spacing treatment. By contrast, in the 75 and 50% spacing treatments the smaller crop canopies and water use appeared to allow more fruit set and growth per plant, more than compensating for the lower plant density. Thus, the spacing treatment impact on fruit yield may in part be due to differences in soil moisture levels.

If irrigation had been optimised for the 100% spacing treatment, the yield in the 100% spacing treatment may have been greater. Previous studies have reported a linear relationship between yield and plant density up to 111,000 plants/ha (Jolliffe & Gaye 1995), a planting density more than three-time greater than then the 100% treatment in this trial.

The trial was conducted over the summer when temperatures would have been suited to rapid growth. This may have allowed the lower density plantings to compensate by the few plants growing more rapidly. Lowering planting density in less favourable growing times may result in reduced yields if the fewer plants are not able to compensate and produce a greater yield per plant.

6 References

Kahn, Brian A.; Leskovar, Daniel I. 2006. Cultivar and plant arrangement effects on yield and fruit quality of bell pepper. HORTSCIENCE 41:1565-1570.

Peter A. Jolliffe, Mary-Margaret Gaye, 1995. Dynamics of growth and yield component responses of bell peppers (Capsicum annum L.) to row covers and population density. Scientia Horticulturae 62:1530164.

V. M. Russo (1991) Effects of fertilizer rate, application timing and plant spacing on yield and nutrient content of bell pepper, Journal of Plant Nutrition, 14:1047-1056.

7 Appendix 1

Spacing trial layout

	row	20m	20m	40m	20m	20m	20m	20m	20m	76m	
	1	75%									100%
Block A	2	85%	33%		33%		50%		50%		100%
	3	100%									100%
	4	85%	33%		33%		WE 50%		50%		100%
Block B	5	100% WE					WE 100%				100%
	6	75% WE					WE 75%				100%
	7	85%	33%		33%		50%		WE 50%		100%
Block C	8	75%							WE 75%		100%
	9	100%							WE 100%		100%
	10	75%									100%
Block D	11	100%									100%
	12	85%	33%		33%		50%		50%		100%

Douglas road

Row length about 400 m

historically worst disease end
WE=wildeye sm probes

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VG15010 Research Report

Experiments to test management options for damping-off disease of baby spinach

Len Tesoriero

March 2019

RMCG

ahr applied horticultural research

Hort Innovation
Strategic levy investment
VEGETABLE FUND

This project has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

VG 15010 A multi-faceted approach to soilborne disease management

'A multi-faceted approach to soilborne disease management' (Project VG15010) *is a three-year project (2015-2018) providing Australian vegetable growers with the tools and resources they need to manage the risk of crop losses due to soil-borne diseases.*

VG15010 delivers new information and resources about soilborne diseases to the vegetable industry through the established Soil Wealth and Integrated Crop Protection framework.

This project is a strategic levy investment under the Hort Innovation Vegetable Fund.

1 Contents

Summary

Spinach damping off was identified by growers as a perennial cause of losses. Intensive baby leaf spinach production favours common soil-borne pathogens that prevent crops from establishing evenly. Post-emergent damping off results in dead patches across beds which are either left unharvested or cause grading and postharvest quality problems.

Diagnostic studies of affected plants from Eastern Australia identified the key fungal and oomycete species involved.

A series of pot experiments confirmed the pathogenicity of fungal and oomycete isolates and then tested efficacy of chemical and microbial biocontrol options for their control.

A chemical seed dressing that became available after the initiation of this project was found to successfully control *Pythium* damping off. Preliminary screening of other chemical and biological treatments did successfully result in intermediate levels of control for *Rhizoctonia* disease.

Higher chemical application rates reduced disease further but they are currently not likely to be acceptable. Both biological and chemical options could be explored further or even integrated to optimise their efficacy.

Cultural controls are currently seen as the best options for sustained control of *Rhizoctonia* damping off and root rot. Rotations with non-host crops and incorporation of cover and biofumigant crops could reduce soil inoculum of the key pathogens prior to planting.

More validation research would be valuable to integrate cultural, chemical and biological options.

Introduction

Several candidate pathogens were isolated from baby spinach affected with damping-off disease in commercial crops across southern and eastern Australia (Tasmania, Victoria, NSW and Queensland). Initial pathogenicity experiments were conducted to confirm Koch's postulates for several isolates of the oomycete *Pythium* (*P. aphanidermatum*; *P. irregulare*; and *P. ultimum*) and isolates of *Rhizoctonia solani (R. solani)*.

A series of pot experiments confirmed the pathogenicity of fungal and oomycete isolates and then tested efficacy of chemical and microbial biocontrol options for their control.

The Trial

Experiments were conducted in 2L plastic pots using a conducive media substrate (UC mix = 1:1 coarse river sand: peat with added lime and gypsum to obtain a pH = 6.0-6.5) and sown with spinach seed without any fungicide dressing (var. Kookaburra [Rijk Zwaan Seeds]). Pots were placed in replicated complete blocks on benches in a greenhouse with a diurnal temperature range 20-30°C. Inoculum of the various oomycete and fungal isolates was added at seeding as macerated agar cultures and plant establishment and post-emergent damping off was scored over a 4-week period.

The second phase of experiments consisted of a further 11 trials where a number of chemical and microbial biocontrol treatments were tested for efficacy. These trials initially followed the same procedure outlined above for the pathogenicity experiments. One trial attempted to demonstrate the effect of diluting the *R. solani* inoculum to reduce disease incidence and avoid over-saturation of the pathogen which may 'swamp' chemical and microbial control products being tested.

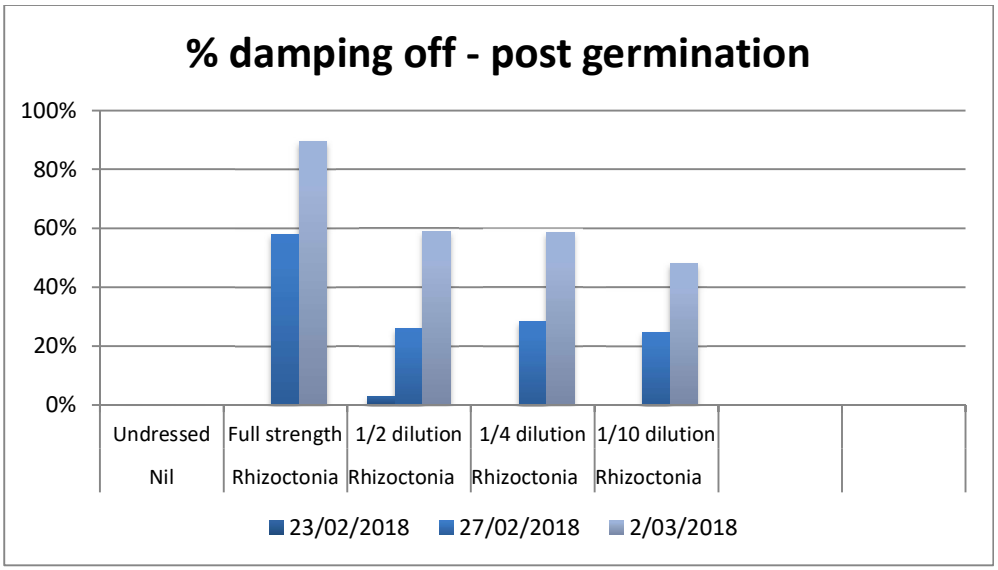
Later experiments employed a modified procedure where either chemical or biological treatments were applied with the pathogen inoculum several days prior to sowing seed in an attempt to reduced disease potential before germinating seed encountered pathogens. One product containing the hyperparasitic fungus *Trichoderma* with known activity to fungal pathogens (including *Rhizoctonia* spp.) was reformulated by growing it on sterile millet seed (in order to potentially increase its inoculum potential). This form of inoculum was prepared for another product containing both *Trichoderma* a bacterial formulation containing *Bacillus* species.

The final set of experiment tested drenches of the fungicides penthiopyrad (Fungicide Activity Group 7) and azoxystrobin (Fungicide Activity Group 11) at registered spray rates and higher application rates to observe dose-responses.

Results and Discussion

All isolates from baby spinach were shown to be pathogens under these controlled-environment experimental conditions. The effect of diluting *R.solani* inoculum on spinach damping off can be seen in the Figure 1 below. In future it would be useful to have these doses quantified using the quantitative test being developed by SARDI.

Figure 1. Percent post-emergent damping off in spinach seedlings with diluted inoculum

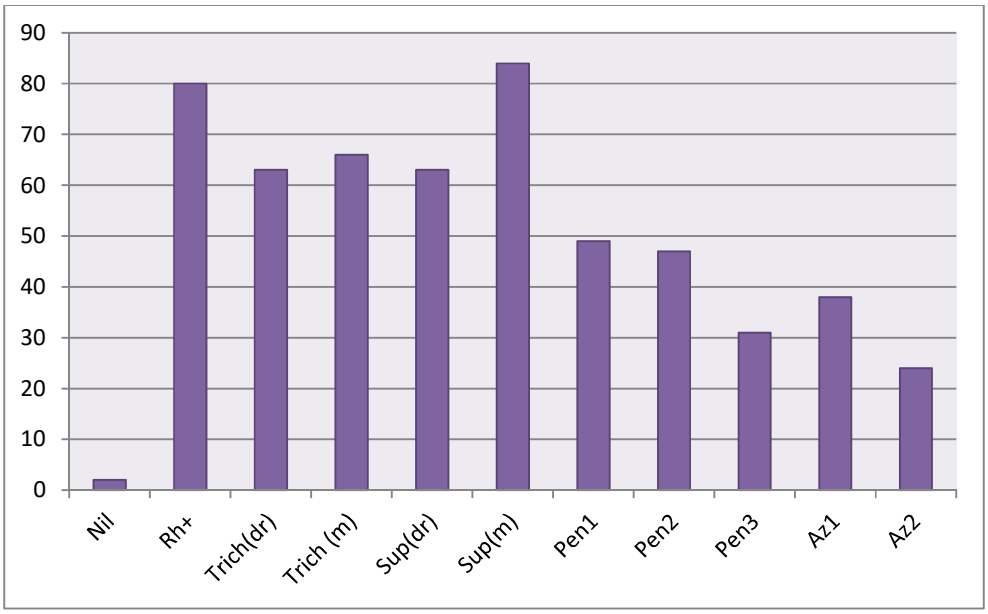


Dressing seed with either Maxim XL® (metalaxyl-M plus fludioxonil) or Farmore™ (metalaxyl-M + fludioxonil + azoxystrobin) provided good protection against *Pythium* species but was not efficacious to *Rhizoctonia solani* isolates tested under these experimental conditions.

Microbial biocontrol products containing *Trichoderma* isolates applied as soil drenches at rates recommended by their distributors did reduce post-emergent damping-off caused by *R. solani* (see Figure 2 below). Both biocontrol products performed less well when applied as millet seed formulations. In other experiments several microbial products tested provided no significant protection from pre-emergent damping-off or post-emergent losses (data not shown). Overall, these results also reflect a common phenomenon of a high variability in efficacy of microbial formulations in pot experiments.

Drenches of the fungicides penthiopyrad and azoxystrobin at registered and higher application rates reduced post-emergent damping off caused by *R. solani* (by 40-70%). These products are currently registered on spinach for foliar disease control so using them at elevated rates for a soil-borne pathogen is not currently acceptable. Applied early in production for the diseases for which they are registered could reduce Rhizoctonia disease, particularly since this pathogen tends to infect plants near ground level. Residue studies for altered use-patterns would also be required. Unfortunately there are limited further chemical options for controlling basidiomycete fungi such as *R. solani* and these experiments demonstrate the recalcitrant nature of this fungal pathogen. Given there are alternatives to azoxystrobin from different chemical activity groups for foliar diseases of spinach there may be scope to re-examine this use-pattern in the future.

Figure 2. Percent post-emergent damping off of spinach seedlings at 17 days after sowing (pre-germinated seed)



Nil = nil inoculum control; Rh+ = Positive inoculum control: Trich (dr) = drench of *Trichoderma* formulation; Trich(m) = *Trichoderma* colonised on millet seed; Sup(dr) = drench of *Trichoderma* and *Bacillus* spp. product; Sup(m) = *Trichoderma* and *Bacillus* spp. product colonised on millet seed; Pen1 = penthiopyrad at 0.35L/ha; Pen2 = penthiopyrad at 0.7L/ha; Pen3 = penthiopyrad at 1.16L/ha; Az1 = azoxystrobin at 100mL/ha; Az1 = azoxystrobin at 1L/ha.

Other cultural controls being explored in related projects are use of cover crops or biofumigants which may reduce inoculum potential prior to growing spinach. Strains of *R. solani* (AG2-II and AG4) determined as the causes of spinach damping off in this study have reasonably wide host ranges but should not attack lettuce, peas and beans. These vegetable species may be useful rotation crops in some areas or at least varieties of these legumes and cereals could be used as cover crops. Caution should be exercised with Brassicas though as they can host *R. solani* AG4.

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VG15010 Research Report

Grafting cucumbers to disease resistant rootstocks; Managing Fusarium Wilt and Pythium Root Rot

L Tesoriero, L Spohr, A Harris, J Lidbetter and F Lidbetter

February 2019

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Hort Innovation Strategic levy investment | VEGETABLE FUND

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Disclaimer:

Contents

Introduction

Greenhouse cucumbers are affected by a number of diseases which can severely reduce yields. Fusarium wilt and Pythium root rot are the most important causes of losses across major production areas of Australia.

The strain of *Fusarium oxysporum* (*Foc*) affecting cucumbers in Australia is unlike any that occurs overseas. There are no commercial cucumber varieties resistant to this strain of *Fusarium* available.

Foc infects plants through the root system and travels up the water-conducting tissue (xylem) into the main stems. It causes a watery rot at the base of plants while older leaves turn yellow and wilt. As the infection progresses up the stem typical pink or orange-coloured fungal spore masses form on the surface.

Foc spores can be dispersed in the air or by insects (such as sciarid flies – also called fungus gnats) or on workers' hands and clothes. Spores land on the growing media or soil surface where they germinate and infect roots of other plants. If left unchecked the disease spreads to surrounding plants in a greenhouse, and potentially infects all plants. Although plants can be infected as seedlings, symptoms may not be expressed until they reach maturity. The extra plant stress at flowering and when fruit are filling appears to weaken them and favours disease development.

Fusarium wilt is commonly accompanied by *Pythium* root rot which can infect plants from the moment seedlings are transplanted. *Pythium* infections cause seedlings to wilt and die (known as damping-off), but some species also cause larger plants to wilt. A combined infection of both pathogens is more likely to make plants of any age wilt and die.

Both *Pythium* and *Fusarium* are difficult to eradicate from a farm as their spores can survive in dirt, dust and water, re-entering cleaned greenhouses and new crops. There is no agrichemical or biological treatments registered for control of Fusarium Wilt in Australia therefore alternative management options are desirable.

The objectives of the study were:

- To assess the efficacy of resistant rootstocks (pumpkin hybrid or resistant cucumber lines) on diseases control in protected cropping cucumber production.
- To determine the economics of using grafted cucumbers under commercial conditions.

