Project title:	Carrots: Improving the management & control of cavity spot
Project number:	FV 391
Project leader:	Dr P Gladders, ADAS UK Ltd[1]
Report:	Final report 2014
Previous report:	None
Key staff:	Dr M McPherson, STC Kirsty Wright and Dr C Burns, STC Dr T O'Neill, ADAS Tim Boor and Jonny Kerley, ADAS Dr A Jukes, University of Warwick David Martin, Plantsystems Ltd
Location of project:	Commercial site in Retford (Nottinghamshire), STC, University of Warwick
Industry representative:	Keith Mawer, Strawson Ltd, Bilsthorpe, Notts
Date project commenced:	01 May 2011
Date project completed (or expected completion date):	30 April 2014

[1] Dr Gladders retired from ADAS on 5th December 2013. Dr Tim O'Neill and Tim Boor completed the project.

DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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Plant Pathologist
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Signature .... Date ....

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CONTENTS

GROWER SUMMARY

Headline

- SL567A reduced carrot cavity spot in two out of four trials where the disease occurred at a high incidence; Limex soil incorporation was effective at one of these sites; no better treatments were identified.
- The level of cavity spot reduction achieved with SL567A was not related to speed of Metalaxyl-M degradation; good control was observed at a site with slow degradation and also at a site with fast degradation.

Background

Carrot cavity spot remains one of the most important diseases of carrots (Koike *et al*., 2007), capable of causing complete loss in parts or even whole crops. Financial losses are particularly high when overwintered crops are lost. Management of the disease has relied on the use of partially resistant or tolerant varieties and metalaxyl-M fungicide treatment early in the life of the crop. Recent HDC projects (FV 353, CP 46) have improved understanding of the pathogen and indicate that the main pathogen *Pythium violae* is able to utilise a wide range of crop and weed hosts. Whilst long rotations (e.g. 1 in 6) have benefited carrot production by reducing the risk of damage from various pests and pathogens, such methods have not effectively reduced cavity spot. Disease development can be strongly influenced by rainfall (soil moisture) and some quantitative data based on irrigation experiments is available from FV 353. Whilst this has helped explain variation in disease development, weather conditions are outside grower control so fungicide treatment remains the main tool that growers can use to counteract infection triggered by rainfall events. Metalaxyl-M has served the industry well for many years though its efficacy has been gradually eroded and this is considered, in part at least, to have occurred as a result of enhanced degradation of the active molecule at some grower sites. As the industry is dependent on a single fungicide with a single site mode of action, the sustainability of this treatment is a major concern. The extent to which fields in carrot production are affected by enhanced degradation is unknown. A soil test would be of interest to growers as a chargeable service if enhanced soil degradation can be shown to affect field performance of metalaxyl-M.

New fungicide active ingredients, particularly those used for potato late blight (*Phytophthora infestans*) or downy mildew were considered candidates for cavity spot control. Screening of new products (mainly strobilurin chemistry) was last reported in 2001 in FV 5f (Pettit *et al*., 2001). New candidate active ingredients and products are now available from various manufacturers including Bayer CropScience and BASF. Treatment impacts on *Pythium violae* were appraised during the growing season of year 2 of the project using a quantitative molecular PCR assay; methodology which was developed earlier in FV 353. Measures of pathogen activity in relation to treatments were undertaken in collaboration with the University of Warwick.

The project also evaluated non-fungicidal treatments including biological control agents, along with soil amendments and calcium treatments. The latter provided some useful activity in pot and field tests in FV 5f and have been used successfully against clubroot (*Plasmodiophora brassicae*) in vegetable brassicas (Defra project HH3227TFV, 2007); calcium applications can be made immediately prior to sowing (e.g. as Limex). The effects of calcium are complex, extending beyond changes in soil pH to modification of soil microflora and direct effects on the host plant. Previously, Scaife *et al.,* 1983 reported decreased incidence of cavity spot when soil exchangeable calcium exceeded 8 milliequivalents per 100 g soil.

The use of varieties with resistance to cavity spot is well-established in the industry. However, resistance is incomplete and therefore additional control measures, particularly fungicides, are still used. Whilst fungicide evaluation has been undertaken on more susceptible varieties, the benefits on the most resistant varieties also needs to be established. In the future it may be possible to refine the range of measures that are required to control cavity spot at field level.

The overall aim of this project was to improve the management and control of cavity spot. Specific objectives were:

1. To evaluate new fungicides and biological treatments with potential to control *Pythium* species in soil;
2. To establish optimum application rates and timings for the most promising new products;
3. To determine the contribution of pre-planting calcium applications for cavity spot control;
4. To determine the prevalence of enhanced degradation of metalaxyl-M in carrot growing areas.

Summary

This project comprised two replicated field experiments (Retford, Notts and STC, Cawood, Yorks) per year over 3 years. The experiments were done using the susceptible variety Chantenay at the Notts site and a confidential susceptible variety at the Yorks site. The aim was to evaluate new fungicides and biological products for the control of carrot cavity spot using both field and laboratory based studies. In addition, soils were tested from carrot crops for enhanced degradation of metalaxyl-M. The effects of pre-sowing calcium treatments (such as Limex or Perlka) were also investigated (Table 1).

In year 1 (2011), cavity spot levels were low and no significant treatment differences in incidence or yield were observed in the two field experiments. However, good comparisons were achieved in years 2 and 3 with disease levels in the untreated controls between 18% and 64%.

In 2012 15 treatments were examined in comparison with the untreated control. The standard fungicide metalaxyl-M (SL567A) was the most effective fungicide at the Notts site where cavity spot incidence was reduced by 35%. None of the experimental products provided significant control, although there was a trend for slight reductions in cavity spot incidence for some treatments. Limex (15 t/ha) provided significant control at the Notts site, decreasing cavity spot incidence by 19%. There was no significant control of cavity spot with any of the treatments at the Yorks site.

Table 1. Effects of novel fungicides, Limex and Perlka in comparison with SL567A on the incidence of cavity spot in 2012.

				Cavity spot incidence (% of carrots affected)	
	7 Days Pre-drilling	4-6 weeks after drilling	4-6 weeks later	Notts	Yorks
1	Untreated	Untreated	Untreated	55	65
2		SL567A (1.3 L/ha)	-	20	55
3		SL567A (0.65 L/ha)	SL567A (0.65 L/ha)	19	60
4		HDC F50	-	51	65
5		HDC F50	HDC F50	53	63
6	HDC F51	-	-	40	68
7	HDC F51	HDC F51		43	62
8		HDC F52		55	78
9		HDC F52	HDC F52	49	69
10		HDC F53		47	55
11		HDC F53	HDC F53	42	62
12	HDC F125	HDC F125	HDC F125	51	49
13	Limex 5 t/ha	-	-	48	68
14	Limex 10 t/ha	-	-	37	60
15	Limex 15 t/ha	-	-	34	60
16	Perlka 400 kg/ha	-	-	74	60
Fpr	-	-	-	<0.001	0.349
SED	-	-	-	9.5	9.28
LSD	-	-	-	19	18.64

In 2013, 16 treatments were examined in comparison with an untreated control utilising eight conventional fungicides (Nativo 75WG, Rudis, SL567A, Switch, HDC F53, HDC F50, HDC F52, HDC F167), one biofungicide (HDC F166) and Calcium treatment (Limex). Products were applied either 7 days pre-drilling and / or up to three times post – drilling; programmes consisted of 1-3 applications (Table 2).

Cavity spot was significantly reduced at one site by SL567A only, SL567A followed by Switch and by Limex applied pre-drilling (Tr15-17). These treatments reduced the incidence of affected carrots by 67-75%. No evidence was found that two half-rate post drilling applications of SL567A or any of the test fungicides was better than one full rate application. There were trends towards disease reduction with several treatments including HDC F50, HDC F52 and HDC F53. A combined treatment of Limex pre-drilling and SL567A post drilling was no better than either treatment alone. Increasing the rate of Limex application from 10 to 15 t/ha did not increase disease control at the Notts site in terms of disease incidence, however there was a trend for increased control in terms of disease severity; there was also a trend towards reduced disease at the higher rate of Limex at the Yorks site. There were significant effects upon pH in the Limex treatments at the later assessments in both the Yorks and the Notts trial, with this being a clearer dose effect at the later assessment. Also it was found that the higher Limex applications resulted in a higher amount of available calcium, Figs 1 and 2. At the Yorks site, levels of cavity spot were higher (56% untreated) and no treatment reduced the disease.