Materials and Methods

A summary of the cucumber trial methods is presented in **Table 1**

Table 1 Summary of trial design and methodology

Project Number	*VG15010*
Trial Name/Number	*Greenhouse cucumber grafting trial*
Site/GPS	*J & Y Boustani Rossmore, NSW*
Crop/cv	*Cucumber cv Larino*
Pathogen(s)	*Pythium spp. & Fusarium oxysporum f.sp. cucumerinum*
Treatments	*1.Nil = Ungrafted cucumber plants (var Larino)* *2. Cucumbers grafted onto cv. Affyne (C. sativus) rootstock* *3. Cucumbers grafted onto cv. Cobalt (C. maxima x C. moshata 'pumpkin')*
Sowing Date	*mid- May 2017 (1st pick 19/6/2017)*
Crop management	*New coir bags*
Design	*Randomised complete blocks consisting of four replicates of three treatments; each treatment being a full row of plants*
Plot size/Total trial size	*Each treatment unit is a full row of 60 bags of coir media, each bag with 2 plants*
Data collection	*1. Score plant health for Fusarium wilt (healthy, wilting, dead)* *2. Collect samples and confirm identity of pathogens* *3. Weigh successive harvests to estimate total marketable yield* *4. Record treatment effects by photography and video images.*
Statistical analysis	*Ordinal logistic regression (generalised linear model with multinomial distribution and logit link function) was used to predict plant health score based on the grafting treatment received. We can also determine whether grafting treatment has a significant effect of plant health score. The model also included the replicate effect. We can also interpret the odds that ungrafted plants have a higher or lower plant health score than the other two treatments.*
Final assessment Date	*7th September 2017*

Results

1.1 Percentage healthy bags

Binomial analysis was used to compare the proportion of bags (each with 2 plants) where both plants are healthy versus a diseased bag which has one or both plants expressing Fusarium wilt symptoms.

The two grafted treatments had significantly higher proportions of healthy bags compared to the ungrafted treatment ($p<0.001$). Table 2 presents these percentages; note that only about 20% of bags of ungrafted plants were healthy. In contrast, roughly 60% of bags with grafted plants were healthy.

Table 2. Proportions of healthy bags (where both plants are healthy) on grafted rootstocks or ungrafted plants

Treatment	Percentage healthy bags (%)
Ungrafted (control)	21.0 a*
Grafted – cv. *Affyne* rootstock	65.0 a
Grafted – cv. *Cobalt* rootstock	58.9 b

**Different letters indicate significant at p=0.001*

1.2 *Plant health scores*

Cucumber plants from the ungrafted treatments had significantly lower odds of being healthy than plants from grafting treatments ($p<0.001$). The two grafted treatments had significantly higher proportions of healthy heads compared to the ungrafted treatments. This is illustrated in **Figure 1**.

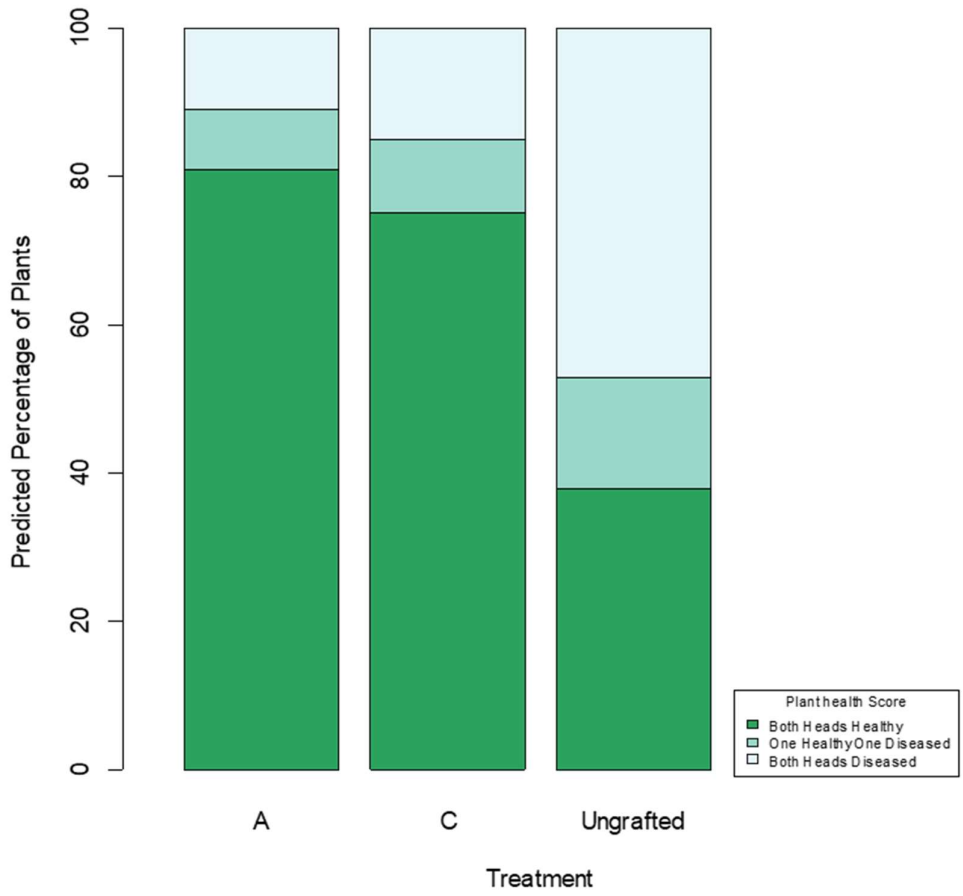

Figure 1. The percentage of cucumbers in each Plant Health score category for A. cv. *Affyne* rootstock, C cv. *Cobalt* rootstock, and Ungrafted seedlings.

Plants with the cv. *Affyne* rootstock had a significantly higher proportion of healthy heads compared to heads on ungrafted plants (Table 3).

Table 3. Percentage of total cucumber heads rated as healthy for grafted and ungrafted treatments.

Treatment	% of healthy cucumber heads
Ungrafted (control)	46.1 a*
Grafted – cv. *Affyne* rootstock	86.2 b
Grafted – cv. *Cobalt* rootstock	79.1 ab

**Different letters indicate significant at p=0.001*

1.3 Cucumber yields

The cucumber yield of *Affyne*-grafted plants was 29% higher than ungrafted plants (

Table 4). *Cobalt*-grafted plants yields were not significantly different from ungrafted controls. These grafted plants were also observed to be slower to mature and less thrifty than other treatments.

Table 4. Cucumber fruit yield on grafted rootstocks or ungrafted seedlings. Letters indicate significant differences between treatments

**Different letters indicate significant at p=0.05*

Treatment	Fruit yield (kg)
Ungrafted (control)	283 a*
Grafted - cv. *Affyne* rootstock	364 b
Grafted - cv. *Cobalt* rootstock	338 ab

Discussion & Conclusions

We confirmed that cucumbers grafted onto resistant rootstocks significantly controlled Fusarium Wilt and Pythium Root Rot in a commercial greenhouse trial. These results and related preliminary studies identified a cucumber rootstock (cv. *Affyne*) and a hybrid pumpkin rootstock (cv. *Cobalt*) as being resistant to Fusarium Wilt caused by the predominant Australian strain of *Foc.* These studies also determined that these rootstocks are also highly tolerant to Pythium Root Rot caused by several species including aggressive strains of the warm temperature pathogen, *P. aphanidermatum*.

In commercial-scale trials we demonstrated that both rootstocks could support healthy plants that easily out-yielded ungrafted plants in the same house. In a winter crop there was a 29% yield difference between a grafted treatment (cv. *Affyne* rootstock) and ungrafted plants.

This can easily translate into an economical benefit under high disease pressure after the increased cost of seedlings is taken into account. These benefits depend on several factors including the magnitude of disease pressure and the cucumber wholesale price. Here's a simple calculation of the net benefit:

In our winter trial there was a 29% yield increase with grafting.

If the average cucumber yield is 7 kg/plant, then that yield difference represents a saving of about 2kg/plant.

If cucumbers sell for $2/kg then it translates to a saving of $4 per plant.

Now if the difference between grafted and ungrafted seedling costs is $2.50 then there is still a saving of $1.50 per plant.

Obviously this number changes for the better if prices are higher and vice versa for lower cucumber values.

Overall, it provides growers with an effective disease management option.

There were a few other issues and factors that were observed during these trials:

- Care needs to be taken when transplants are placed into media so that the graft union is not buried too deep so that roots do not form above the graft union and become infected by Fusarium. Using seedlings growing in rookwool cubes prevents this problem.
- If plants are layered or vine training is delayed, roots can form above the graft union and become infected. Again using rockwool cubes mitigates this by keeping more space between the medium and the stem above the graft union.
- In a single trial over winter reported here, the cucumber rootstock outperformed the pumpkin rootstock. In a similar trial conducted over summer, both rootstocks performed equally. Further validation studies are required to test the robustness of these results.
- It is possible to use two heads on grafted plants to off-set increased grafted seedling costs. This may require other changes to crop management so should be done with caution.
- Another saving is that Fusarium-infected media does not need to be replaced as frequently. For growing in soil, it lessens need for more disruptive interventions such as using fumigants between crops.

Acknowledgements

This trial was conducted by project VG15010 'Multi-faceted approach to soil-borne disease management'. The project is funded by Horticulture Innovation Australia Limited using the vegetable industry research and development levy and funds from the Australian Government.

The authors would like to acknowledge the production team at J & Y Boustani Rossmore, NSW Ltd for assistance with the trial.

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VG15010 Demonstration Report

Soilborne disease management in greenhouse capsicums

North Adelaide Plains, Virginia, South Australia

Tom Lioulous, Steven Coventry, EE Muir, Doris Blaesing, RMC, August 2017

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VG 15010 A multi-faceted approach to soilborne disease management

'A multi-faceted approach to soilborne disease management' (Project VG15010) *is a three-year project (2015-2018) providing Australian vegetable growers with the tools and resources they need to manage the risk of crop losses due to soil-borne diseases.*

VG15010 delivers new information and resources about soilborne diseases to the vegetable industry through the established Soil Wealth and Integrated Crop Protection framework.

This project is a strategic levy investment under the Hort Innovation Vegetable Fund.

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Contents

Summary and conclusions

A simple on farm demonstration trial was set up for a preliminary assessment of the effect of dry Caliente pellets (Biofence) on root health and crop growth of greenhouse capsicums in the Northern Adelaide Plains.

Preliminary findings suggest that Biofence at 200g/m^2 on its own, applied once pre-planting to a soil with high root knot nematode (*Meloidogyne*) levels cannot provide adequate nematode control for a capsicum crop over a nine-month growing period.

Further work is required to understand the most beneficial and economically viable use of this soil amendment. Biofence may have to be used in higher rates, different timing, repeatedly or in combination with other practices. Biofence may be assist in suppressing soilborne diseases, if used when inoculum levels still low.

Introduction

Biofence, a pelletised organic soil amendment made from the brassica biofumigation plant Caliente, was used in an on-farm demonstration trial in the Northern Adelaide Plains, Virginia, South Australia. The main target organisms were root knot nematodes (*Meloidogyne* spp.*)* The grower, Tom Lioulous, was also interested in reducing the risk posed by damping off fungi such as *Pythium* spp. and *Rhizoctonia* spp.

The trial was as an initial screening of Biofence in a greenhouse capsicum production system, typical for the region. In the Northern Adelaide Plains, intensive greenhouse production of vegetables has a long history. Therefore, soil borne diseases, and especially nematodes, have become a significant problem. Metham Sodium (MS) fumigation has been used for many years to manage nematodes and other soilborne diseases. However, growers are increasingly interested in replacing the chemical. It appears that Metham Sodium does no longer have the desired effect. Many growers are also concerned about its effect on soil health as well as the wellbeing of their families and those who work for them.

Conversations with numerous growers and agronomists in the Virginia area suggest that enhanced biodegradation of Metham Sodium may occur in the Adelaide Plains. Currently, a testing service for enhanced biodegradation of MS is not available in Australia. Detailed information about Metham Sodium use and alternatives that can be tried in the vegetable industry can be found in the following report VG 13045 - Identification of Potential Alternatives to Metham Sodium.

Site, trial details and methods

This section summarises information about the demo site, treatments and assessments.

TRIAL NAME BIOFENCE USE IN	
Site and management information	
Site location	Virginia, South Australia
Producers	Tom Lioulous and family

TRIAL NAME	BIOFENCE USE IN
Agronomist	Steve Coventry, EE Muir & Sons
SBD team contact	Doris Blaesing, RMCG
Crop	Capsicum (yellow)
Soil texture	Loam
Soil condition (structure, fertility)	No obvious root zone restrictions
Irrigation	Drip delivering uneven amount of water along the length of the line i.e. the slight slope of houses / gravity lead to more water being applied to the lower lying section of beds end the end of lines; all beds are affected; the differences in water application have not been assessed.
Relevant management inputs	Chicken manure composts used regularly
Rotation	Capsicums, several months fallow, capsicums
Trial details	
Situation	Continuous cropping in plastic tunnels has led to a build-up of nematodes, identified via root damage symptoms, and fungal pathogens, identified via damping off issues
Trial Objectives	Investigate the effect of BioFence, a Caliente based mustard meal extract (Appendix 1), on levels of nematodes and soil borne fungi as well as disease incidence and severity. Establish whether BioFence can be used as a replacement for fumigation
Target Pathogen(s)	Nematode spp, damping-off fungi; refer to preplant DNA test results attached as Appendix 2
Trial site dimensions	Greenhouse tunnel group size: 350 m^2 x 8 houses =2,800 m^2 for the group
Treatments	Control – no Biofence, Treated – Biofence pellets at 200g/m^2 (refer to Appendix 1 for product information and image)
Planting Date	30/8/16
Termination	May 2017
Planting Density	TBA
Crop management	Standard fertiliser and irrigation management across all houses

TRIAL NAME	BIOFENCE USE IN
Design and plot size	Replicated strips Control: two houses (# 4, 8) by 350m^2 each - no treatment Treated: six houses by 350m^2 each - (# 1, 2, 3, 5, 6, 7) treated with Biofence (sample taken with Predicta soil probe across all the treated houses prior to treatment)
Data collection	**DNA soil testing** a week after planting and after crop establishment (October 16) Sampling using Predicta probe and methodology, 1 sample bulked across control houses plus 1 across treated houses **Plant assessment** visually during site visits 31/10/16, 23&25/11/16 (observations recorded and photos taken by Steve Coventry) **Plant height measurements and root health assessments** were conducted 18/1/17 and 17/7/17; average plant height within a row was measured at 22 positions in treated and untreated beds and photos taken at each position. Root health was assessed using a scale of 1-5 with 1 indicating healthy a root system and 5 a root system heavily infested with root knot nematodes and lacking new root growth. **Harvest assessments** given the long period of time the crop was harvested and the available resources, a yield assessment was not done.
Statistical analysis	Not possible, demo trial to evaluate whether Biofence should be included in replicated trials
Harvest Period	End October 16 to End May 17

Findings and discussion

Observations and measurements

Visual assessment made during crop visits 31/10/16, 23 & 25/11/16 showed differences between the treated beds and the control. The main differences were a slightly lighter leaf colour in control beds and a larger number of poorly growing plants than in treated beds as show in below images.

31-10-16 control bed

31-10-16 treated beds

At the time of crop assessments 18/1/17 (5% yellow fruit) and 17/2/17 (harvest commenced), differences in the appearance of surviving plants in treated and untreated (control) rows had largely disappeared. At the time of the 2nd assessment 17/2/17 plants in untreated and treated beds did not show noticeable height differences (refer to Table 1 and above images).

Root health assessments (1 = good, 5 = poor) produced no difference in overall ratings between treated and untreated (control) beds at both visual assessment dates. However, some of the plants in treated plots had less nodules and more fine roots than others, and more than those in control plots. Images on the following 2 pages show examples of plant and root assessments.