Over the entire project, six field trials were conducted, with significant treatment effects identified in two of these trials. The standard fungicide metalaxyl-M (SL567A) showed trends to have the greatest level of efficacy in 2012, although control was not significantly different from the 10 and 15 t/ha rate of Limex. In 2013 there were no significant differences between the Limex and metalaxyl-M treatments. When assessing the disease severity data across all sites and years of the project, Limex effects and the effect of SL567A were only found to have small effects on disease severity overall, with this result thought to be due to the low levels of disease severity observed throughout. The experimental fungicides were not found to have a significant influence upon cavity spot incidence in the first two years, although there were trends for useful control in 2013 when rates of products were increased. It is worth considering that when the original work with metalaxyl-M was undertaken in the early 1980s the rate of use found to be efficacious was 8 x the rate used on potatoes for blight control (McPherson, pers com). It is therefore important to consider much higher fungicide rates of use than normal for cavity spot control, though it is important to note that any increase in rate of application could have an impact on future regulatory approval. Across the project not all soil amendments resulted in positive results, with Perlka resulting in significantly higher cavity spot incidence than the untreated control. Perlka was dropped in year 3 of the project.

Table 2. Effects of novel experimental fungicides, Switch, Nativo 75WG, Rudis and Limex in comparison with SL567A on the incidence of cavity spot in 2013.

	Application timing				Cavity spot incidence (% of carrots affected)	
	7 Days Pre-drilling	4-6 weeks after drilling	4-6 weeks later	4 weeks later	Notts	Yorks
1	Untreated	-	-	-	19	55.8
2		SL567A (1.3 L/ha)	-	-	8	44
3		SL567A (0.65 L/ha)	SL567A (0.65 L/ha)	-	6.2	36
4		SL567A (1.3 L/ha)	Switch 0.8 L/ha	Switch 0.8 L/ha	4.8	40
5		HDC F53	-	-	12	49
6		HDC F53	HDC F53	-	15.5	47
7		HDC F53	Nativo 75WG 0.3 L/ha	Nativo 75WG 0.3 L/ha	18.5	62.5
8		HDC F53	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	20.5	65
9		HDC F50	-	-	18	46.5
10		HDC F50	HDC F50	-	7.8	57.5
11		HDC F52	-	-	8.5	61.5
12		HDC F52	HDC F52	-	14	44.5
13	HDC F166	HDC F166	-	-	18.5	44.5
14	HDC F167	HDC F167	-	-	15.8	56
15	Limex 10 t/ha		-	-	6	53
16	Limex 15 t/ha	-	-	-	5	36
17	Limex 10 t/ha	SL567A (1.3 L/ha)	-	-	6	33.5
	Fpr				0.08	0.138
	SED				6.22	11.41
	LSD				12.5	22.9

Alternaria control

A number of treatments at the Notts site were found to provide significant control of alternaria blight (*Alternaria dauci*) compared to the untreated (25% leaf area affected). HDC F53 applied 4 weeks post drilling resulted in 7% leaf area affected, with clear improvements in control observed as additional products were added to HDC F53 within treatment programmes. HDC F53 followed by Nativo 75WG and Rudis 4 and 8 weeks later was the most effective treatment overall (0.1% leaf area affected). The standard, SL567A, applied either once or twice post drilling, did not provide significant control of alternaria (13.7-15.9% leaf area affected), however where SL567A was followed by Switch twice, disease severity was reduced significantly (9.7% leaf area affected).

Tests for enhanced degradation of metalaxyl-M

Soils were tested for enhanced degradation of metalaxyl-M throughout the project. A number of samples were collected from commercial carrot growers as well as the Notts and Yorks trial sites. In 2011, soil from 32 fields (including the two fungicide trial sites) was assessed for the persistence of metalaxyl-M. In 15 soils the half-life was less than 10 days, a breakdown rate previously associated with control failure. In 12 soils the half-life was greater than 20 days. The remaining 5 soils fell between 10 and 20 days. There was some evidence of correlation between half-life and pH with half-life appearing to diminish with increasing pH. The effect of organic matter was weak. In 2012 no soils sampled degraded in less than 10 days, but nine soils degraded between 10 and 13 days. Metalaxyl-M control is unlikely to be effective in these situations. In eleven soils the half-life was greater than 20 days where control is likely to be more effective with the greater persistence. In 2013 soils from the two trial sites was tested. Both soils were found to have a half-life of less than 10 days, a break down rate which would be associated with disease control failures.

Measurement of Pythium in soil

During the 2012 experiments a soil test was completed across all experimental plots at both sites to detect for the presence or absence of *P. violae* DNA. The test demonstrated promising signs of detection. For example, at Notts all of the untreated and HDC F125 plots gave positive results for the detection of *P. violae* DNA, and these also had the highest cavity spot incidence. However some of the other results were not consistent with cavity spot disease. At the Yorks site, none of the plots tested positive for *P. violae* DNA, yet a high incidence of cavity spot was recorded in many plots. More work is needed in the future to refine this technique.

Novel fungicides

In 2013, a laboratory agar plate test at ADAS Boxworth examined activity of five novel fungicides (HDC F168, HDC F169, HDC F170, HDC F171 and HDC F172) for reduction of mycelial growth of three isolates of *P. violae* in comparison with SL567A. SL567A was the most effective at inhibiting mycelial growth, which compared well to the field work. Promising results were produced by HDC F172 which was identified as the most effective experimental product. This product has not been evaluated in the field yet.

Financial Benefits

This study identified no alternative candidates to SL567A as a chemical control for cavity spot, however Limex soil amendment was found to be of considerable benefit. Limex might be the preferred treatment on sites where a history of enhanced degradation is already known as well as on sites where pH is not currently very high. The cost of 10 t/ha of Limex (delivered and applied) can vary between £150/ha to in excess of £300/ha depending on distance from British Sugar factories (Cogman, pers comm). With the costs of SL567A approaching £300/ha delivered and applied, Limex could be a viable alternative for a number of growers. The financial benefits are likely to be greatest where the treatment application timing is optimized. For chemical treatments, previous studies have shown, this should be post-emergence to moist soil no later than 6 weeks after sowing.

Action Points for growers

1. Limex can provide good control of cavity spot and may be an effective alternative treatment to Metalaxyl-M.
2. No benefit was identified from applying products at half rate at more spray timings.
3. Alternaria was significantly reduced by a number of treatment programmes, with the most effective programme containing HDC F53 4 weeks post drilling followed by Nativo 75WG and Rudis 4 and 8 weeks later.

SCIENCE SECTION

Introduction

Carrot cavity spot is one of the most important diseases of carrots, causing UK losses in between £20 and £30 million according to DEFRA. In severe cases growers have reported over 35% of crops unmarketable. Financial losses are particularly high when overwintered crops are lost. Current management of the disease relies on the use of partially resistant or tolerant varieties as well as metalaxyl-M fungicide (e.g. SL567A) treatment early in the life of the crop.

Recent HDC projects (FV 353, CP 46) have improved understanding of the pathogen and indicate that the main pathogen *Pythium violae* is able to utilise a wide range of crop and weed hosts. Whilst long rotations (e.g. 1 in 6) benefit carrot production by reducing the risk of damage from various pests and pathogens, they have not very effective for controlling cavity spot. Disease development is strongly influenced by rainfall (soil moisture) and some quantitative data based on irrigation experiments have been completed (FV 353). Whilst has helped explain variation in disease development, weather conditions are outside grower control so fungicide treatment remains the main tool that growers can use to counteract infection triggered by rainfall events. Metalaxyl-M has served the industry well for many years though its efficacy has been eroded and performance affected by enhanced degradation at some grower sites. Grower expenditure on this fungicide has been >£1 million per annum. The extent to which fields in carrot production have been affected by enhanced degradation is unknown. Suitable methodology for soil testing is available (see FV 5f). A soil test would be of interest to growers as a chargeable service if enhanced soil degradation can be shown to affect field performance of metalaxyl-M.