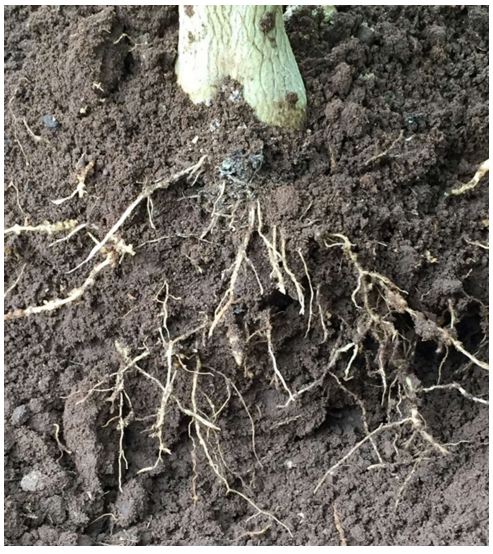
DNA tests for root knot nematodes shown in Table 2 suggest that in December 2016 nematode levels in treated beds were much higher than in untreated beds; a difference which is difficult to explain from the information collected.

Table 1 – Plant height and root health assessments

DATE	CONTROL - HOUSES 4 & 8		TREATED - HOUSES 1-3, 6 & 7	
	Average plant height (cm)	Root health rating	Average plant height cm	Root health rating
18/1/17	62	4.2	70	4.2
17/2/17	84	4.3	85	4.3

18-1-17 control bed

18-1-16 treated bed



17-2-17 control bed

17-2-16 treated bed

Predicta soil DNA test results

Michael Rettke, South Australian Research and Development Institute (SARDI), conducted the DNA soil tests as part of project VG15009. He suggested that the main clade I *Pythium* species is most likely *P. ultimum*. It is a cooler temperature pathogen, which can cause root rot. *P. ultimum* does not produce zoospores so the population does not change quickly. It is difficult to interpret the detected Pythium DNA level in terms of significance for disease risk. Some isolates can be very aggressive while others are not.

Rhizoctonia levels are low and a potential effect on the crop is not clear. *Colletotrichum coccodes* (fruit anthracnose) was found, which causes a black dot root rot on tomatoes. This disease has not been reported on capsicums.

Biofence reduced total *Meloidogyne incognita* levels in the first two months after treatment, compared to the control. However, levels were still high. By December, nematode levels found in soil from the treated areas where higher than in untreated areas. This suggests that Biofence at 200g/m^2 on its own, applied once pre-planting to a soil with high root knot nematode (*Meloidogyne*) levels cannot provide adequate nematode control for a capsicum crop with some 9 months of growing.

Table 2 – Predicta soil DNA test results prior to planting and in-crop

Sampling date	**Houses**	***Pythium* clade I** (pgDNA/g Sample)	***Pythium* clade f** (pgDNA/g Sample)	***Rhizoctonia solani* AG2.1** (pgDNA/g Sample)	***Rhizoctonia solani* AG4** (pgDNA/g Sample)	***Colletotrichum coccodes*** *(Anthracnose)* *(pgDNA/g Sample)*	***Macrophomina phaseolina*** (Charcoal Rot) (copies/g soil)	***Meloidogyne javanical incognital arenaria*** (pgDNA/g Sample)	***Meloidogyne incognita*** (pgDNA/g Sample)
Pre-planting **25/08/16**	**4 & 8 Control**	**43**	**0**	**1**	**0**	**80**	**0**	**1382**	**3176**
	1,2,3,5,6,7	**45**	**0**	**3**	**0**	**79**	**0**	**1406**	**5251**
6/10/16	**4 & 8 Control**	**31**	**0**	**0**	**1**	**57**	**0**	**482**	**1645**
	1,2,3,5,6,7	**43**	**0**	**0**	**0**	**113**	**0**	**466**	**1230**
19/12/16	**4 & 8 Control**	**31**	**0**	**1**	**0**	**144**	**233**	**2050**	**Not analysed**
	1,2,3,5,6,7	**31**	**2**	**4**	**0**	**101**	**368**	**4004**	**Not analysed**

Appendix 1: BioFence information

For details visit http://www.headlandamenity.com/SDS_2011/Biofence_SDS_110124_DT.pdf

headland AMENITY PRODUCTS

PRODUCT SAFETY DATA SHEET

BIOFENCE

1. Identification of the substance/mixture and of the company/undertaking:

1.1 Product identifier:

BIOFENCE

1.2 Relevant identified uses of the substance or mixture and uses advised against:

Organic Soil Amendment

1.3 Details of the supplier of the safety data sheet:

Headland Amenity Ltd,
1010 Cambourne Business Park,
Cambourne
Cambridgeshire
CB23 6DP
Tel : +44 (0) 1223 597834
Fax - +44 (0) 1223 598052
e-mail info@headlandamenity.com

1.4 Emergency telephone number:

Tel : +44 (0) 1223 597834 during office hours (9am – 5pm, Monday – Friday)

2. Hazards Identification:

2.1 Classification of the substance or mixture;

This mixture is not classified as harmful to humans or the environment according to Directive 1999/45/EC and statutory instrument No.716 2009 Chemicals (Hazard Information and Packaging) regulation)

2.2 Label elements:

There are no statutory labelling requirements under Directive 1999/45/EC as the mixture is not classified as harmful to humans or the environment

2.3 Other hazards:
None Known

Date of MSDS completion: 24-01-2011
Version: 2
Supersedes MSDS dated: 05-2009

Appendix 1: [cont.]

Biofence application

VG15010 Demonstration Report

The effect of custom made composts on the performance of a carrot crop and soil health

Francis Tedesco, Center West Exports, Justin Wolfgang C-Wise, Doris Blaesing, RMCG

August 2017

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Summary

A large-scale compost trial was conducted with Center West Export (CWE) and C-Wise in the Gingin area of WA.

The focus was on disease suppression, mainly cavity spot, and maintaining organic carbon and structure in intensively cropped, sandy soils. Fresh organic matter such as manure cannot be used in the Gingin area due to stable fly issues; food safety requirements also mean that fresh manure should not be used just prior to a carrot crop. Any organic amendments must be well composted; they also needed to be of a quality than can be repeatedly produced.

If that was not the case, i.e. compost quality would be variable from batch to batch, the information from this compost trial could not be relevant for other carrot crops on the farm.

Center West Exports provided a 10-ha trial area under solid set irrigation.

C-Wise provided two types of compost – "Humicarb Compost" and "Premium Compost". These were both used at 30 t/ha and 50 t/ha in 2 replicates of 0.5 ha each. Untreated control areas did not receive compost.

Both companies put in a considerable effort into setting the trail up and looking after it.

Data collection included:

- Soil analyses before and after planting (nutrients, pathogen DNA by SARDI)
- Pre-harvest assessment of roots against CWE grading criteria
- Carrot root analysis (nutrients)
- Commercial grading by CWE
- Field observations and photos

Trial results can be summarised as follows:

- Compost appears to have reduced soil levels of some Pythium and Rhizoctonia species / groups that can attack carrots.
- Compost increased phosphorus availability in the soil.
- Compost had no effect on soil pH.
- Nitrogen (nitrate and ammonium) carrot roots were lower in composted areas while levels of available soil nitrogen (nitrate and ammonium N) was higher in composted areas than in the control but not above the desirable level of <50 kg N/ha.
- In composted areas, carrots had higher potassium levels, up to double that of those in the control.
- The total concentration of nutrients in the carrot roots increased with increasing compost rates and compost quality.
- The compost had no significant effect on carrot yields in its first year.
- The improved nutritional status of the carrots may have had a beneficial effect on shelf life; however, this was not investigated as part of the trial.

RECOMMENDATIONS

Continue to observe the trials site to assess longer term effects of compost applications on carrot crops and economic benefits.

Investigate the costs and benefits of using lower, affordable rates, and or band placing compost to reduce initial costs.

General background

Property and location

Sun City Farms, Center West Exports, LOT 55 Croot Place, Woodridge WA 6041

Farm Management by Francis Tedesco.

Top 3 soil issues

Rank	Soil constrains	Reason for constrain
1	Soil borne diseases	Pythium (acidification/pH drop is a risk in connection with Pythium, need pH 6.5-7.)
2	Soil structure issues	Some compaction (subsoil), infiltration, drainage, water holding capacity – in some areas more than others
3	Loss of organic matter	Low organic matter (<1%) due to sandy soils and climate

Trial rational

Issues

- Land availability and cost/market price pressures do not allow for long rotations.
- A carrot crop will be grown on the same land at least once each year.
- The economically ideal gap between two crops would be 6 months (to fully utilise the factory and other resources).
- A quick brassica break crop plus chicken manure (Jarrah sawdust based) at about 7.5 m3/ha provided good 'soil rejuvenation' in the past; however, the stable fly issue and widespread P & N increase in groundwater led to a ban on using fresh chicken manure.
- Yellow Mustard (BQ Mulch?) biofumigation was tried but had its challenges: cost due to seed cost, need to irrigate up and maybe irrigate again and fertilise, especially at high seeding rate, (now using a fast growing fodder brassica); also tried field peas and Fumigator; Fumigator worked well in a couple of small scale trials but was a disaster in a 50 acre (20 ha) trial, planted at 25kg/ha, due to Pythium crop loss!
- Previous experience with “compost” to replace manure has not been good as the compost contained glass and other foreign matter, 'conditioned chicken manure' used in other crops is not suitable due to its content of large pine shavings and acidifying effect of pine wood.

- Metham Sodium is used strategically and not each year.
- Main Pythium control is achieved via: maintaining neutral to alkaline pH, good irrigation management, balanced nutrition especially adequate potassium (K) and not too much nitrogen (N).
- Some areas of paddocks and some soils are more prone to Pythium due to poorer drainage (texture / parent material related).

Criteria for new approaches by Center West Exports

- Fit with production imperatives
- Not too costly to implement and tying up labour and equipment and needing water, fertiliser and a lot of looking after, preferable decreased input costs, machinery use or labour
- Fit with time of year paddocks are harvested and replanted.
- Not acidifying soil
- No food safety risk
- More even water infiltration and drainage, no water logging
- Easy paddock preparation
- Even crop growth – root sizing to be more predictable and even, ideally increased marketable yield, pack out of high-grade product, or total yield
- Pythium management / reduction of soil inoculum, ideally reduced or no need to use Metham Sodium due to good soil health
- Maintaining organic carbon levels and soil condition / biology

High quality compost has been identified as one possible option of addressing the three above mentioned soil constrains, soil biology / Pythium, soil structure and loss of organic matter. It also meets or has the potential to meet (based on previous experiences on other sites) most criteria for new approaches listed above. The cost of compost (material, transport, application) could be an impediment.

Research questions

Do the benefits of using good, known quality compost justify the costs?

Do benefits occur ASAP after application, if not, when will they occur?

How long does a beneficial effect last?

Does any management input have to be adjusted (irrigation, nutrition)?

Trial details and methods

Main soil type and texture	Weakly leached siliceous sands represented by Karakatta, Spearwood, Cowalla and Battordal Soil Series formed in alluvial-lacustrine sediments. Brown weak clayey sand becoming yellow-brown with depth 200cm+. Associated with limestone, pH - neutral.[1]
Compost supply	C-Wise, 139 Nambeelup Rd, Nambeelup
Trial set up and data collection	Francis Tedesco, Center West and Justin Wolfgang, C-Wise
Data Analysis	Doris Blaesing, RMCG and Liam Southam-Rogers, AHR
Trial area	10 ha paddock under solid set irrigation
Individual plot area	0.5 ha
Rotation / previous land use	Field pea green crop
Soil preparation (depth)	Ripping (30 cm), Discing (30 cm), Rotary hoeing (20 cm)
Crop management	Standard across all treatments including the fertiliser program.
Irrigation scheduling across all treatments	Soil moisture probes and ETo used as guidance plus visual / tactile checks of soils
Compost spreading dates	9&10/6/16
Planting date	13/6/16
Pre-harvest assessment	17/11/16
Harvest date	20-24/11/16

Treatments

PLOT	TREATMENT	AMOUNT
Beds 22/32	Premium compost	*30 m^3/ha*
Beds 24/34	Premium compost	*50 m^3/ha*
Beds 26/36	Humicarb compost	*30 m^3/ha*

[1] Henry J. Smolinski and G G. Scholz 1997; Soil assessment of the west Gingin area. http://researchlibrary.agric.wa.gov.au/land_res/15/

PLOT	TREATMENT	AMOUNT
Beds 28/38	Humicarb compost	*50 m^3/ha*
12 Beds	no compost	control

Data collection

DNA Testing

Plant and soil sampling for DNA testing was conducted as per SARDI instructions ("Sampling for SARDI Soil DNA pathogen testing VEGETABLE CROPS").

1. Pre-plant soil DNA test (standard Predicta test prior to development of specific *Pythium sulcatum* and *P. violae* test) – SARDI

2. DNA test of soils and roots at harvest (standard Predicta test prior and specific *Pythium sulcatum* and *P. violae* test – test under development)

Site visits / observations

Regular site visits to check on crop development and take photos.

Plant sampling – nutrient analysis

At growth stage 4.8, just before harvest, 30 random carrot roots (subsamples) were collected across each treated and control block, the central section of each root was submitted for NU-test sap nutrient analysis. The purpose of this analysis was to determine differences in nutrient uptake as influenced by the compost treatments.

Soil sampling - nutrient analysis

10 random subsamples were taken to 30 cm depth across each treated block and control blocks, combined & mix well. The 10 subsamples from the 2 replicates blocks of each treatment made up one composite sample per treatment (= 3 soil samples). 500g of the mixed sample was submitted for soil analysis

Pre-harvest assessment

30 carrots per plot were hand harvested on 17/11/2016. During sampling, stems of some carrots snapped; these carrots were then not removed from the ground and a different one was chosen for sampling. This braking off of tops was most noticeable in control plots.

After sampling, carrot tops were removed, and roots washed. Carrots per sample were then assessed for weight, individual root diameters (Small: 28-35 mm, Medium: 35-45 mm, Large: >45mm) and defects (Pythium, less than 7.5 cm length or less than 28 mm diameter, splits, cracks, badly deformed roots); photos were taken of each sample.

Rejected carrots (roots with defects) were not measured and were excluded from size distribution and average carrot weight assessments. Most rejections were due to Pythium, either forking or cavity spot.

Factory Pack out

Each plot was harvested separately and graded in the factory applying the usual quality standards. They were graded into Small, Medium and Large carrots (Pre-packs, Small: 28-35 mm, Medium: 35-45 mm, Large: >45mm) and defects (Pythium, less than 7.5 cm length or less than 28 mm diameter, splits, cracks, badly deformed roots); weights recorded for each category.

Desktop research

Interpretation of findings were guided by findings from a literature review on Pythium species causing cavity spot and forking in carrots.

Findings & Discussion

Desktop research findings

The main Pythium species affecting carrots in Australia have been identified as *P. sulcatum* (in most cases) and *P. violae* (in some cases).

Factors affecting cavity spot development and survival

Dormant resting spores of Pythium species formed during pathogenic and/or saprophytic colonisation of plant tissues have long been identified as the primary sources of inoculum for succeeding crops.

P. sulcatum, which is the main pathogen causing cavity spot of carrot in Australia according to Davison and MacKay 1998 and 2000, appears to have a relatively restricted host range compared with *P. violae* (main cause of cavity spot in carrots in most other countries and identified in some part of Australia). Apart from carrots, *P. sulcatum* has been isolated from parsley (Plaats-Niterink 1981[2], Minchinton et al. 2006, 2007[3]), from parsnip (Minchinton et al. 2008) and in a very low frequency from spinach (McKay and Davison 2000).