The window for using metalaxyl-M most effectively was defined in early experiments (Gladders & McPherson, 1986) and more recent work in FV 5f indicated that timing at early post-emergence is rather more effective than pre-emergence applications. Some evaluation of later timings to protect crops over-winter has been undertaken in response to French research on secondary infection (Suffert et al., 2008). The results were disappointing and it seems unlikely that further residue work to secure new recommendations can be justified.

As the industry is dependent on a single fungicide with a single site mode of action, the sustainability of this treatment has been a major concern. New fungicide active ingredients, particularly those used for potato late blight (*Phytophthora infestans*) and downy mildew were natural candidates for cavity spot control. Screening of new products (mainly strobilurin chemistry) was last reported in 2001 in FV 5f (Pettitt et al., 2001). New candidate active ingredients and products were available from Bayer CropScience, BASF and other companies. These included active ingredients already showing promise in the USA (Farrar, 2009; University of Florida 2010. Plant Disease Management Guide: Chemical Control Guide for Diseases of Vegetables, Revision No.21). There were also opportunities to appraise treatment impacts on *Pythium violae* during the growing season using PCR methodology developed in FV 353. Measures of pathogen activity in relation to treatments will be undertaken during this project in collaboration with the University of Warwick.

There are also opportunities to evaluate non-fungicidal treatments including biological control agents (bacterial and fungal products are available), soil amendments and calcium treatments. The latter provided some useful activity in pot and field tests in FV 5f and have been used successfully against clubroot in vegetable brassicas (Defra project HH3227TFV - Clubroot control using novel and sustainable methods; HGCA work on oilseed rape (RD-2007-3373). Calcium applications can be made immediately prior to sowing (e.g. as Limex or Perlka). The effects of calcium are complex, extending beyond changes in soil pH to modification of soil microflora and direct effects on the host plant. There were beneficial effects against cavity spot even on high pH soils in pot tests in FV 5f. Previously, Scaife *et al.,* 1983 reported decreased incidence of cavity spot when soil exchangeable calcium exceeded 8 milliequivalents per 100 g soil. Further study will be required to quantify the benefits of liming against cavity spot and to understand when to integrate calcium into management regimes in carrots.

The use of varieties with resistance to cavity spot has been well established in the industry. However, resistance is incomplete and therefore additional control measures, particularly fungicides are still used. Whilst fungicide evaluation has been undertaken on more susceptible varieties, the benefits on the most resistant varieties should also be established. There may be opportunity to decrease dose or number of applications on the more resistant varieties. The contribution of host resistance and the need to add one or more control components should be tested on contrasting resistant and susceptible cultivars. It may be possible, in future to refine at field level, the range of measures that are required to control cavity spot.

The overall aim of this project was to improve the management and control of cavity spot. Specific objectives were:

1. To evaluate new fungicides and biological treatments with potential to control *Pythium* species in soil;
2. To establish optimum application rates and timings for the most promising new products;
3. To determine the contribution of pre-planting calcium applications for cavity spot control;
4. To determine the prevalence of enhanced degradation of metalaxyl-M in carrot growing areas.

Materials and methods

Field experiments - 2013

1. Retford, Notts

This replicated field experiment using a Chantenay variety was sown on 26 May 2013, 2 weeks after soil treatments (Limex at two rates and coded products HDC F166 and HDC F167 as a high volume spray) had been applied and incorporated by passage of the bed former. There were a total of 17 treatments (Table 1) replicated four times in a randomised block design. An untreated control and a grower standard treatment (SL567A applied 4 weeks post drilling at 1.3 L/ha) were included. Full details of treatment applications are given in Appendix 1. Plots were a standard bed width (1.8 m) and 5 m in length, with the exception of treatments 13-16 where soil incorporation was required for Limex, HDC F166 and HDC F167. These soil incorporation plots were 10 m bed lengths with 2 m discards at each end to prevent movement of treatments into the next plot. Soil samples were taken on 10 May for routine soil analysis, pH and calcium tests.

April 2013 had around half the average rainfall for the Notts area, with May having around average rainfall levels. Therefore conditions at drilling were fairly dry, particularly as the trial was established on free draining sandy loam. The crop grew well and regular crop vigour assessments were made (1-9 score, with 1 denoting the least vigorous and 9 the most vigorous plants). Carrot samples (100 roots) were taken throughout the season (23 August, 4 September, 15 September and 17 October) from control plots and examined for cavity spot. Additional soil samples were taken from all the control plots and Limex treatments on 13 May, 1 July and 30 October for pH and extractable (=free) calcium analyses.

The final harvest was delayed as long as possible to allow cavity spot to develop. Harvest yields were based on a harvested area of 1m x 1m from the centre of the bed. Cavity spot assessments were done on 50 roots per plot scoring disease incidence (% of roots affected) and severity (% area of roots affected). Site details are given in Appendix 3.

2. STC, Yorks

This field experiment was sown with a confidential, but susceptible cultivar on 21 May 2013, after soil treatments (Limex at three rates, HDC F166 and HDC F167) had been applied on 14 May and incorporated the same day by passage of a bed former. Similar to the Notts site, there were a total of 17 treatments replicated four times in a randomised block design. This site had a double untreated control and a grower standard treatment (SL567A applied once 32 days post drilling at 1.3 L/ha) included. Treatments were identical to those at Notts and post-emergence sprays were applied on 20 June, 31 July and 5 September. Plot sizes were 10m of bed length where incorporation of treatments (plus 2m guard at each end) was required and 5m bed length for post-emergence spray treatments. Soil samples were taken once for routine soil analysis and on three occasions for pH and calcium tests.

Regular assessments were made for phytotoxicity and foliar disease. Carrot samples were taken on 14 October and 12 November from control plots to monitor progression of cavity spot by determining the disease incidence and severity.

Soil samples were taken from all the control plots and Limex treatments on 13 May, 1 July and 30 October for pH and extractable (=free) calcium analyses.

The final harvest was delayed as long as possible to allow cavity spot development. Plots were harvested on 27 November. Harvest yields were based on a harvested area of 2m x 2m rows from the centre of the bed. Cavity spot assessments (number of lesions and percent of root affected) were done on 50 roots per plot subsampled from harvested roots. Site details are given in Appendix 4.

The treatment programmes for the 2013 trials at both sites are included in Table 3 below.

Table 3. Fungicides, biofungicides and Limex treatments examined for control of cavity spot, 2013.

	Application timing			
	7 Days Pre-drilling	4-6 weeks after drilling	4-6 weeks later	4 weeks later
1	Untreated	Untreated	Untreated	-
2	-	SL567A (1.3 L/ha)	-	-
3	-	SL567A (0.65 L/ha)	SL567A (0.65 L/ha)	-
4	-	SL567A (1.3 L/ha)	Switch 0.8 L/ha	Switch 0.8 L/ha
5	-	HDC F53 (4.5 kg/ha)	-	-
6	-	HDC F53 (2.25 kg/ha)	HDC F53 (2.25 kg/ha)	-
7	-	HDC F53 (4.5 kg/ha)	Nativo 75WG 0.3 L/ha	Nativo 75WG 0.3 L/ha
8	-	HDC F53 (4.5 kg/ha)	Nativo 75WG 0.3 L/ha + Rudis 0.4 L/ha	Nativo 75WG 0.3 L/ha + Rudis 0.4 L/ha
9	-	HDC F50 (3.2L/ha)	-	-
10	-	HDC F50 (3.2L/ha)	HDC F50 (3.2L/ha)	-
11	-	HDC F52 (10L/ha)	-	-
12	-	HDC F52 (10L/ha)	HDC F52 (10L/ha)	-
13	HDC F166	HDC F166	-	-
14	HDC F167	HDC F167	-	-
15	Limex 10 t/ha		-	-
16	Limex 10 t/ha	SL567A (1.3 L/ha)	-	-
17	Limex 15 t/ha	-	-	-

Product HDC F166 was a biofungicide; all other coded products are conventional fungicides.

Field experiments – 2011 and 2012

Field experiments in previous years were conducted along similar lines to those mentioned above. Full details are available in the annual reports which are available online from the HDC website: http://www.hdc.org.uk/project/carrots-improving-management-and-control-cavity-spot-4.