Pythium spp. survive as resting spores between susceptible crops. *Pythium sulcatum* only infects carrots and closely related plants, it can survive for at least two years between carrot crops. Cavity spot caused by *Pythium sulcatum* is most severe in summer and autumn harvested crops,

Pythium violae has a much wider host range and can survive for at least five years between carrot crops. Cavity spot caused by *Pythium violae* is most severe in winter harvested crops.

Temperatures

The prime growth temperatures for *P sulcatum are:* minimum 2 to 3°C, optimum 20 to 28°C, and maximum 36 to 37°C. The optimum temperature for saprophytic growth of *P. sulcatum* (25 °C) is higher than that for *P. violae* (19 °C). 30 °C is a lethal temperature for *P. violae*[4].

2 Plaats-Niterink AJ van der (1981) Monograph of the genus *Pythium*. Studies in Mycology 21, 242pp.

3 Minchinton EM, Auer D, Martin H, Tesoriero L, Thomson F. Trapnell LN, Forsberg L, Nadesan S, Vujovic S (2006) Scoping study to investigate management of root-rot diseases in parsley. Report of Horticulture Australia Project VG04025, 87 pp.

Minchinton EM, Auer D, Martin H, Thomson F, Vujovic S (2007) Identification and management of parsley root rot. Report of Horticulture Australia Project VG06046.

4 Suffert F., M. Guibert. 2006. The ecology of a *Pythium* community in relation to the epidemiology of carrot cavity spot. Applied Soil Ecology 35 (2007) 488–501

This sensitivity to high temperatures may be a reason for the low number of *P. violae* detections in Australia. The relatively high optimum temperature for *P. sulcatum* may be one reason why it is not a predominant species causing carrot cavity spot in most Northern Hemisphere countries.

Soil moisture

High soil moisture supports greater *Pythium* infections; refer to comments under 'irrigation' in the next section (management approaches).

Management approaches

Varieties

Genetic tolerance to Pythium spp. varies however, there are currently no resistant varieties.

Chemical control

Metalaxyl can reduce the incidence and severity of cavity spot disease when applied at or shortly after seeding. However, if it is used too frequently it can lose its effectiveness because of an increase in its rate of breakdown in soil[5]. Bailey and Coffey (1985)[6] reported that metalaxyl had a half-life of 28 days in sandy soils due to biological degradation. It also leaches from sandy soils. P. *sulcatum* is considered by some researchers to be naturally tolerant of Metalaxyl[7]. However, the reason for this may be enhanced degradation with repeated use in some soils.

A UK study found a correlation between the half-life (degradation) of Metalaxyl and pH; the higher the pH, the faster the degradation. In Australia, [8]the half-life varied from less than 1 day to 43 days, compared with a published value of 70 days. Enhanced breakdown of metalaxyl appears to be a widespread problem.

Metham sodium has failed to control cavity spot[9] in trials in WA. Still, is used commercially in Australia to control the disease.

Soil pH

In WA, it has been shown that liming soil to increase pH reduces the incidence and severity of cavity spot[10]. The recommended range is pH 6.5-7.5 with a target pH of 7.2 or higher (measured in calcium chloride)[11]. The effect of lime (calcium carbonate) may be due to inducing a soil microflora that is inhibitory to filamentous fungi like Pythium. However, this is not confirmed. The application of lime may also be beneficial in the longer term via increased calcium availability.

5 Davison, E.M. and McKay, A.G. (1999). Reduced persistence of metalaxyl in soil associated with its failure to control cavity spot of carrots. Plant Pathology 48, 830-835.

6 Bailey AM, Coffey MD, (1985) Biodegradation of metalaxyl in avocado soils. Phytopathology 75, 135–137.

7 Minchinton E. et al. 2012. Identification of IPM strategies for *Pythium* induced root rots in Apiaceae vegetable crops. Final report for VG08026.

8 Davison, E.M. and McKay, A.G. 2001. Integrated management of *Pythium* diseases of carrots. Final Report for VG98011

9 Davison E.M. and McKay A.G. 2000. Cavity spot in Australia. Agriculture Western Australia. Proceedings of the Carrot conference Australia, Perth 2000.

10 Galati, A. and McKay, A.G. (1996). Carrot yield decline. Final Report HRDC Project VG036.

11 Davison, E.M. and McKay, A.G. (1999). Cavity spot disease of carrots. Farmnote 29/99, Agriculture Western Australia.

Nutrition

UK research found that increasing the level of exchangeable calcium above 8 meq/100 g soil decreased the incidence of cavity spot.[12] High inputs of available calcium pre-planting (e.g. 15 t/ha as Limex) also decreased cavity spot incidence. In both cases, *P. violae* was the target organism.

According to the review by Minchinton et al. (2012), reports on the effects of nutrition on cavity spot vary. She concludes: "In general, there do not appear to be any clear cut or consistent relationships between soil nutrition, plant nutrition or other soil factors (conductivity, moisture holding capacity, organic matter, total and exchangeable calcium and particle size distribution) reported. The reason for this may be that in experiments involving nutrients researchers often try to test the effect of a certain nutrient on the disease, rather than comparing a well-balanced, site specific nutrition program (and overall crop management) with practices that lead to imbalances, oversupply or shortages.

Irrigation

Previous work on a *Pythium* species showed that cyclic wetting and drying reduced *Pythium* populations in the field[13]. Observations by growers confirm that high soil moisture levels support the development of cavity spot. However, a threshold soil moisture tension/ water potential and the length of time at a certain tension/potential is required to cause infection with *P. sulcatum* or *P. violae* has not been found. Literature recommendation talk about minimising total water inputs e.g. < 30 mm/wk. However, when using fungicides early in the season, at least 15 mm were required to get the fungus to grow rapidly at the time of application to achieve good control (UK). The assumption is that soil moisture above field capacity may be too high. However, the level of oxygen in the soil may be an important factor. This may mean that a clay soil or a compacted soil (soil with a lack of fast draining pores) may not supply sufficient oxygen to the rootzone, even at field capacity.

Rotation

Rotation with broccoli has shown promising results in WA. However, *P. violae* can attack broccoli[14] and using this as a rotational crop may exacerbate cavity spot where *P. violae* is present. When P. *sulcatum* is present rotation with broccoli, lettuce or onions is mentioned as beneficial. For P. *violae*, rotation with onions, corn, potatoes or beans are mentioned. Views on the positive effect of rotation in publications differ.

> *"Severe cavity spot caused by Pythium violae and P. sulcatum may develop on carrots grown in newly cleared land or cultivated fields where umbelliferous crops have never been grown. Conversely, fields where carrot has been cultivated repeatedly may have no history of cavity spot. Fields known to produce carrots infected with cavity spot may not show disease from one year to the next depending on environmental conditions.*
> *Crop rotation is not recommended because there is no relationship between cropping history and cavity spot severity nor any evidence that rotation will reduce cavity spot. Carrot should not be planted in soils with a high clay content.*
> *While no direct relationship between soil nutrients and cavity spot has been shown, decreasing the level of chemical fertilizers applied to a field has been observed to reduce the severity of cavity spot."*
>
> (from: Howard R.J., J. A. Garland, W. L. Seaman (Editors). 1994. Diseases and Pests of Vegetable Crops in Canada: an illustrated compendium. Co-published by: Entomological Society of Canada).

13 Stanghellini ME, Burr TJ (1973) Effect of soil water potential on disease incidence and oospore germination of *Pythium* aphanidermatum. Phytopathology 63, 1496–1498.

14 Schrandt, J.K., Davis, R.M. and Nuñez, J.J.(1994). Host range and influence of nutrition, temperature and pH on growth of *Pythium violae* from carrot. Plant Disease 78, 335-338.

Cover crops/biofumigation

Reports on the benefits of cover crops and biofumigants vary. In some instances, good control or reduction of disease incidence were achieved, especially with mustards, in other trials and field experiments by growers, cavity spot incidence or severity were not altered or the disease was even worse. It appears that biofumigation or cover crops may not reduce inoculum levels, even in cases where disease expression is reduced. The conclusion is that the effect of cover crops on *Pythium sulcatum* and *P. violae* is not well enough understood to make recommendations.

Other

Crop hygiene, selection of planting date and crop density, tillage to ensure good drainage, crop residue management, and timely harvest are some cultural practices to reduce the impact of root diseases.

Some ICP strategies that may help reducing the likelihood of infection in combination with other management practices listed above are: Bacillus subtilis and other biocides[15], Calcium Cyanamide or use of silicon (to induce a defense reaction). So far reports on the efficacy of integrated approaches vary.

Conclusions

While some general rules apply, especially the need for managing soil moisture, pH soil calcium and crop maturity, carrot producers will have to find their own optimum combination of additional management strategies that fit their production system and growing conditions.

Disease prediction

A substantial research effort has been made to predict *Pythium* inoculum levels in vegetable crops, including carrots. Most research had a focus on identifying threshold levels of inoculum rather than identifying conditions (temperature, soil moisture, soil (solution?) nutrient levels, level of other diseases or pests) that cause infections to occur in different commercial production systems.

SARDI is working on the development of a DNA probe for *P. sulcatum* and *P. violae*. Once these have been developed and tested, the next step is to understand the relationship between inoculum levels and production factors, both environmental and production factors.

Compost trial findings and discussion

Weather conditions during the trial

15 Seaman, Abby, Editor. (2015) Production Guide for Organic Carrots for Processing. Publisher: New York State Integrated Pest Management Program, Cornell University (New York State Agricultural Experiment Station, Geneva, NY).

2016 weather data was compared to long term averages (GinGin Aerodrome). Below tables show that temperatures for the months July to October consistently were below the longer-term average (average). September was especially cold with all temperature indicators around 2 (°C) below the average. In November, temperatures, apart from the mean minimum, were higher than average.

Month	Mean minimum temperature (°C) 2016	Mean minimum temperature (°C) 21 yr average	Mean maximum temperature (°C) 2016	Mean maximum temperature (°C) 21 yr average
Jul	6.0	6.2	17.6	18.3
Aug	6.1	6.5	17.6	19.1
Sept	**5.3**	7.4	**18.8**	20.6
Oct	8.1	9.2	22.7	24.4
Nov	10.6	12	29.2	28

Month	Mean 9am Temperature (°C) 2016	Mean 9am Temperature (°C) 14 yr average	Mean 3pm Temperature (°C) 2016	Mean 3pm Temperature (°C) 14 yr average
Jul	11.1	12	16.5	17.1
Aug	11.8	12.8	16.2	17.6
Sept	**13.2**	15.1	**17.2**	18.9
Oct	17.4	17.9	20.9	22.1
Nov	22.4	21.1	26.5	25.6

Below table shows that rainfall was above average for July, August and October, but below average for September and November. Total rainfall for the 5 months was about 29 mm (7.2% above average).

Month	Monthly rainfall (mm) 2016	Mean monthly rainfall (mm) 18 yr average	2016 rainy days >1 mm	Mean number of days of rain ≥ 1 mm
Jul	145	125.8	10	13
Aug	153.2	107.3	14	12.1
Sept	47.4	83.2	6	10.5
Oct	49	35.6	11	5.5
Nov	5.6	19.6	2	3.6
Total	**400.2**	**371.5**	**43**	**44.7**

August was especially wet and quite cold while September was especially cold but not wet.

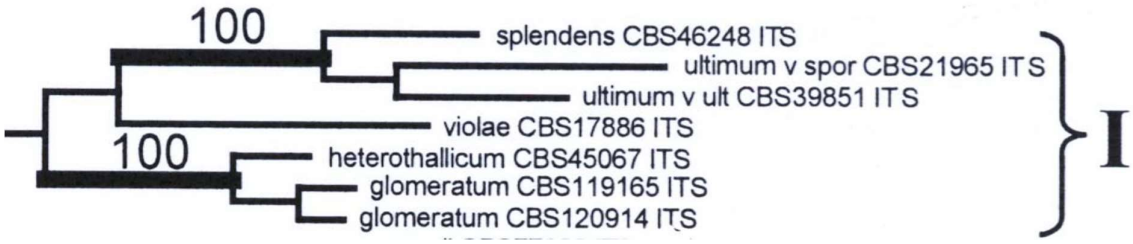
The weather conditions led to a slower than normal development of the crop.

Pre-plant soil DNA

At the time of planting, a specific test for *P. sucatum* or *P. violae* was not yet available. SARDI offered a general horticultural soil test. The interpretation of results for carrots must be done with caution because the use of DNA test for carrots is in the very early development stage.

The standard Predict B test (SARDI) produced the following results, which may be relevant:

1. 1 pg DNA/g soil of *Pythium* Clade I – this may be an overall low level



Above: Clade I *Pythium* species - No obvious common morphological characters in this clade. Most species do not produce zoospores.

2. 15 pg DNA/g soil of Rhizoctonia solani AG4

This anastomosis group (AG) can cause crown rot and cavity spot like symptoms in carrots. We do not know whether the level found poses a commercial risk to carrot crops.

Observations

Visual assessments of carrots on 21/08/16 and 19/9/16 showed little difference between treatments. The addition of compost appeared to have led to carrots developing more fine roots than in the control. However, without root length measurements a definite statement cannot be made.

Pre-harvest assessments

The below table shows treatment averages for carrot root weight, percentage of weight difference to the control and the percentage of defects. Defects consisted mainly of forking and cavity spot.

Treatment	Mean root weight (g)	*Mean % weight difference from control*	Mean defect rate (%)
30 t/ha Humicarb compost	**131**	***5.7***	**0.0%**
50 t/ha Humicarb compost	**129**	***4.1***	**6.7%**
30 t/ha Premium compost	120	*-3.1*	8.0%
50 t/ha Premium compost	120	*-2.7*	8.7%
Control	124		**6.3%**

The Humicarb compost treatment produced slightly higher root weights and a lower defect rate compared to the Premium compost.

The next table shows the averaged size distributions for the pre-harvest carrot samples.

Treatment	Small (28-35mm)	Medium (35-45mm)	Large (>45mm)
30 t/ha Humicarb compost	7.1%	**73.7%**	19.2%
50 t/ha Humicarb compost	5.5%	**78.5%**	16.0%
30 t/ha Premium compost	**8.8%**	71.4%	19.8%
50 t/ha Premium compost	**15.1%**	67.5%	17.4%
Control	7.9%	74.0%	18.1%

The Humicarb compost treatment produced slightly more medium size carrots and less small carrots compared to the Premium compost.

Commercial harvest results

The next table shows the results from the commercial harvest.

Treatment	Yield (t/ha)	Defect rate (%)	Pack out Rate (%)
30 t/ha Humicarb compost	42.1	20%	80%
50 t/ha Humicarb compost	41.6	21%	79%
30 t/ha Premium compost	42.2	**25%**	**75%**
50 t/ha Premium compost	41.0	**22%**	**78%**
Control	42.9	21%	79%

The control and Humicarb compost had slightly higher pack out rates than the Premium compost treatments. The control had the overall highest yield but differences to other treatments were not significant. The defect rate was slightly higher in the Premium compost treatments.

The size distribution of carrots obtained from the commercial packing operation is shown in the following table:

Treatment	Prepack	Small (28-35mm)	TOTAL < 35mm	Medium (35-45mm)	Large (>45mm)
30 t/ha Humicarb compost	12%	**60%**	**72%**	24%	3%
50 t/ha Humicarb compost	12%	**62%**	**74%**	23%	3%
30 t/ha Premium compost	**19%**	51%	**70%**	24%	5%
50 t/ha Premium compost	**19%**	48%	**67%**	25%	3%
Control	15%	58%	**73%**	24%	3%

The commercial pack out showed that most carrots were in the < 35 mm range (prepacks and smalls) while the pre-harvest assessment had most roots in the medium range.

In the factory pack out, the Humicarb compost and untreated control produced a slightly greater amount of carrots in the < 35 mm range than the Premium compost treatment. This compares to the medium size carrot pack out in the pre-harvest assessment. The percentage of medium and large carrots packed out were about the same in each treatment.

Soil and plant testing at harvest

Post-harvest soil DNA test

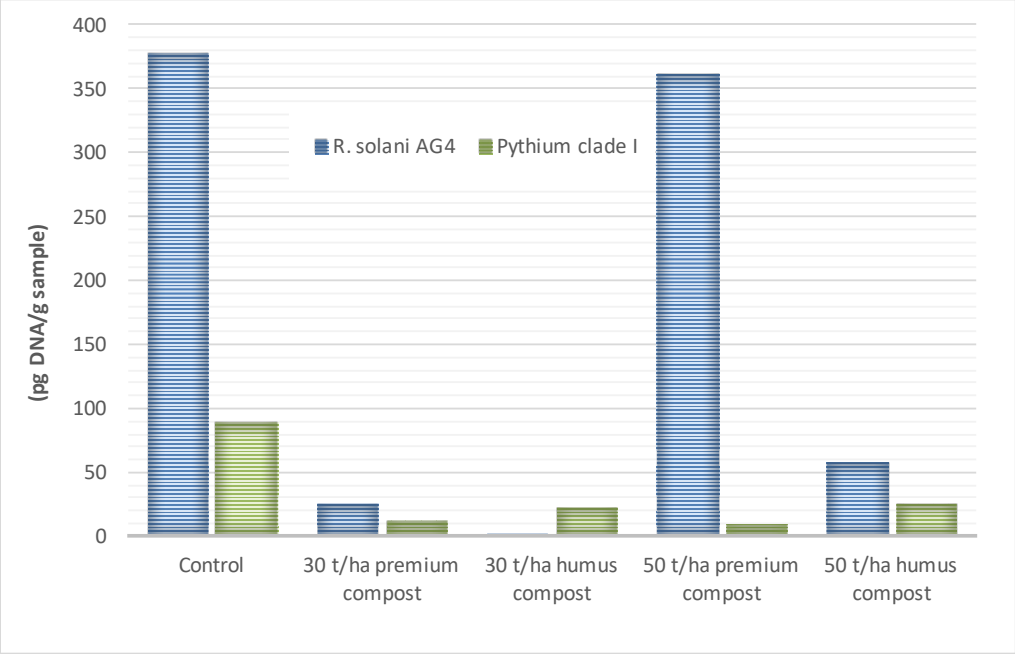
At the time of harvest, SARDI's specific test for *P. sucatum* or *P. violae* was available as a research tool. The interpretation of results is tentative because the use of DNA testing for carrots is in the very early development stage and the specific *Pythium* tests need further research.

The soil DNA test did not detect nematodes or other pathogens than the ones discussed below.

Below graph illustrates post-harvest findings of pathogen DNA in the soil (pg = pico gram).

Rhizoctonia solani AG4 levels increased during the growth of the crop from a starting point of 15 pg/g soil sample. The increase was greatest in the control and the 50 t/ha Premium compost treatment. It is not clear why the 50 t/ha treatment had similar levels to the control. This treatment had the highest defect rate and a low average root weight in the pre-harvest assessment. It also had the highest level of small roots and second highest defect rate (after the 30 t/ha Premium compost treatment) in the commercial harvest assessment.

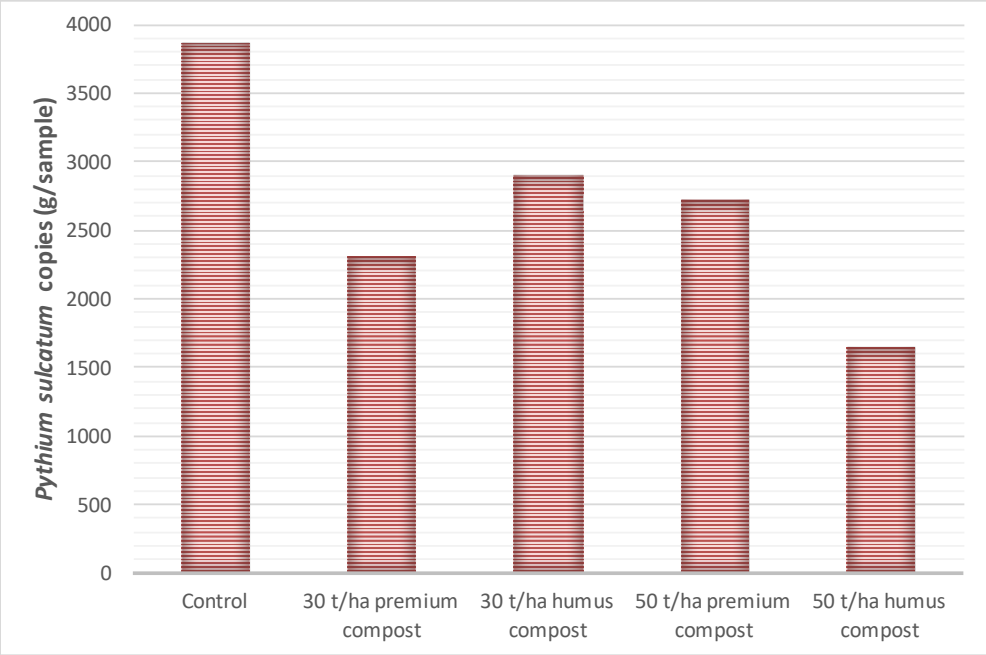
Pythium clade 1 levels also increased in the soil during crop growth. The increase was substantially higher in the control plots than in the compost treated plots. Overall, the 30 t/ha Humicarb treatment had the lowest level of pathogens.



Humus compost = C-Wise Humicarb, premium compost = C-Wise Premium compost

The next graph shows *Pythium sulcatum* counts as copies/g sample. *P. violae* was not detected. Again, the control treatment had the greatest *Pythium* level of this species.

These are results obtained as part of a SARDI led Hort Innovation R&D project VG. They are first indications only as the research is still in its early stages.



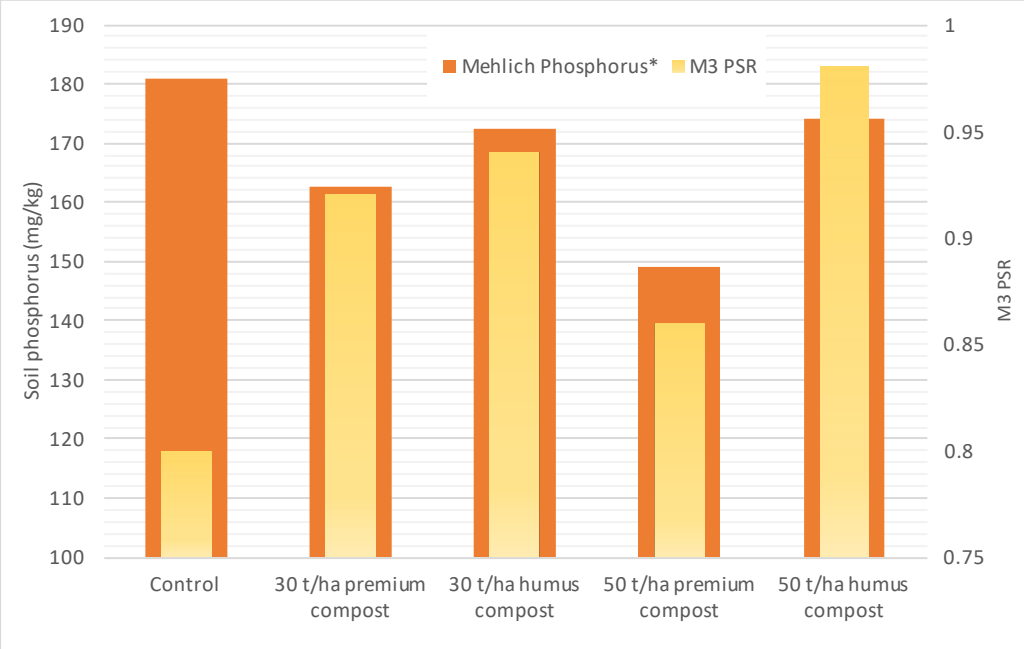
Humus compost = C-Wise Humicarb, premium compost = C-Wise Premium compost

Soil nutrient levels at harvest

The following graphs illustrate treatment differences in soil nutrient levels shortly after harvest.

The first graph shows treatment differences in soil phosphorus (P) levels, both, the concentration (mg/kg) obtained via a Mehlich 3 extraction, and an indicator for the potential P availability (for plant uptake) in the soil solution.

Soil P was quite high in all treatments. Availability was highest in the 50 t/ha Humicarb compost treatment. The type of organic matter and its effect on soil microbial activity influences P availability to plants. It is generally accepted that the level of microbial activity can have an impact on P availability.



Humus compost = C-Wise Humicarb, premium compost = C-Wise Premium compost

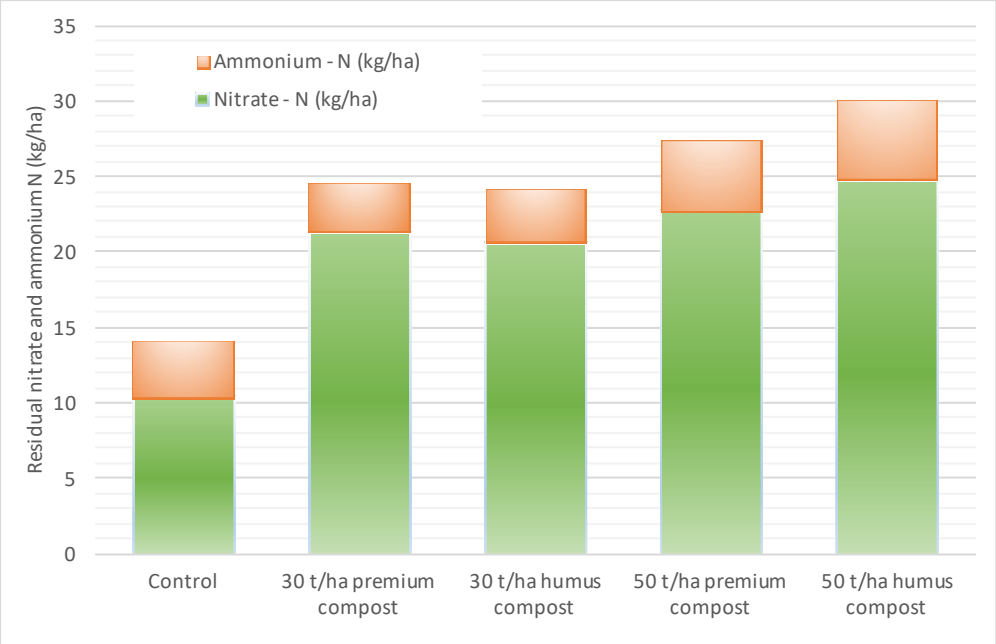
The following graph shows levels of residual nitrogen in the topsoil after harvest. All levels are relatively low, reflecting the careful management of nitrogen inputs to the carrot crop to avoid excess top growth and short tap roots.

After carrot production, residual soil nitrogen levels of about 30 kg/ha are a good level to aim at. On heavier soils, residual levels of up to 50 kg/ha are acceptable.

The below graph illustrates that the addition of compost to the soil resulted in higher residual available nitrogen levels in the topsoil, compared to the control treatment. The trend shows that higher inputs, here 50 t/ha, can lead to higher residual N levels.

Quality compost, if not used excessively, releases nitrogen slowly via microbial activity; it also improves nitrogen cycling while preventing leaching.

Research and field experience has shown that the positive effect of compost on nutrient cycling and availability will continue for more than one season (refer to the Vegetables WA Good Practice Guide).



Humus compost = C-Wise Humicarb, premium compost = C-Wise Premium compost

Nutrients in carrots at harvest

This section presents and discusses treatment differences in carrot root sap. Nutrient levels were tested shortly after harvest using NU-test technology.

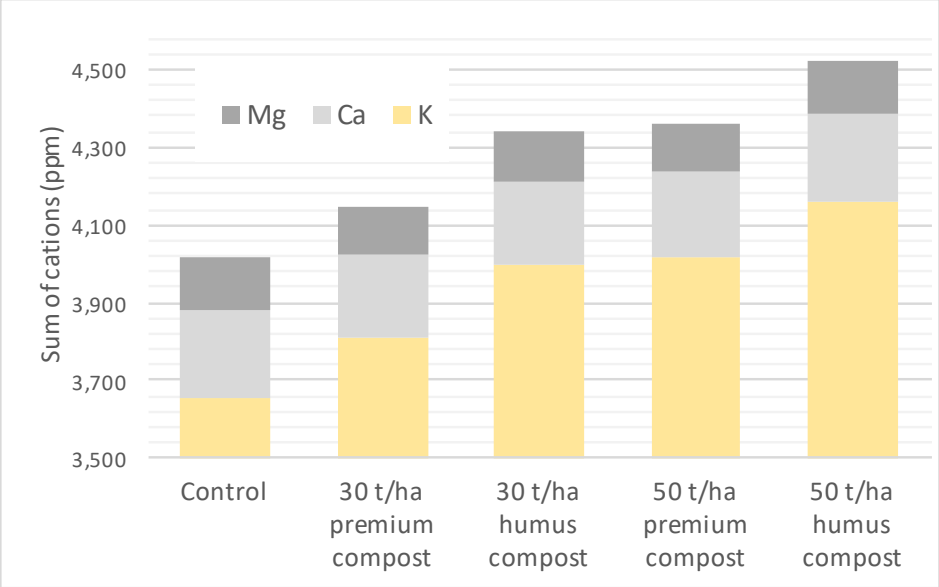
The levels of the three cations potassium (K), calcium (Ca) and magnesium (Mg) are presented in the below graph. All compost treatments led to higher levels of potassium than the control. The highest level (4157.5 ppm) was found in the 50t/ha Humicarb compost treatment; the lowest level was in the control (3566.5 ppm), a 12% difference.

Potassium is important for regulating water loss, cell growth and sugar development.

Calcium (Ca) and magnesium (Mg) levels did not differ much across treatments. The highest levels of both cations occurred in the 50 t/ha Humicarb compost treatment, followed by the control.