Metalaxyl-M degradation

Sampling for degradation study

Throughout the project, representative soil samples of approx. 1kg in weight were collected from each of thirty commercial carrot sites. The samples were kept cool and transported to Warwick Crop Centre, Wellesbourne for analysis. Sample sites were provided by members of the British Carrot Growers Association (BCGA) and were also used in another cavity spot project FV 373. Records are available for the incidence and severity of cavity spot from these sites, together with soil analysis and previous cropping details and will be reported in FV 373.

Details of the soil analyses which took place are included below:

Soil properties

a) Moisture holding capacity

Moisture holding capacity (MHC) was determined by saturating duplicate soil samples contained within a filter paper cone inside a plastic funnel. The soil surface was covered with polythene to prevent evaporation and excess water was allowed to drain for 24 hours into a conical flask. Sub-samples of the soil were dried to constant mass in a microwave oven to determine the moisture holding capacity of each soil. Subsequent degradation experiments were conducted at 50 % of the moisture holding capacity.

b) pH

A sub-sample from each soil sample was air-dried and sieved to 2 mm. 10 ml of soil was shaken with 25 ml R.O. water for 15 min and the pH measured using a calibrated pH meter.

c) Organic matter

A sub-sample from each soil sample was oven dried at 80°C to constant mass. Organic matter was determined by measuring the change in weight after combustion at 450°C. (Data not presented).

Degradation studies

a) Treatment and sampling

The soils were treated in two batches. Batch 1 contained 14 soils and batch 2 contained 13 soils. Both soil batches were treated in the same way and allowed to dry to a moisture level below 50% MHC. The moisture content was calculated by drying a sub-sample to constant mass in an oven and mass equivalent to 600 g dry soil was taken and spread out on polythene sheets. A solution of metalaxyl-M was prepared from SL567A (Syngenta) containing 0.6 mg a.i./ml. Each soil was treated with 10 ml of the treatment solution (6 mg a.i.) by 'dribbling' from a 10 ml pipette over the soil surface. Further water was added, as required, to take the soil moisture content up to 50% MHC. The soils were allowed to equilibrate (15 – 30 minutes), mixed by hand and split equally between two polythene bottles (600 ml). The bottles were loosely sealed and transferred to an incubator maintained at 15°C. Sub samples (20 g) were taken from each bottle 0, 5, 11, 18 and 25 days after treatment and weighed into polythene centrifuge tubes (50 ml). The centrifuge tubes were sealed and frozen until extraction.

b) Extraction and analysis

The centrifuge tubes were removed from the freezer and the soil was allowed to defrost. Methanol (30 ml, HPLC grade) was added and the tubes were shaken (end-over-end) for 1 hour. The tubes were centrifuged (1 min, 9000 rpm) and a sub-sample (approximately 1.5 ml) of the supernatant was transferred to an HPLC vial using a polythene Pasteur pipette. The vial was sealed and frozen until analysis.

Before analysis, samples were allowed to warm to room temperature and shaken. Analysis was performed on a 1100 series Agilent High Performance liquid Chromatograph (HPLC) fitted with a Genesis C8 column (25 cm x 4.6 mm). The mobile phase was acetonitrile:water (70:30) at a flow rate of 1.2 ml/min and detection was by UV absorption at 220 nm. The retention time of metalaxyl-M was 3.6 mins and quantification was performed by comparison with an external standard of metalaxyl-M (6 µg/ml in methanol).

c) Half-life

The results for each soil were plotted. First order kinetics was assumed so the plots were fitted to an exponential curve. Half-lives were calculated based on the formulae of the curves.

Laboratory experiment – 2013

A replicated experiment was set up in the ADAS Boxworth pathology laboratory to investigate the efficacy of six fungicides against mycelial growth of *P. violae*. Products known to have efficacy against oomycete diseases were evaluated. These products were HDC F168, HDC F169, HDC F170, HDC F171 and HDC F172. SL567A (metalaxyl-M) is approved for use on outdoor carrots, and was used as the industry standard to compare with the experimental products.

Fungicides were tested against mycelial growth of *P. violae* using agar plates amended with each fungicide at four concentrations (0.01, 0.1, 1, 10 and 100 ppm active ingredient). Corn Meal Agar (CMA) was autoclaved and transferred to bottles held in a water bath at 50°C. In a laminar flow cabinet, each bottle was amended with a calculated amount of fungicide stock solution so that the plates poured would be at the appropriate concentration. Control plates remained free of fungicide. Agar plates were allowed to set and were stored in a dark refrigerator until required.

Plates were inoculated in a laminar flow cabinet using a 0.5 mm (No.2) cork borer, taking *P .violae* from the edge of actively growing colonies also grown on CMA. The experiment was replicated four times and three isolates were used (2C, 3A and 26B, received from University of Warwick and isolated from the same affected field). Inoculated plates were placed in a dark incubator at 20°C. Assessments were carried out 1.5 and 3 days later and involved measuring colony diameter twice at right angles. The degree of inhibition for a fungicide concentration was calculated by comparing growth of an isolate on a fungicide amended plate with that on unamended control plates, using the formula below.

$$\%\text{ inhibition} = \frac{(\text{growth on control agar} - \text{growth on fungicide agar})}{\text{growth on control agar}} \times 100$$

Results

Field experiments - 2013

1. Retford, Notts

Overall

Cavity spot occurrence was lower in 2013 compared to 2012, with incidence reaching levels up to 19% of roots affected in the untreated controls.

Cavity spot

At an 8% probability level, five treatments (Treatments 3, 4, 15, 16 and 17) resulted in notable decreased disease incidence compared with the untreated control (19.0%) (Table 4). Cavity spot incidence was least at 4.8% where Tr 4 (SL567A, 0.65 L/ha followed by two applications of Switch 0.8 L/ha) had been applied. Where Limex was applied at 15 t/ha (Tr 17), cavity spot incidence was 5%. Limex at 10 t/ha was tested with and without SL567A (1.3 L/ha 4 to 6 weeks post-drilling) and both decreased cavity spot incidence to 6% (Tr 15 and Tr 16). The inclusion of SL567A at 1.3 L/ha following Limex did not provide additional cavity spot control. SL567A at 0.65 L/ha applied twice after drilling provided a significant decrease in cavity spot incidence to 6.2% (Tr 3). The standard treatment SL567A at 1.3 L/ha applied once after drilling, decreased cavity spot incidence to a similar extent.

All experimental fungicides appeared to give reductions in cavity spot incidence, however, none gave significant reductions relative to the untreated control. Experimental fungicide HDC F50 applied twice after drilling was only marginally not significant from the untreated control with cavity spot incidence of 7.8%. However, when HDC F50 was applied once at 4 weeks after drilling, cavity spot incidence was 18%. No reductions were observed for experimental products applied once only at 4 weeks after drilling or in programmes with other products compared with the untreated control.

Disease severity, as determined by the percentage root area affected by cavity spot, was low with 0.37% root area affected in the untreated control and differences between treatments were not statistically significant. Limex at 10 t/ha resulted in the smallest root area to be affected by cavity spot (0.03%), however Tr 2 (SL567A), Tr 3 (SL567A applied twice), Tr 4 (SL567A followed by Switch) and Tr 17 (Limex 15 t/ha) all resulted in between just 0.04 to 0.07% root area affected.

Considering the percentage root area affected of infected carrots, there were significant decreases ($P<0.05$) for five treatments compared with the untreated control (1.88% root area affected). Tr 2 (SL567A at 1.3 L/ha), Tr 3 (SL567A at 0.65L/ha applied twice), Tr 4 (SL567A applied at 1.3 L/ha, followed by Switch at 0.8L/ha twice), Tr 17 (Limex 15 t/ha) and Tr 16 (Limex 10 t/ha followed by SL567A) all resulted in significant control with disease severities <0.75% root area affected. Increasing the dose of Limex from 10 t/ha to 15 t/ha was found to decrease the severity of cavity spot by 45% in this assessment category.

Table 4. Effect of fungicide, biofungicide and Limex treatment on carrot cavity spot at harvest – Notts site, 3 December, 2013.