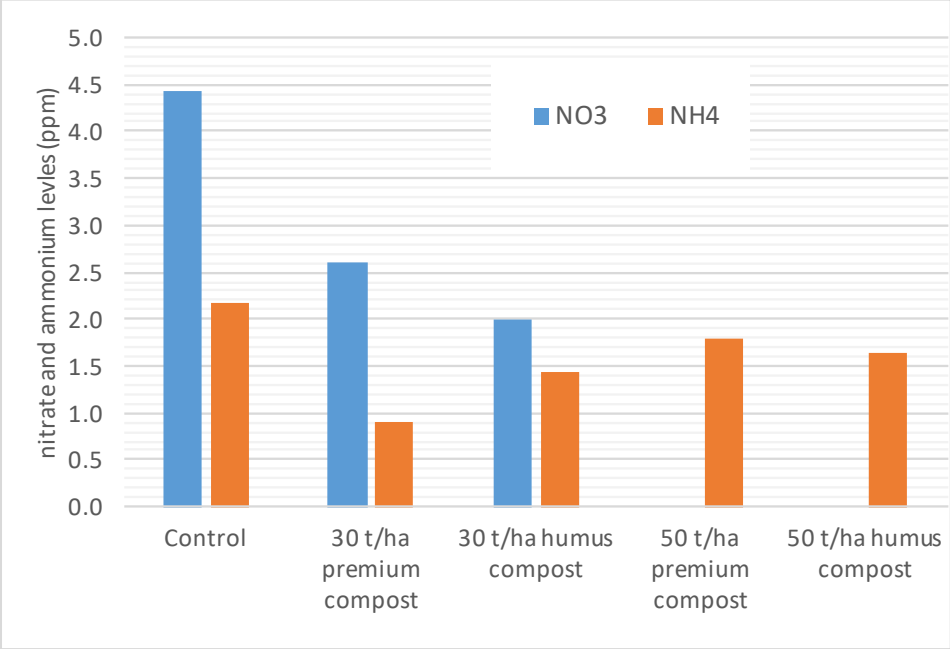
The second graph shows that carrot root nitrogen levels, measured as nitrate and ammonium were overall low, reflecting the careful nitrogen management of the crop. The control had the highest levels of both N forms in the root, while the residual soil levels were low, as presented previously.

The higher compost inputs resulted in the lowest overall nitrogen uptake into carrot roots around the time of harvest, while soil levels were higher than those in the control. Nitrogen dynamics in carrot crops following the addition of compost need to be further investigated to understand why carrots grown in soil with compost amendment accumulate less nitrogen.



Humus compost = C-Wise Humicarb, premium compost = C-Wise Premium compost

High soil ammonium levels may lead to a higher risk of cavity spot[16]. The fact that ammonium reduces soil pH during conversion to nitrate may play a role in this. However, the trial does not provide supporting information for this idea.



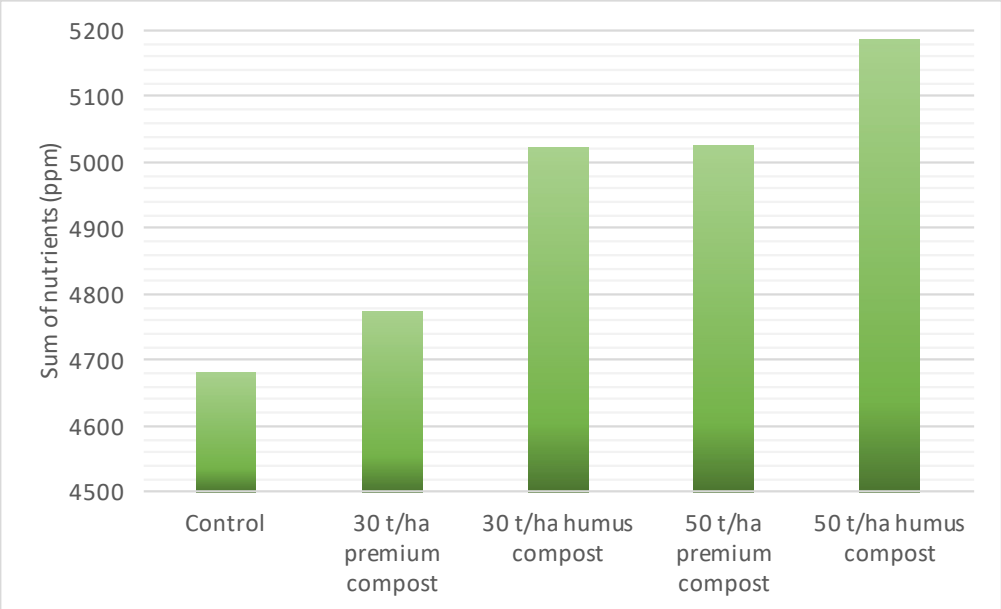
[16] Scaife M. A. et al. 1980. Cavity spot of carrots - an association with soil ammonium Communications In Soil Science And Plant Analysis Vol. 11, Iss. 6,1980

Humus compost = C-Wise Humicarb, premium compost = C-Wise Premium compost

We did not find major differences in the levels of other nutrients i.e. phosphorus (P), sulphur (S) and trace elements in carrot roots.

Sodium levels were high in all treatments and the control had the highest 'salinity level' (Na ppm plus Cl ppm). The higher salinity in the control and the higher overall nutrient level in the 50 t/ha Humicarb compost treatment may be the reason for both treatments having the highest brix levels compared to the other treatments (9.3 and 9.4 respectively compared to 9.1 for the 30 t/ha Premium compost and 9.0 for the other two treatments).

The last graph illustrates the total concentration of nutrients in the extracted carrot sap. Nutrient uptake, when measured around the time of harvest, was the highest in the 50 t/ha Humicarb compost treatment. Knowledge from other crops suggest that a high nutrient concentration may have a positive effect on flavour and storage life. However, this aspect was not investigated in this trial.



Humus compost = C-Wise Humicarb, premium compost = C-Wise Premium compost

Answers to research questions

Do the benefits of using good, known quality compost justify the costs?

This will be the next assessment step. However, economic benefits of compost need to be looked at over at least a 3 period. The trial site will be monitored over the coming years.

Do benefits occur ASAP after application, if not, when will they occur?

Benefits in year 1 were the improved nutrient status of the carrot roots and a decline in some diseases that attack carrots.

How long does a beneficial effect last?

This will be investigated.

Do any management inputs must be adjusted (irrigation, nutrition)?

Yes, nutrient and irrigation monitoring of the crop can help to fine-tune inputs.

Does the trial fit with the criteria for new approaches on the farm?

PRODUCTION IMPERATIVES	
Not too costly to implement and tying up labour and equipment preferable decreased machinery use or labour	*No, cost where high if looking at 1 year only*
Not too costly through needing water, fertiliser and a lot of looking after, preferable decreased input costs	*Yes*
Fit with time of year paddocks are harvested and replanted.	*Yes*
Not acidifying soil	*Yes*
No food safety risk	*Yes*
More even water infiltration and drainage, no water logging	*Yes*
Easy paddock preparation	*Yes, if no counting spreading*
Even crop growth – root sizing to be more predictable and even, ideally increased marketable yield, pack out of high-grade product, or total yield	*Need more data over the coming years*
Pythium management / reduction of soil inoculum, ideally reduced or no need to use Metham Sodium due to good soil health	*Potentially, Need more data over the coming years*
Maintaining organic carbon levels and soil condition / biology	*Yes*

SoilWealth
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VG15010 Demonstration Report

Can calcium cyanamide (CaCN2) fertiliser affect Pythium spp and other soilborne diseases in carrots – findings of an on-farm demonstration

Doris Blaesing

May 2017

RMCG

ahr applied horticultural research

Hort Innovation Strategic levy investment | VEGETABLE FUND

This project has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

VG 15010 A multi-faceted approach to soilborne disease management

'A multi-faceted approach to soilborne disease management' (Project VG15010) *is a three-year project (2015-2018) providing Australian vegetable growers with the tools and resources they need to manage the risk of crop losses due to soil-borne diseases.*

VG15010 delivers new information and resources about soilborne diseases to the vegetable industry through the established Soil Wealth and Integrated Crop Protection framework.

This project is a strategic levy investment under the Hort Innovation Vegetable Fund.

Disclaimer:

1 Contents

Summary

Calcium Cyanamide ($CaCN_2$) Fertiliser was tested for efficacy against *Pythium sulcatum* and *P. violae* in a grower led demonstration trial in a commercial carrot crop in Western Australia. The wax coated fertiliser was applied according to manufacturer's instructions at 300 kg/ha and 500 kg/ha of fertiliser to one full length carrot bed each. An untreated bed adjacent to each treated bed was used as control. All standard commercial crop management inputs were applied consistently to treated and control beds. This included nitrogen fertilisers.

Assessments included post-harvest soil testing for available nitrate and ammonium (N-check®), soil and root peel DNA testing for soilborne pathogens by the South Australian Research and Development Institute (SARDI). The SARDI DNA tests for *Pythium sulcatum* and *P. violae* were under development at the time of testing.

Carrots from treated and the two control beds were harvested separately by machine and graded in a commercial factory using typical sizing and quality standards.

The pack out figures showed that total fresh yields in the $CaCN_2$ treated beds were higher than in untreated beds; on average by 15.4% for the 300 kg/ha and 18.7% for the 500 kg/ha treatment. The greatest difference was in the weight of processing carrots. One reason for the higher weight of processing carrots may have been the impact the additional nitrogen from the $CaCN_2$ fertiliser that became available early in the season. While it reduced root length it may have had an impact on the timing of bulking and thus final root weight at harvest. Oversized carrots are used for processing.

Calcium cyanamide fertiliser contains 19.8 % N. An application of 300 kg/ha supplies 59.4 kg N/ha, 500 kg/ha supply 99 kg N/ha. The effect of additional nitrogen was observed early in the crop as typically shorter roots and lusher tops compared to untreated controls. Despite the differences in nitrogen inputs, the treated and control beds showed no differences in available nitrogen measured just before harvest.

DNA testing results from root and soil samples suggested that cavity spot symptoms seen on carrots after harvest may be mainly caused by *Pythium sulcatum*. Both DNA tests implied that $CaCN_2$ fertiliser may have reduced the *Pythium sulcatum* soil inoculum, the main pathogen causing cavity spot in carrots in Australia.

Take away messages: In research trials with $CaCN_2$ fertiliser, soil N dynamics and plant biomass production (root and shoot) should be included in assessments. If $CaCN_2$ fertiliser is used commercially the N mineralisation from the product must be considered in the crop's N budget and application schedule.

Replicated trials, including proven DNA testing for *Pythium sulcatum* and *P. violae* should be conducted to confirm the efficacy of Calcium Cyanamide Fertiliser on these diseases. If efficacy is confirmed, commercial use options for carrot crops under different production conditions should be investigated.

Introduction

This report presents findings from a grower led, on-farm demonstration trial. Grower led pilot trials provide preliminary feasibility assessments of new practices. They can lead to on farm adaptation of practices and or replicated research trials to rigorously test assumptions made because of initial findings.

Metabolism of calcium cyanamide in the soil

Calcium Cyanamide fertiliser is wax coated to prevent dust development[1]. In principle, it is a nitrogen fertiliser. Within hours after application to moist soil, hydrogen cyanamide is formed which disperses with the soil water. Hydrogen cyanamide is phytotoxic, hence the herbicidal effects and the required withholding periods before planting. It has strong fungicidal properties and thus can inhibit growth and sporulation of many pathogenic fungi. Calcium dihydroxide, which has liming effect, is a further immediate breakdown product.

Hydrogen cyanamide completely breaks down in soils within 7 to 14 days. This leads to the formation of urea and, to a certain extent, dicyandiamide, which is known as a nitrification inhibitor. Urea eventually converts to ammonium. The dicyandiamide delays the nitrification of ammonium to nitrate, which easily leaches or is lost as nitrous oxide under wet conditions. In combination with the liming effect of the calcium dihydroxide the nitrogen is kept in the less leachable ammonium form for some time. The same as ammonium from other sources, the ammonium from calcium cyanamide can be taken up by plants and microorganisms, or temporarily fixed to clay minerals (source: https://www.alzchem.com/en/agriculture/calcium-cyanamide-perlka/effect).

Influence of calcium cyanamide on Pythium spp.

Many studies have demonstrated the efficacy of Calcium Cyanamide Fertiliser in controlling diseases caused by soilborne fungi in many host/pathogen systems. In several studies, the addition of compost or soil solarisation provided added benefits. Reports about the effectiveness of Calcium Cyanamide fertiliser on *Pythium* spp. differ. Some trials achieved good control, others little to no control. These differences in trial results may have been due to the following factors: application rates used, the way the product was applied and incorporated, timing of application and subsequent planting, environmental production conditions or level of disease pressure.

[1] Unrefined, industrial grades of calcium cyanamide are not formulated for the safe use as fertiliser on soils and crops; they are not wax coated to suppress dust development. The dust may be a risk to work place safety. It may contain free, carcinogenic carbide, and potentially further toxic substances. Industrial grade products may also lead to crop losses and soil contamination.

Calcium cyanamide fertiliser use in carrots

ITEM	MANAGEMENT
Application for carrots	Recommended by manufacturer: 300-400 kg/ha 2-3 weeks before sowing
Soil moisture at application	Just below or at field capacity
Incorporation depth & method	Normal cultivation depth, can be applied to the top of soil but then N losses may occur and the effect on diseases and weeds lessened
Withholding time before seeding & impact of soil organic matter level	Rule of thumb: at least 2 – 3 days per 100 kg/ha Use the longer withholding periods in light soils and soil with low organic matter levels
Soil moisture at & after application	Conversion from calcium cyanamide to urea and then ammonium will only happen when soil conditions are moist i.e. just below or at field capacity. Conversion usually takes: 6 – 9 days for 300 kg/ha Calcium cyanamide 8 – 12 days for 400 kg/ha Calcium cyanamide 10 – 15 days for 500 kg/ha Calcium cyanamide Soil must be kept moist to incorporation depth during the conversion time. If the crop is sown after more days than it takes to convert it (e.g. 2 weeks), keep soil moist for the duration of conversion only.
Adjacent crop safety	If there are crops close by that are in a sensitive development stage (e.g. establishment to 5 leaf for carrots) ensure that calcium cyanamide dust does not affect them
N fertiliser program (needs adjusting)	As with any N-fertiliser the application rate of calcium cyanamide may depend on the nitrogen requirements of the crop and the nitrogen supply from the soil (residual N from crops or cover crops and mineralisation from organic matter)
Liming	Needs adjusting given Calcium cyanamide has a liming effect

ITEM	MANAGEMENT
Environmental	Even where chemical pesticides must be omitted in part or entirely, calcium cyanamide may still be used to take advantage of its phytosanitary effects in addition to its effect as fertiliser In light soils, N may be washed through the rootzone – monitoring recommended

(source of information https:// www.alzchem.com/en/ agriculture/calcium- cyanamide-perlka)

Demonstration trial questions

The trial was to provide preliminary information on the following questions. If results were encouraging, the plan was to conduct a fully replicated follow up R&D trial.

1. Could calcium cyanamide reduce cavity spot / forking incidence and severity caused by *Pythium* spp. in carrots?
2. Could calcium cyanamide reduce *Pythium* spp. inoculum?
3. Should nutrient inputs be adjusted when using calcium cyanamide fertiliser (especially nitrogen nutrition)?
4. How long would a beneficial effect last?
5. Would economics stack up?

Site details and methods

Property and location

Sun City Farms, Center West Exports, LOT 55 Croot Place, Woodridge WA 6041, Farm and trial Management by Francis Tedesco.

- Background
- Land availability and cost/market price pressures do not allow for long rotations; therefore, a carrot crop will be grown on the same land at least once each year.
- The economically ideal gap between two crops would be 6 months (to fully utilise the factory and other resources).
- Metham Sodium fumigation is used strategically and not every year. Reducing the use of fumigation is desirable.
- Largely, satisfactory *Pythium* control is achieved via: maintaining neutral to alkaline pH, good soil moisture management, balanced nutrition, especially adequate potassium (K) inputs and carefully managing nitrogen (N) available to the crop,

keeping it adequate but low.

Some areas of paddocks and some soils are more prone to *Pythium* due to texture / parent material related poorer drainage.

Main soil type and texture	Weakly leached siliceous sands represented by Karakatta, Spearwood, Cowalla and Battordal Soil Series formed in alluvial-lacustrine sediments. Brown weak clayey sand becoming yellow-brown with depth 200cm+. Associated with limestone, pH – neutral.[2]
Trial set up and sampling	Francis Tedesco, Center West and Justin Wolfgang, C-Wise
Soil DNA testing	Michel Rettke, SARDI
Interpretation of findings	Doris Blaesing, RMCG and Michel Rettke, SARDI
Trial plot area	1 standard bed per treatment
Soil preparation (depth)	Ripping (30 cm), Discing (30 cm), Rotary hoeing (20 cm)
Crop management	Standard across all treatments including fertiliser and irrigation programs
Irrigation scheduling across all treatments	Soil moisture probes and Et_o used as guidance plus visual / tactile checks of soils
Application of wax coated calcium cyanamide fertiliser	4 weeks before sowing
Sowing	July 16
Harvest	December 16

[2] Henry J. Smolinski and G G. Scholz 1997; Soil assessment of the west Gingin area. http://researchlibrary.agric.wa.gov.au/land_res/15/

Chemical properties of Wax Coated Calcium Cyanamide fertiliser

PROPERTY	DETAIL
Total nitrogen	19.8%
Nitrate nitrogen	1.8%
Cyanamide nitrogen	> 15%
Dicyandiamide nitrogen	approx. 0.5%
Neutralising value (CaO)	> 50%

Treatments

PLOT	TREATMENT	AMOUNT
1	Control 1	0 kg/ha CaCN2
2	Calcium Cyanamide	500 kg/ha CaCN2
3	Control 2	0 kg/ha CaCN2
4	Calcium Cyanamide	300 kg/ha CaCN2

Data collection

Site visits / observations

- Regular site visits and observation of crop development and soil moisture by the farm manager to check on crop development.

Soil analysis

- One week before harvest, 10 random subsamples were taken to 20 cm depth across each treated block and control blocks, combined and mixed well. Then, 500g of each mixed sample was submitted to AgVita Analytical for N-check® soil analysis (for available nitrate and ammonium).

DNA testing

- Carrot root (peel) and soil sampling for DNA testing was conducted at harvest (06/12/2016) as per instructions provided by SARDI (“Sampling for SARDI Soil DNA pathogen testing VEGETABLE CROPS”).

- DNA test of soils and root peel at harvest (standard Predicta test plus specific *Pythium*
- *sulcatum* and *P. violae* test – the *P. sulcatum* & *violae* tests were under development at the time of testing)

Factory Pack out

- Each plot (entire bed) was harvested separately in early December 2016 and graded over the commercial grading line applying commercial quality standards. Carrots were graded into the following classes: Pre-packs, Small: 28-35 mm, Medium: 35-45 mm, Large: >45mm) and defects (cavity spot, forking, less than 7.5 cm length or less than 28 mm diameter, splits, cracks, badly deformed roots); weights were recorded for each class.

Findings and discussion

Results from the demonstration trial must be viewed with caution. Treatments were not replicated, while samples within treatments were replicated and bulked. Like results from replicated trials, results from demonstration trials are influenced by the specific production conditions at the chosen location. In this case conditions included, sandy soils and agronomic practices typical to the farm. An unusually cool growing season may have had an impact on crop growth and nitrogen dynamics.

Available nitrogen (N) after harvest

Calcium cyanamide fertiliser contains 19.8 % N. An application of 300 kg/ha supplies 59.4 kg N/ha, 500 kg/ha supply 99 kg N/ha. Observations during the season showed that carrot roots in the treated bed were shorter and tops larger, with longer, lusher leaves, than in control beds and the remainder of the paddock. The 'stumpy' appearance of treated carrots suggests excess N availability early in the season, when root length is determined by the carrot plant.

Below table shows that, despite the extra N inputs via calcium cyanamide fertiliser, available soil N levels just before harvest did not differ between treatments. The additional N inputs may have been partly used to produce extra carrot biomass (tops and root bulk); some of it may have leached from the rootzone, given the light, sandy soil in the paddock, and higher than normal rainfall during the early growing season (Bureau of Meteorology, data not shown).

Take away message: In research trials with $CaCN_2$ Fertilser, soil N dynamics and plant biomass production should be included in assessments.

PADDOCK	POST HARVEST NO3-N (KG/HA)	POST HARVEST NH4-N (KG/HA)	TOTAL N (KG/HA)
CONTROL (average of two beds)	25	2.2	27.2
300 (kg/ha) $CaCN_2$	27.6	1.9	29.5
500 (kg/ha) $CaCN_2$	26.1	3	29.1

Commercial harvest results

The below table shows the pack-out results from the commercial trial harvest.

TREATMENT	CONTROL 1	CONTROL 2	300 (KG/HA) $CACN_2$	500 (KG/HA) $CACN_2$
Grades	**Packed out weight (kg)**			
All Class 1	17,025	14,715	17,170	18,770
All other marketable	9,900	10,350	5,400	8,550
Processing	8,550	9,000	17,550	13,950
TOTAL Fresh	35,475	34,065	40,120	41,270

The pack out figures show that yields in the $CaCN_2$ treated beds were higher than in untreated beds. Differences were15.4% for the 300 kg/ha and 18.7% for the 500 kg/ha treatment compared to the average of the two controls. The greatest increase was in the weight of processing carrots. One reason for the higher weight of processing carrots may have been the impact the additional nitrogen from the $CaCN_2$ fertiliser that became available early in the season. While it reduced root length it may have had an impact on the timing of bulking and final root weight at harvest. Oversized carrots are used for processing.

Given the trial's location within a commercial crop, nitrogen fertiliser rates could not easily adjusted to account for the additional N inputs via $CaCN_2$ fertiliser.

Take away message: If $CaCN_2$ fertiliser is used commercially the N mineralisation from the product must be considered in the crop's N budget and application schedule.

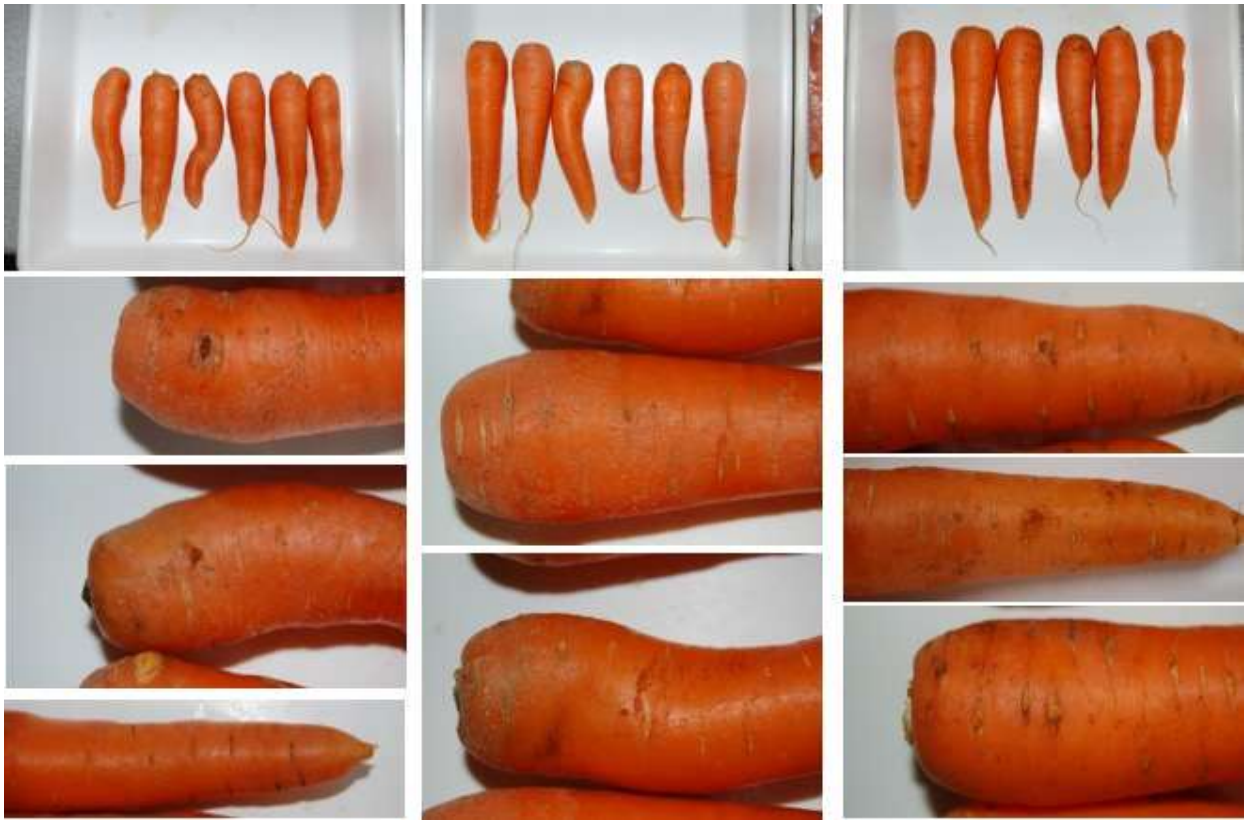
DNA testing of soil and carrot roots

DNA assays for *Pythium sulcatum* and *Pythium violae* were in the development phase at the time of this trial. The trial was used to assist in their development. Therefore, results must be viewed with caution. Any questions about the tests and results should be directed to Michael Rettke (SARDI), mobile 0401 122 124 or email michael.rettke@sa.gov.au.

Cavity spot symptoms were easily found in the trial a month before harvest, especially in a low-lying, wetter area across the trial beds. A visual assessment indicated that cavity spot and forking may have been more prevalent in the control beds than the treated beds. However, these treatment differences were not distinctly noticeable during random sampling of carrot roots for DNA testing across the entire trial area.

The following photos were taken from sampled roots prior to DNA testing. They show that roots from the untreated control bed had some deep cavity spot lesions; roots from the treated areas appear to be somewhat affected by *Pythium* as well.

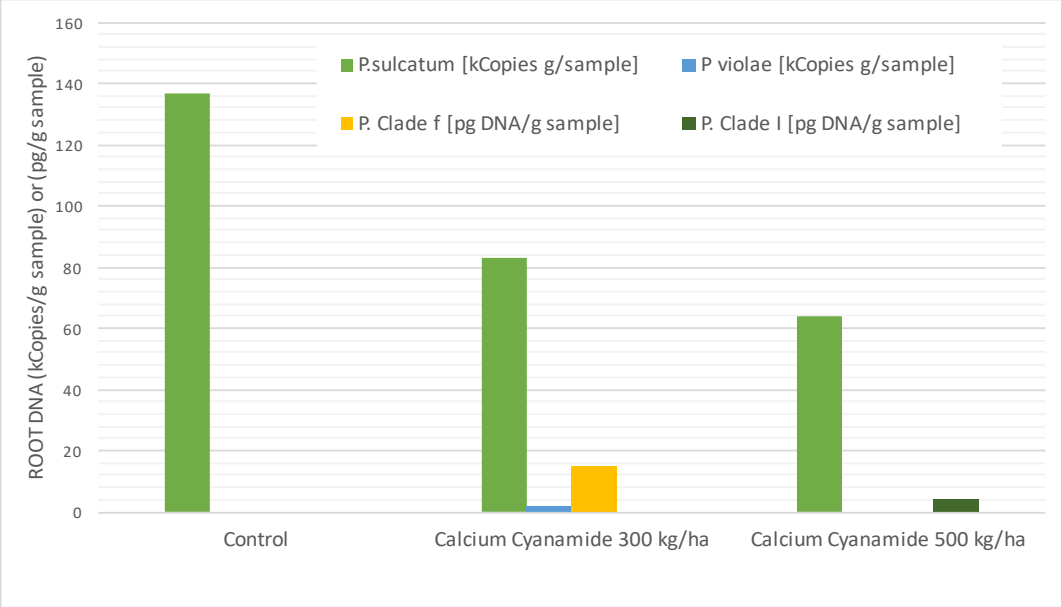
Control	Calcium Cyanamide (500 kg/ha)	Calcium Cyanamide (300 kg/ha)



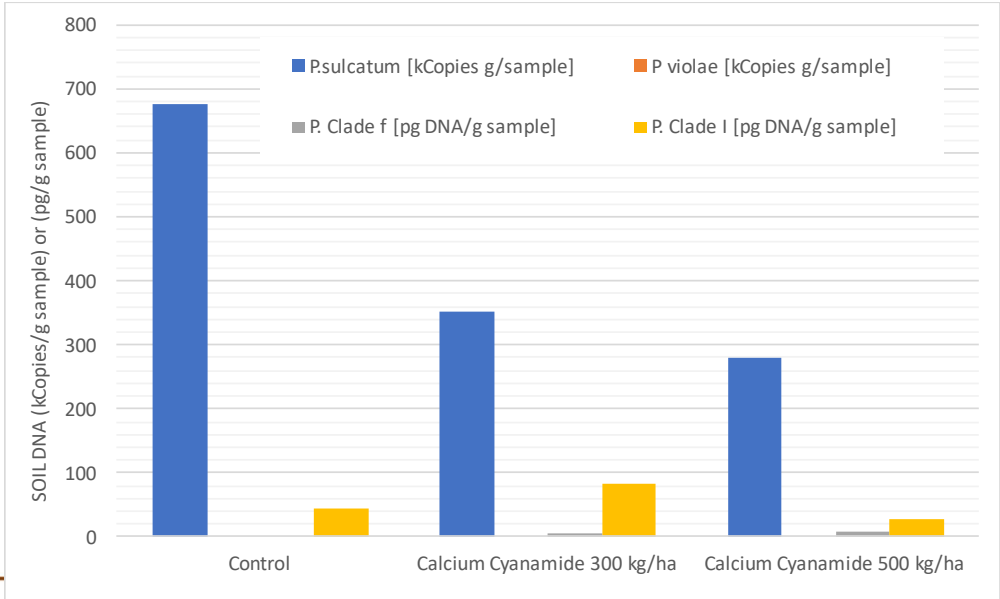
Photos by Michael Rettke, SARDI

The following graphs show the results from the DNA assay, which is under development by SARDI (VG15009).

DNA testing results of carrot roots (peel) shown below suggest that cavity spot symptoms seen on carrots roots may be caused by *Pythium sulcatum*. NB. At the time of the trial, limited testing had been conducted using this assay on peel and soil samples.