	Application timing				Cavity spot				
					Incidence	Severity			
	7 Days Pre-drilling	4-6 weeks after drilling	4-6 weeks later	4 weeks later	% of carrots affected	% area affected	% area of infected carrots affected	No. Cavities per infected carrot	No. Cavities per carrot
1	Untreated	Untreated	Untreated		19	0.37	1.88	1.25	0.26
2		SL567A (1.3 L/ha)	-		8	0.07	**0.62**	0.8	0.09
3		SL567A (0.65 L/ha)	SL567A (0.65 L/ha)		6.2	0.05	**0.75**	1.17	0.08
4		SL567A (1.3 L/ha)	Switch 0.8 L/ha	Switch 0.8 L/ha	4.8	0.04	**0.5**	0.75	0.05
5		HDC F53	-		12	0.2	1	1.13	0.18
6		HDC F53	HDC F53		15.5	0.26	1.5	1.3	0.22
7		HDC F53	Nativo 75WG 0.3 L/ha	Nativo 75WG 0.3 L/ha	18.5	0.38	1.62	1.16	0.21
8		HDC F53	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	20.5	0.37	1.88	1.22	0.26
9		HDC F50	-		18	0.31	1.38	1.21	0.23
10		HDC F50	HDC F50		7.8	0.15	1.88	1.49	0.1
11		HDC F52	-		8.5	0.11	1	1.26	0.12
12		HDC F52	HDC F52		14	0.27	1.88	1.27	0.18
13	HDC F166	HDC F166	-		18.5	0.48	2.25	1.29	0.25
14	HDC F167	HDC F167	-		15.8	0.36	1.5	1.25	0.22
15	Limex 10 t/ha		-		6	0.1	1.38	1.17	0.08
16	Limex 10 t/ha	SL567A (1.3 L/ha)	-		6	0.04	**0.56**	0.75	0.06
17	Limex 15 t/ha	-	-		5	0.03	**0.62**	1.44	0.07
Fpr					0.08	0.19	0.022	0.497	0.099
SED					6.22	0.178	0.54	0.306	0.092
LSD					12.5	0.359	1.09	0.615	0.184

Values in bold are significantly different from the untreated at P<0.05.

Treatment effects against alternaria blight

When considering the additional benefits of treatments, it was found that several products and programmes gave a reduction in alternaria blight (*Alternaria dauci*) (Table 5). At the first assessment on 1 October 2013, 25.2% leaf area was affected by alternaria blight in the untreated control and statistically significant differences were identified between treatments. Tr 8, which comprised HDC F53 4 weeks post drilling followed by Nativo 75WG and Rudis 4 and 8 weeks later, was the most effective treatment overall, reducing leaf area affected to 6.2%. Tr 7 which contained HDC F53 followed by Nativo 75WG twice offered significant control with 9.7% plot area affected. Treatments which included HDC F52 were also found to be effective, reducing leaf area affected to between 8.5% and 10.8%. At the second assessment on 17 October 2013 untreated alternaria levels remained the same (25%), however there were significant levels of disease control from a number of fungicides. Tr 8 (HDC F53 4 weeks post drilling followed by Nativo 75WG and Rudis 4 and 8 weeks later) remained the most effective treatment (0.1%), with clear improvements in control from Tr 5 (HDC F53 applied once post drilling) to Tr 8, with the inclusion of additional products improving disease control. Treatments 9, 10, 11 and 12 (HDC F50 applied once or twice and HDC F52 applied once or twice) also provided high levels of control (3.0-3.7%). The standard, SL567A applied either once or twice post drilling, did not provide significant control of alternaria, however where SL567A was followed by Switch twice (Tr 4) percentage leaf area affected was reduced significantly. A significant increase in green leaf area (GLA) remaining relative to the untreated control (67.3%) was observed for Tr 8, which contains HDC F53 at 4 weeks post drilling followed by Nativo 75WG and Rudis 4 and 8 weeks later (84.8%). Tr 7 which contains HDC F53 and Nativo 75WG also had significantly greater GLA (76.8%) than the control as did Tr 16, which contained Limex at 10 t/ha and SL567A (76.8%).

Table 5. Effect of fungicide, biofungicide and Limex treatment on alternaria levels and green leaf area – Notts site, 2013.

	Timing 1	Timing 2	Timing 3	Timing 4	Alternaria (% LA affected)		Green LA (%)
	7 Days Pre - drilling	4-6 weeks after drilling	4-6 weeks after Timing 2	4 weeks after Timing 3	01/10/2013	17/10/13	17/10/2013
1	Untreated	Untreated	Untreated		25.2	25	67.3
2		SL567A (1.3 L/ha)	-		25	15.5	67.5
3		SL567A (0.65 L/ha)	SL567A (0.65 L/ha)		15.5	13.7	69.5
4		SL567A (1.3 L/ha)	Switch 0.8 L/ha	Switch 0.8 L/ha	15	**9.7**	73.8
5		HDC F53	-		16.5	**7**	70.8
6		HDC F53	HDC F53		22.5	**5.7**	70.5
7		HDC F53	Nativo 75WG 0.3 L/ha	Nativo 75WG 0.3 L/ha	**9.7**	**3.9**	**76.5**
8		HDC F53	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	**6.2**	**0.1**	**84.8**
9		HDC F50	-		25	**3.1**	68.8
10		HDC F50	HDC F50		18.5	**3.7**	70.3
11		HDC F52	-		**10.8**	**3.7**	73
12		HDC F52	HDC F52		**8.5**	**3**	**76.8**
13	HDC F166	HDC F166	-		20.5	15.5	67.5
14	HDC F167	HDC F167	-		22.5	14.2	66.8
15	Limex 10 t/ha		-		22.2	**11.2**	65.5
16	Limex 10 t/ha	SL567A (1.3 L/ha)	-		13.8	**11.7**	**76.8**
17	Limex 15 t/ha	-	-		14.5	15.2	74.3
	Fpr				0.033	0.029	0.001
	SED				6.12	6.46	3.97
	LSD				12.31	12.99	7.98

Values in bold are significantly different from the untreated at P<0.05.

Yield

Yield was not significantly affected by treatment, although there was a trend for the untreated to have the lowest total yield (5.16 kg/m^2) and marketable yield (4.22 kg/m^2) (Table 6). The treatment with the highest marketable yield was Tr 17 (6.12 kg/m^2) which was Limex at 15 t/ha, consistent with this treatment providing good cavity spot control. Tr 12, HDC F52 when applied at twice post drilling, was also found to provide reasonable marketable yields (5.73 kg/m^2). The treatment with the highest total yield was Tr 7 (6.99 kg/m^2) which contained HDC F53, Nativo 75WG and Rudis, which is consistent to this treatment having the lowest levels of alternaria and also the highest green leaf area.

Table 6. Effect of fungicides, biofungicides and Limex treatments on yield of carrots – Notts site, 2013.

	Application timing				Total Yield	Marketable yield
	7 Days Pre-drilling	4-6 weeks after drilling	4-6 weeks later	4 weeks later	(kg/m^2)	(kg/m^2)
1	Untreated	Untreated	Untreated		5.16	4.22
2		SL567A 1.3 L/ha	-		6.35	5.82
3		SL567A 0.65 L/ha	SL567A 0.65 L/ha		5.86	5.50
4		SL567A 1.3 L/ha	Switch 0.8 L/ha	Switch 0.8 L/ha	5.95	5.67
5		HDC F53	-		6.02	5.27
6		HDC F53	HDC F53		5.81	4.93
7		HDC F53	Nativo 75WG 0.3 L/ha	Nativo 75WG 0.3 L/ha	6.19	4.96
8		HDC F53	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	6.99	5.51
9		HDC F50	-		6.26	5.21
10		HDC F50	HDC F50		6.36	5.86
11		HDC F52	-		6.15	5.64
12		HDC F52	HDC F52		6.62	5.73
13	HDC F166	HDC F166	-		6.12	4.98
14	HDC F167	HDC F167	-		5.66	4.9
15	Limex 10 t/ha		-		6.01	5.65
16	Limex 10 t/ha	SL567A (1.3 L/ha)	-		5.87	5.54
17	Limex 15 t/ha	-	-		6.45	6.12
Fpr					0.514	0.499
SED					0.588	0.675
LSD					1.182	1.357

In-season progress of cavity spot

Samples were taken from the untreated control plots to monitor disease progress at the Notts site. Cavity spot incidence was low throughout the season ranging from 1 to 3%, and severity scores ranged from 0.01 to 0.09% root area affected (Table 7). Scab (*Streptomyces scabies*) incidence was slightly higher, with 5% of roots affected at the 17 October assessment.