DNA testing results from soil samples are shown below. They support the above suggestion that symptoms seen on carrots may be mainly caused by *Pythium sulcatum*. Both tests imply that $CaCN_2$ fertiliser may have reduced soil inoculum levels by *Pythium sulcatum,* the main pathogen causing cavity spot in carrots in Australia. Still soil results for *Pythium sulcatum* appear to be high (Michael Rettke, pers. comms). A single, low level detection of *Pythium violae* suggests that this pathogen could be present in the soil; however suitable research is required to test this hypothesis



Answers to trial questions

	Question	Answer
1	Could calcium cyanamide fertiliser reduce cavity spot and forking incidence and severity in carrots?	Potentially yes, and if caused by Pythium
2	Could calcium cyanamide fertiliser reduce Pythium inoculum levels in soils?	Potentially yes
3	Should nutrient inputs be adjusted when using calcium cyanamide fertiliser?	Yes, nitrogen programs, lime inputs based on soil testing
4	How long does a beneficial effect last?	Needs further investigation
5	Do economics stack up?	Needs further investigation
6	What are negative side effects?	Potentially excessive nitrogen available to young crops

Next steps

Results of the initial on-farm demonstration trial are encouraging, especially the potential inoculum reduction and the possible yield increase. Still, follow up research and on-farm trials are required to substantiate initial findings. Well designed trials with CaCN2 fertiliser would have to be undertaken to:

- Confirm the effect of $CaCN_2$ on *Pythium* spp, especially P. *sulcatum* and P. *violae*
- Understand soil N dynamics and N effects on plant biomass production including root to shoot ratios
- Develop an approach of adjusting the nitrogen fertiliser program to account for the N content in $CaCN_2$
- Investigate whether calcium cyanamide fertiliser should be used ahead of a cover crop to avoid providing excessive N to young vegetables
- Confirm the magnitude of a liming effect via $CaCN_2$ fertiliser additions
- Reduce the proportion of processing carrots
- Look at the fit of $CaCN_2$ fertiliser in production systems / rotations

- Determine optimum rates and application timing ahead of a carrot crop under different Australian production conditions (soils, climate, agronomic practices)
- Determine the longevity of a potential reduction in *Pythium* inoculum
- Determine whether a reduction in *Pythium* inoculum is cumulative with repeated $CaCN_2$ fertiliser applications
- Determine the effect of $CaCN_2$ on other soil borne diseases e.g. *Rhizoctonia*
- Determine whether $CaCN_2$ fertiliser use in combination with other measures e.g. compost or cover crops will provide added benefits, and
- Determine economic benefits.

In smaller production units and for other crops, e.g. greenhouses, a combination of $CaCN_2$ fertiliser use and soil solarisation may be worth exploring.

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An integrated research into practice approach to Soilborne disease threats in the Australian vegetable industry

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Soil-borne diseases are a major threat to vegetable production costing Australia's $4 billion vegetable industry around $120 million per annum and have been identified as the top challenge for soil management and crop protection in recent surveys of growers and agronomists. There are five soil-borne disease groups that continue to be a major problem for vegetable growers: Sclerotinia spp. (S. sclerotiorum and S. minor), Fusarium spp. (F. oxysporum and F. solani), water moulds (primarily Pythium spp.), nematodes and Rhizoctonia spp. The management of these diseases has become increasingly complex due to a decline in chemical control options combined with more intensive production and consumer demands for "perfect" produce.

The industry has responded by funding three projects to provide an integrated research → practice → research approach. Two research projects are currently; 1. developing and testing disease management systems that work at a whole-farm level, and 2. validating molecular diagnostics assays for vegetables pathogens for assessing risk at a paddock level. These research projects are strongly linked to the Soil Wealth and Integrated Crop Protection extension projects, which include 14 demonstration sites.

A key to this approach is partnering with growers and advisors, as the system experts, to integrate risk management approaches and control measures into the wide diversity of vegetable production systems. An example of this approach is the Soilborne Disease Masterclass where growers, agronomists and research are brought together to translate the key principles and new research into integrated control measures for vegetable production systems.

Control of Sclerotium Rot of chillies in Australia

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Capsicum and chilli production in Australia is currently valued at $136M annually. Summer crops in NSW and Queensland can be affected by Sclerotium Rot caused by the basidiomycete *Athelia rolfsii* (asexual state = *Sclerotium rolfsii*). Affected plants develop a basal stem and crown rot causing them to wilt and die. Greater than 25% of plants commonly die by their harvest date. Fruit from wilting plants are unacceptable for fresh markets and only a few producers have a secondary processing market. Our aim was to develop effective controls for this disease. We conducted two field experiments in the summer of 2016-7 to evaluate chemical and biological controls for Sclerotium Rot of chillies. One trial was located on a farm in Bundaberg, Queensland that was known to be infested with *S. rolfsii*. The second trial was established at Somersby in NSW where a sclerotial inoculum was applied. At both sites untreated control treatments were compared with chemical (pyraclostrobin or a combined formulation of cyprodinil and fludioxoni)l or biological control treatments which were drenched around the base of plants at three-weekly intervals commencing at transplanting. The trial at the Somersby site used a commercial formulation containing an isolate of *Pseudomonas fluorescens* while the Bundaberg site used a product of an undisclosed microbial formulation. Plots were rated for disease severity at three growth stages with a final assessment at harvest. Yield data was collected at the Bundaberg site only. Chemical treatments generally reduced Sclerotium Rot significantly at both sites. *P. fluorescens* also significantly reduced the disease whereas the microbial formulation at Bundaberg was ineffective. These trials demonstrate that there are potential chemical and biological control options for Sclerotium Rot of chillies. Further studies are also addressing potential cultural controls such as plant spacing and irrigation scheduling.

Managing damping off in baby-leaf spinach in Australia

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Baby-leaf spinach production in Australia has surged in recent years. It is currently valued at $55M annually. Year-round supply of semi-processed product requires a network of growers spanning all states except the Northern Territory. Damping off has become a significant constraint in this intensive production system where multiple crops are often grown without rotation. Diseased plants have yellow or wilted leaves which contaminate the harvested marketable product. Furthermore when plants are damped off the remaining healthy plants have a flatter habit making machine harvesting more difficult and causing many leaf blades to be cut rather than at the petiole. This leads to a reduced shelf life and sometimes rejection by the processor. This study has identified the pathogens causing damping off in different production areas and we have commenced field trials to evaluate a number of chemical, cultural and biological control options. The key pathogens determined so far are various species of *Pythium*, namely *P. aphanidermatum*, *P. ultimum* var *ultimum* and *P. irregulare*; *Rhizoctonia solani*; and *Fusarium oxysporum* f.sp. *spinaciae*. They appear to have both temporal and spatial differences in their occurrence and importance. A field trial in Richmond, Tasmania over the past summer compared drench treatments at sowing of metalaxyl-M, azoxystrobin, propamocarb, fosetyl-Al, and a commercially formulated strain of *Bacillus subtilis*. A combination of metalaxyl-M and azoxystrobin and another treatment with a combination of propamocarb, fosetyl-Al and *B. subtilis* resulted in significantly fewer diseased plants although yield differences were not significant. Both *Rhizoctonia* and *Pythium ultimum* were confirmed as the key causes of the diseased plants. Further studies are planned with chemically dressed seed and biocontrol treatments as well as assessments of the ameliorative effects of different cover crops and biofumigants.

Managing damping off in baby-leaf spinach in Australia

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Field production of baby-leaf spinach surged in Australia over the past decade. It is currently valued at AU$55M annually. Year-round supply requires a network of growers spanning diverse regions and production environments. Damping off has become a significant constraint particularly where multiple crops are grown without rotation. Diseased plants have yellow or wilted leaves which contaminate harvested product. Furthermore when plants are damped-off the remaining healthy plants have a flatter habit making machine harvesting more difficult and resulting in broad cuts across leaf blades rather than at the petiole. This reduces shelf life and failure to meet processor specifications. Our current study has identified and confirmed the key pathogens causing damping off in different production regions. They are: various species of *Pythium*, namely *P. aphanidermatum*, *P. ultimum* var *ultimum* and *P. irregulare*; *Rhizoctonia solani*; and *Fusarium oxysporum* f.sp. *spinaciae*. They occur either as single pathogens or more commonly as disease complexes. Greenhouse and field trials are evaluating chemical, cultural and biological control options. Chemical soil drenches at sowing or dressed seed with certain chemicals has successfully controlled Pythium but not always Rhizoctonia rots. To date microbial biological control products tested have yielded similar results highlighting our challenge to find robust management options for Rhizoctonia rots.

RD&E prioritisation of soilborne diseases affecting Australian vegetable crops

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INTRODUCTION

Vegetable growers and their advisers have identified soilborne diseases as one of their main challenges. Soilborne diseases cost Australia's $4 billion vegetable industry an estimated $120 million each year.

Disease management has become more challenging due to fewer chemical control options, intensified production systems and consumers demanding perfect looking produce, with minimal use of pesticides.

Growers and advisers are increasingly interested in integrated control methods, especially soil health management to reduce soilborne disease pressure. Therefore, Horticulture Innovation Australia is funding RD&E for a multifaceted approach to soil borne disease management in vegetable crops (VG15010).

The first project activity was to prioritise the main soilborne diseases affecting major Australian vegetable crops and determine RD&E activities.

MATERIALS AND METHODS

A comprehensive gap analysis and prioritisation of soilborne diseases, vegetable hosts and regions were conducted using a process that built on previous research and targeted surveys. The key components of the process were:

- A review of previous Australian soil borne disease projects and disease priority lists
- Consideration of the Strategic Agri-chemical Review Process (SARP) priorities for minor use applications
- Consultation with pathologists, nematologists, advisers, agronomists and industry experts
- Targeted survey of Australian vegetable growers
- Input from the project reference group of growers and technical experts
- Consideration of the value of production of each crop and associated losses to soil borne diseases.

The analysis included a review of recommended soilborne disease management practices.

RESULTS AND DISCUSSION

The analysis resulted in identifying the following disease and crop combinations as priorities for the project:

Brassicas

- Clubroot (*Plasmodiophora brassicae*)
- Sclerotinia (*S. sclerotiorum*)
- Damping off complex (*Rhizoctonia* spp*, Pythium* spp*., Fusarium* spp.)

Carrots

- Cavity spot and forking (*Pythium sulcatum, P violae*)
- Damping off complex (Qld) (*Rhizoctonia spp., Pythium spp*.)
- Root-knot nematodes (*Meloidogyne* spp.)
- Carrot Scab (Tas) (*Streptomyces scabies*)

Babyleaf spinach

- Damping off complex (*Rhizoctonia* spp*, Pythium* spp*., Fusarium* spp.)

Lettuce

- Sclerotinia (*S. sclerotiorum, S. minor*)
- Damping off complex (*Rhizoctonia spp, Pythium* spp*., Fusarium* spp.)
- Big Vein (lettuce big-vein associated virus via *Olpidium brassicae*, Mirafiori lettuce virus)

Capsicums, chillies

- Southern blight (Qld) (*Sclerotium rolfsii*)
- Damping off complex (*Rhizoctonia spp, Pythium spp., Fusarium spp., Phytophthora spp*.)
- Root-knot and root lesion nematodes (*Meloidogyne* spp*., Pratylenchus* spp.)

Beans

- Sclerotinia (*S. sclerotiorum*)
- Damping off (*Rhizoctonia spp*.)
- Southern blight (Qld) (*Sclerotium rolfsii*)
- Charcoal rot (Macrophomina phaseolina)

Leeks, celery

- Basal plate rot (*Fusarium* spp.)
- Pink root (*Pyrenochaeta terrestris*)

The analysis highlighted that many key management practices apply to all major soilborne diseases in vegetable crops. These are therefore a focus for extension and field demonstration activities. They are:

Understanding risks

- Pre-plant soil tests, seed tests; inoculum density-disease relationships are often unreliable because disease expression usually depends on site specific production conditions – R&D required
- Crop histories and monitoring of diseases in previous crops to guide site selection and crop choices
- Observing surrounding host crops (area wide management) and eliminating weed hosts
- Weather monitoring and disease forecasting to help with managing risks identified by e.g. soil and seed tests and to target pesticide applications
- Understanding the relationship between soilborne disease and soil conditions / soil health; these relationships are not quantified - R&D required

Most abovementioned risk assessments are not routinely used for commercial crops because R&D gaps still exist; priorities are listed below under R&D gaps.

Managing risks

- Site selection using knowledge of paddock conditions and (disease) history
- Rotation with non-hosts
- Selection of optimal planting times (especially for susceptible varieties and or 'risky' paddocks)
- Soil health management, especially biological diversity and soil structure (minimum tillage, cover crops, controlled traffic), suitable organic amendments (suppressive soils)
- Good infiltration and drainage, no compaction

- Microclimate manipulation - irrigation (minimising wet foliage periods, drip irrigation) and humidity (row direction and plant spacing, canopy type)
- Use of tolerant or resistant cultivars
- Functional and mixed cover crops, avoiding hosts
- Avoiding excess nitrogen, balanced overall nutrient / fertility management
- Good weed control, controlling hosts
- Rogueing infected plants early if appropriate
- Minimising soil, water and equipment movement from infested fields to clean sites, hygiene and sanitation
- Optimising fungicide types, application methods and timing, pesticide resistance management
- Fumigation for protected and high value crops e.g. seed (last resort)

For damping off fungi important approaches are:

- Clean seed and transplants, good nursery practices
- Minimisation of plant stress via good overall crop management
- Monitor water sources (especially for hydroponic crops) to ensure they are no pathogen free
- Support quick emergence from soil and good early root growth

R&D gaps were similar for most soil borne diseases and crops. They are:

1. Predicting site specific risk / commercial validation of existing decision-support tools and development of additional tools:
   - soil and seed testing incl. DNA detection assays to quantify the pathogen status - understanding inoculum level thresholds to develop risk categories
   - predicting risk of infection (e.g. monitoring of micro and macro climate, soil moisture monitoring (critical wetness levels and periods) and disease forecasting - understanding predictive values / risk categories / thresholds)
   - determining disease levels before harvest to understand market risks and risk to following crops
2. Biocides - evaluate efficacy in different production systems and conditions (soils, climate) and compatibility with commonly used fungicides (all pesticides?) and fertilisers in different production systems
3. Methods and economics of inoculum reduction, evaluation of different cultural, integrated and innovative (stimulants, biocides etc.) approaches (short and long term)
4. Understanding and managing fungicide resistance and cross-resistance problems on a regional basis (regional monitoring required)
5. Minor use permits for effective pesticides, new registrations

In addition, for damping off fungi (e.g. Pythium spp., Fusarium spp., Rhizoctonia spp.) R&D gaps are:

1. Identify, utilise or create suppressive soils for diseases disease complexes,
2. Disease and soil community characterisation
3. Seed treatments esp. for *Pythium* spp.
4. Understanding sources of primary inoculum (esp. for Rhizoctonia spp.)
5. Understanding the relative threat of seed borne +/- soil borne inoculum
6. Anaerobic soil disinfestation, solarisation and other soil treatments to replace Metham Sodium (refer to Hort Innovation report VG13045) including economics.

PRIORITISATION BASED ACTIVITIES

Materials and undertakings to support growers and advisers with soil-borne disease management

Many of the diseases identified in the prioritisation process have been the subject of a great deal of research, and various control practices are ready to be used. The project is delivering extension materials and activities for the vegetable industry such as: fact sheets, videos, webinars, field days associated with demonstration sites, workshop, best practice guides and masterclasses via www.soilwealth.com.au.

Research

The project has a small research component, which focusses on new methods for managing the damping off complex in babyleaf spinach, *Sclerotium rolfsii* and damping off in capsicums and cavity spot in carrots. To date, field trials on new fungicide chemistry have been established in Tasmania and Bundaberg, and the impact of improved soil and nutrient management, including cover crops and compost additions are being evaluated in Tasmania and Western Australia. Several greenhouse trials are running to tests new disease control approaches.
Irrigation management can have a major impact on the development of soil borne disease. Soil moisture levels are being measured in carrots and chillies, and the results related to the incidence of soilborne disease.

SUMMARY

- A solid approach was used to prioritise RD&E needs for soilborne diseases in vegetables
- Many management practices have already been established thought research; multifaceted extension and training is now being delivered
- R&D needs have been identified and work has commenced on several priority aspects; still, further research is required in areas of risk management and soil health management approaches, including biological / biocide control options.

ACKNOWLEDGEMENTS

This project has been funded by Horticulture Australia Limited using the vegetable industry levy and funds from the Australian Government.

REFERENCES

N/A