Table 7. Disease progress through growing season (100 carrots from across the untreated plots).

Date	Cavity spot incidence (% of roots affected)	Cavity Spot severity (% root area affected)	Cavity Spot severity No. lesions / carrot	Scab incidence (% of roots affected))	Scab severity (% root area affected)
23/08/2013	3	0.09	0.04	1	0.01
04/09/2013	1	0.01	0.01	1	0.01
15/09/2013	1	0.01	0.01	2	0.02
17/10/2013	3	0.03	0.03	5	0.05

Soil pH

Soil pH analysis was conducted on the untreated control and the three Limex treatments (Treatments 1, 15, 16 and 17) to quantify effects on soil acidity at three timings: at drilling, mid-season, and pre harvest. At drilling there were significant pH differences (P=0.006) (Table 8). The untreated control had the lowest pH (pH 6.32), with the Limex treatments having a pH significantly greater than this (pH 6.61-6.76). At the October sample timing, significant differences between treatments were still apparent. The untreated had a pH significantly lower (7.1) than the other treatments (>7.5). Treatments 15 and 16 both had Limex applied at 10 t/ha, and pH results were similar (pH 7.48-7.53). Tr 17 (Limex applied at 15 t/ha) had the greatest pH of 7.58, however this was not significantly greater than Limex 10 at t/ha (Table 8).

Table 8. Effect of soil liming on soil pH and extractable calcium at 0, 7 and 25 weeks after Limex application – Notts, 2013.

Treatment	Limex Rate (t/ha)	Soil pH 13-May	Soil pH 01-Jul	Soil pH 30-Oct	Soil Ca (mg/L) 13-May	Soil Ca (mg/L) 01-Jul	Soil Ca (mg/L) 30-Oct
1	0	6.5	6.3	7.1	869	925	756
15	10	6.3	6.6	7.5	778	1074	1083
16	10	6.1	6.8	7.5	762	1279	1045
17	15	6.3	6.7	7.6	770	1353	1158
Fpr		0.026	0.006	0.008	0.035	0.047	0.002
SED		0.1	0.1	0.12	33.4	138.8	74.2
LSD		0.22	0.22	0.28	75.6	313.9	167.9

Available Calcium

At the drilling assessment (13 May), calcium availability followed a similar trend to the pH results (Table 8). The untreated control had the greatest calcium availability (869 mg/l), significantly more than the other treatments (762-778 mg/l), although there were no significant differences between the Limex treatments (P>0.05). At the July assessment, differences in calcium availability between the untreated control and Limex treatments were larger. Tr 17 (Limex at 15 t/ha) had the greatest calcium availability (1353 mg/l), with a trend for higher levels of available calcium than Tr 15 (Limex 10 at t/ha, 1074 mg/l), as well as Tr 16 (Limex at 10 t/ha followed by Metalaxyl-M, 1279 mg/l). At the October assessment, calcium availability had decreased for all treatments. The results followed a similar trend to the July assessment, with Tr 16 (Limex at 15 t/ha), having significantly higher levels of available calcium (1158 mg/l) than the untreated (756 mg/l), however not significantly different to the 10 t/ha Limex treatments (Tr15 and 17; 1045-1059 mg/l).

Weather

Rainfall was minimal for the period around the first spray application, although May rainfall was not significantly different from the 20 year average. June continued to be a dry month at Notts, with below average rainfall (112 mm), although temperature was around average (13.2^{O}C). July and August continued to provide average rainfall, with September seeing rainfall drop below half the average for September (49.6mm). This trend did not continue into October, when the trial received above average rainfall. Further details are available in Appendix 5 (Figure 11 and Figure 12).

2. STC, North Yorkshire

Overall

The Yorks site had a higher level of cavity spot than the Notts site with an untreated disease incidence of 55.8%, which is just slightly lower than the high disease incidence of 64.8% seen in 2012. Disease severity in the untreated control however was still low, with only 0.72% root area affected by cavities. Although disease incidence was high, there were differences in disease development across the trial site, which added variation to the results.

Cavity spot

Cavity spot incidence was not significantly different between treatments (P = 0.138) (Table 9). The lowest disease incidence was found with Tr 16, pre-drilling Limex at 10 t/ha followed by SL567A at 4 weeks post drilling (33.5% incidence). Limex applied pre-drilling at 15 t/ha also appeared to reduce the disease with 36% incidence. SL567A applied at two treatment timings had the same level of disease (36%) as the Limex at 15t/ha. Tr 8 (HDC F53), followed by Nativo 75WG and Rudis) had the greatest level of cavity spot with a disease incidence higher than the untreated control (65% incidence). A similar trend was apparent for Tr 7, which contained HDC F53 followed by Nativo 75WG (62.5% incidence), as well as Tr 12 which contained HDC F52 (61.5% incidence). Although not statistically significant, these results match well with those achieved at the Notts site.

There were significant differences between treatments in cavity spot severity (P=0.027), although no treatment reduced the disease compared with the untreated control. There were however trends towards disease reduction with some treatments. Disease severity in the untreated control was 0.72% carrot area affected. Limex at 15 t/ha appeared the most effective treatment overall with a severity of 0.23% root area affected, along with SL567A (0.65L/ha applied twice) (0.29% root area affected). SL567A (1.3 L/ha) (Tr 2) applied once 4 weeks post drilling appeared to provide reasonable control, with 0.36% root area affected. Application of SL567A at 1.3 L/ha followed with applications of Switch 0.8 L/ha (Tr 4) had a similar level of disease to SL567A alone (0.37% root area affected). Some treatments had significantly greater disease severity than the untreated. The least effective treatment was Tr 7 (HDC F53 followed by Nativo 75WG twice; 1.71% root area affected). Tr 8 (HDC F53 followed by Nativo 75WG plus Rudis) also was found to have significantly greater cavity spot severity than the untreated (1.46% root area affected).

The number of cavities per infected carrot was also assessed, with results correlating well with the incidence and severity scores. Limex at 15 t/ha (Tr 17), was the most effective treatment with 0.95 cavities on average per infected carrot. SL567A applied twice at 0.65L/ha (Tr 3), as well as SL567A applied once at 1.3L/ha (Tr 2) appeared to reduce severity, with 1.23 and 1.77 cavities per carrot respectively. No treatment had significantly fewer cavities per root than the untreated, however some treatments did result in a significantly greater number of cavities per root. As with the incidence and severity scores, the trend continued with HDC F53, followed by Nativo 75WG (Tr 7) having the highest number of cavities per carrot (6.01), closely followed by HDC F53, followed by Nativo 75WG + Rudis (Tr 8) with an average of 9.7 cavities per carrot. The number of cavities per infected carrot demonstrated a similar trend.

Table 9. Effect of fungicide, biofungicide and Limex treatments on carrot cavity spot at harvest – STC site, 2013.

	Application timing				Cavity spot	Cavity Spot	
					incidence	severity	
	7 Days Pre-drilling	4-6 weeks after drilling	4-6 weeks later	4 weeks later	(% of carrots affected)	(% area affected)	(No. Cavities per infected root)
1	Untreated	Untreated	Untreated		55.8	0.72	3.55
2		SL567A (1.3 L/ha)	-		44	0.36	1.77
3		SL567A (0.65 L/ha)	SL567A (0.65 L/ha)		36	0.29	1.23
4		SL567A (1.3 L/ha)	Switch 0.8 L/ha	Switch 0.8 L/ha	40	0.37	2.38
5		HDC F53	-		49	0.87	5.02
6		HDC F53	HDC F53		47	0.49	2.89
7		HDC F53	Nativo 75WG 0.3 L/ha	Nativo 75WG 0.3 L/ha	62.5	**1.71**	9.72
8		HDC F53	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	65	**1.46**	9.72
9		HDC F50	-		46.5	0.55	2.63
10		HDC F50	HDC F50		57.5	0.95	5.38
11		HDC F52	-		61.5	1.2	6.3
12		HDC F52	HDC F52		44.5	0.66	3
13	HDC F166	HDC F166	-		44.5	0.87	4.28
14	HDC F167	HDC F167	-		56	0.78	5.06
15	Limex 10 t/ha		-		53	0.97	6.35
16	Limex 10 t/ha	SL567A (1.3 L/ha)	-		33.5	0.62	2.22
17	Limex 15 t/ha	-	-		36	0.23	0.95
	Fpr				0.138	0.027	0.019
	SED	min.rep			11.41	0.403	2.548
		max-min			9.88	0.349	2.206
	LSD	min.rep			22.9	0.809	5.112
		max-min			19.84	0.7	4.427

Values in bold are significantly different from the untreated at P<0.05.

Yield

Total yield was not significantly different between treatments (Fpr 0.848), although yields from most treatments (Table 10) were higher than the untreated control, with the exception of Tr14 (HDC F167) and Tr 15 (Limex at 10 t/ha). Marketable yield also was not significantly different between treatments (Fpr 0.33), with Tr14 and 15 again showing a trend for the lowest yields.

Table 10. Effect of fungicides, biofungicides and Limex treatments on yield of carrots – STC site, 2013.

	Application timing				Total yield (kg/m^2)	Marketable yield (2 rows x 2 m)
	7 Days Pre-drilling	4-6 weeks after drilling	4-6 weeks later	4 weeks later		
1	Untreated	Untreated	Untreated		18.34	16.03
2		SL567A (1.3 L/ha)	-		19.36	17.67
3		SL567A (0.65 L/ha)	SL567A (0.65 L/ha)		19.58	18.41
4		SL567A (1.3 L/ha)	Switch 0.8 L/ha	Switch 0.8 L/ha	18.65	17.33
5		HDC F53	-		19.95	16.49
6		HDC F53	HDC F53		19.18	17.49
7		HDC F53	Nativo 75WG 0.3 L/ha	Nativo 75WG 0.3 L/ha	18.87	12.88
8		HDC F53	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	Nativo 75WG 0.3 L/ha +Rudis 0.4 L/ha	19.27	14.87
9		HDC F50	-		19.06	16.91
10		HDC F50	HDC F50		19.38	15.52
11		HDC F52	-		19.57	15.52
12		HDC F52	HDC F52		20.16	17.36
13	HDC F166	HDC F166	-		19.8	17.36
14	HDC F167	HDC F167	-		17.08	13.84
15	Limex 10 t/ha		-		18.11	14.44
16	Limex 10 t/ha	SL567A (1.3 L/ha)	-		19.68	17.96
17	Limex 15 t/ha	-	-		19.86	19.09
	Fpr				0.848	0.33
	SED	min.rep			1.436	2.237
		max-min			1.244	1.937
	LSD	min.rep			2.882	4.489
		max-min			2.496	3.888

Soil pH

Soil pH analysis was conducted on the three Limex treatments (Tr 15, 16 and 17) in order to quantify the treatment effects upon soil acidity (Table 11). The pre drilling sample identified little difference between pH (6.22-6.37). Near significant differences were identified at the July assessment with a pH of 6.49 in the untreated control compared to pH 6.73-6.88 for the Limex treatments. Differences between individual Limex treatments however were not identifiable at this stage. At the harvest assessment, greater separation was apparent between all the treatments. No significant differences were identified between treatments, however the results followed a similar trend to those at the Notts site, with Tr 17 (Limex at 15 t/ha) having the greatest pH effect (7.6), slightly greater than Limex at 10 t/ha (7.4-7.5 pH).

Calcium

Available calcium was found to be consistent across all treatments at the pre drilling sample (987-1026 mg/l) (Table 11). Available calcium peaked at the July assessment, with levels of available calcium reaching 1494 mg/l for Tr 16 (Limex at 15 t/ha). The untreated control had significantly less available calcium (1155 mg/l) than Tr 16. The Limex at 10 t/ha treatments showed a trend for reduced calcium availability compared with the Limex at 15 t/ha, but differences were not significant. At the October sample, available calcium levels had dropped from the July assessment levels, with no significant differences identified between treatments. All Limex treatments had similar levels of available calcium (1245-1271 mg/l), but the untreated control had notably less (998 mg/l).

Table 11. Effect of soil liming on soil pH and extractable calcium at 0, 6 and 23 weeks after Limex application – Yorks, 2013.

Treatment	Limex Rate	Soil pH			Soil Ca (mg/L)		
	(t/ha)	13-May	01-Jul	30-Oct	13-May	01-Jul	30-Oct
1	0	6.4	6.5	7	1026	1155	998
15	10	6.3	6.9	7.5	1012	1366	1245
16	10	6.2	6.7	7.4	987	1376	1254
17	15	6.3	6.8	7.6	1023	1494	1271
Fpr		0.598	0.073	0.074	0.888	0.002	0.124
SED		0.12	0.13	0.21	55.1	58.8	115.9
LSD		0.26	0.3	0.49	124.7	132.9	262.1

Metalaxyl-M degradation study – 2013

Soil samples from both the Notts and Yorks experimental sites were sent to Warwick Crop Centre, Wellesbourne for degradation analysis. The analysis revealed that the Notts site had a half-life of 10 days (Figure 1) and the Yorks site had a half-life of 7.8 days. Both soil types were considered to be fast degrading soils, which would have been likely to reduce the level of control achieved by metalaxyl-M.

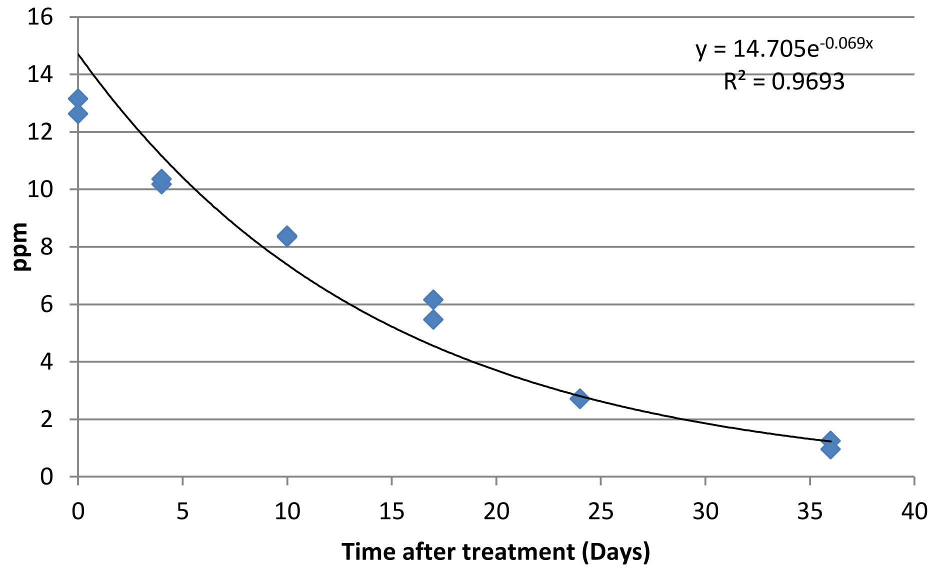


Figure 1. Degradation results from the Notts site, 2013.

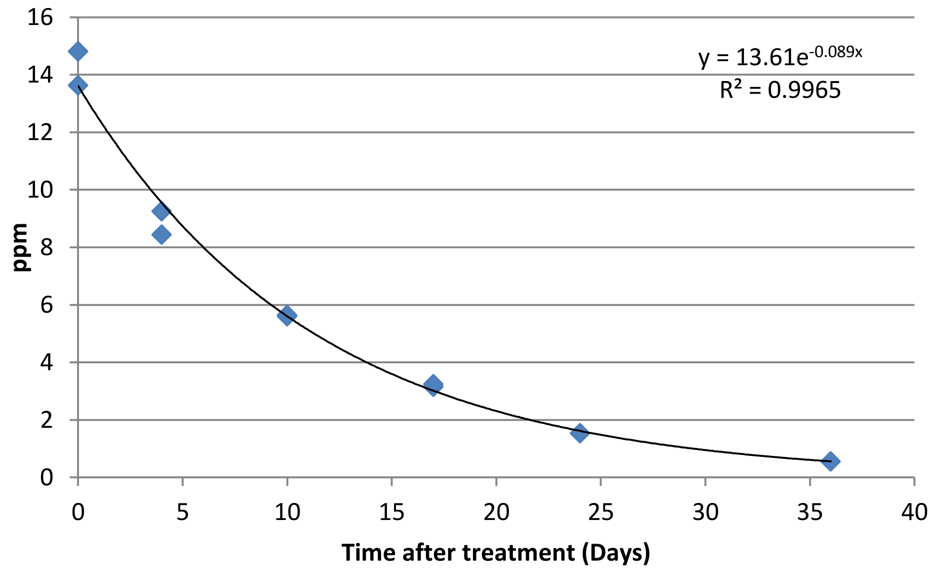


Figure 2. Degradation results from the Yorks site, 2013.

Laboratory experiment - 2013

All products tested had some inhibitory effect on the growth of *P .violae* in culture at all concentrations. SL567A was most effective, and was over 95% inhibitory at 0.1 ppm and upwards (Table 12 and Figure 13). HDC F169 and HDC F170 were the two least effective products, achieving 25.2% and 45.3% growth inhibition respectively at 100 ppm.

Increasing efficacy with concentration of fungicide product can be seen in the figures below. ED50, the median effective dose, was also calculated for each fungicide and also shows treatments 1 (SL567A) and 6 (HDC F172) (Figure 5) to most effectively inhibit *P .violae*. Tr 5 (HDC F171), most closely fitted the dose response expected (p=0.0025) (Figure 6). Results from SL567A fit well with the results from the field experiments, with this product being consistently effective across sites and years at reducing cavity spot symptoms.

Table 12. % Effect of six fungicides at a range of concentrations on the growth of *P. voilae* (mean of 3 isolates).

	Treatment	Concentration	Mean % inhibition	ED50
1	SL567A	0.01	19.92	0.01
		0.1	99.43	
		1	98.97	
		10	98.89	
		100	99.32	
2	HDC F168	0.01	7.53	0.33
		0.1	14.34	
		1	81.78	
		10	99.40	
		100	95.73	
3	HDC F169	0.01	4.83	*
		0.1	4.20	
		1	5.78	
		10	-2.54	
		100	25.21	
4	HDC F170	0.01	16.06	4.11
		0.1	6.50	
		1	22.15	
		10	41.56	
		100	45.29	
5	HDC F171	0.01	16.56	0.47
		0.1	34.59	
		1	69.14	
		10	95.43	
		100	99.28	
6	HDC F172	0.01	4.50	0.15
		0.1	48.89	
		1	76.41	
		10	93.78	
		100	96.64	

*ED50 could not be calculated for treatment 3, as levels of inhibition approaching 50% were never realised.

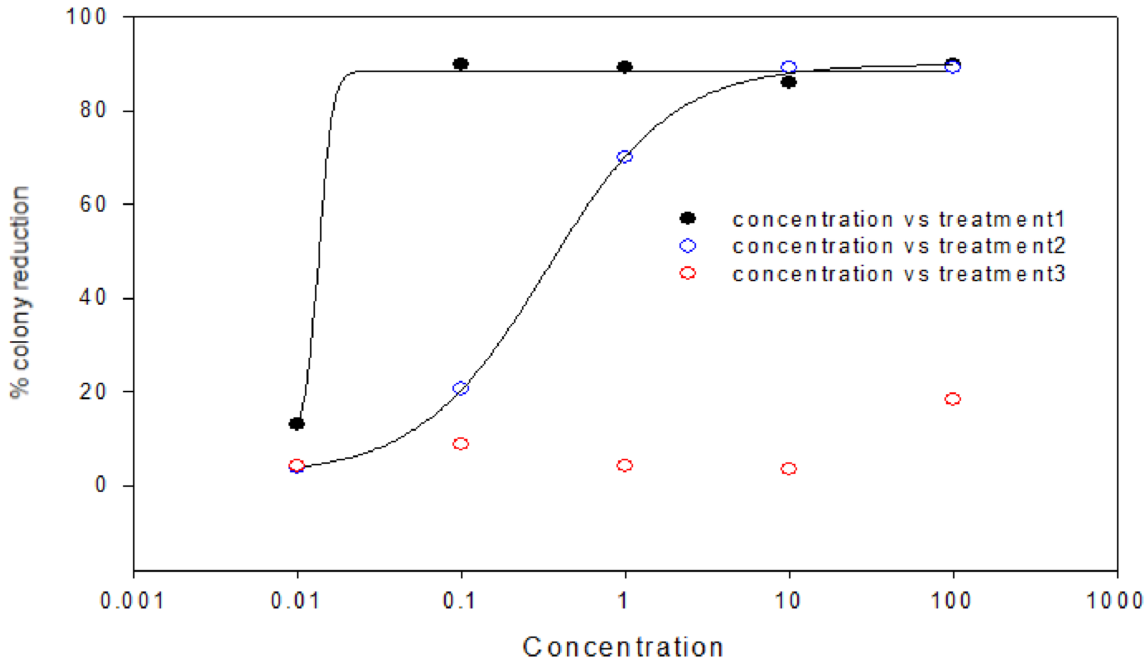


Figure 3. Dose response curves for treatments 1-3 (SL567A, HDC F168 and HDC F169). No dose response curve could be fitted for treatment 3.

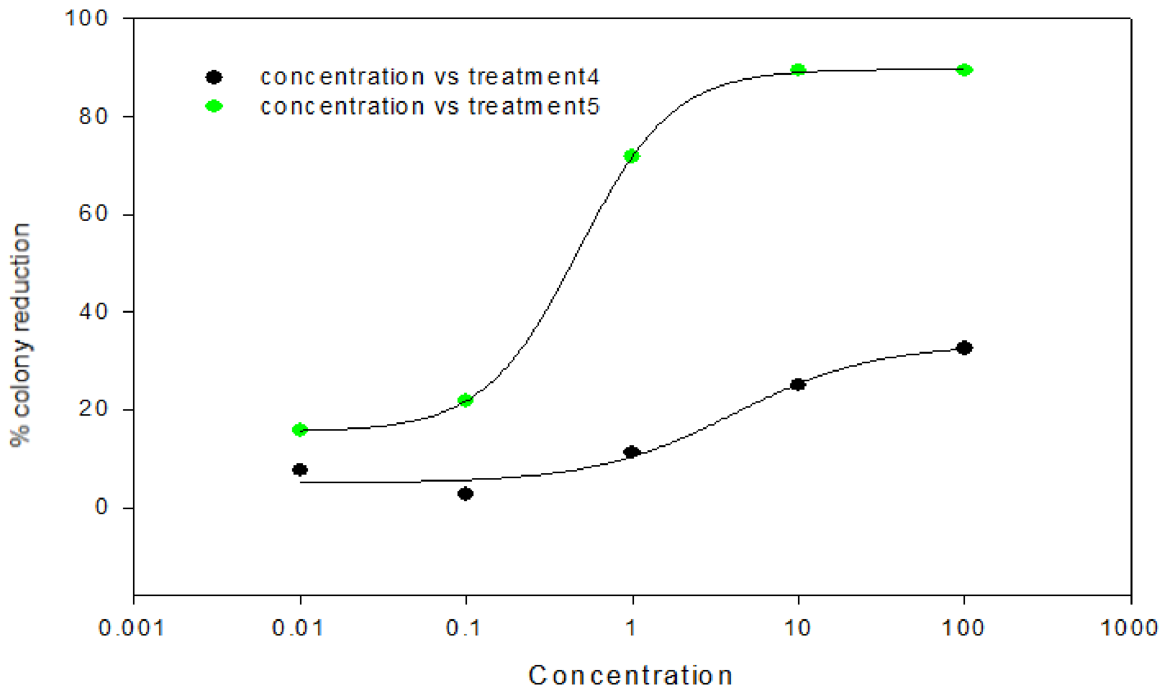


Figure 4. Dose response curves for treatments 4 and 5 (HDC F170 and HDC F171).

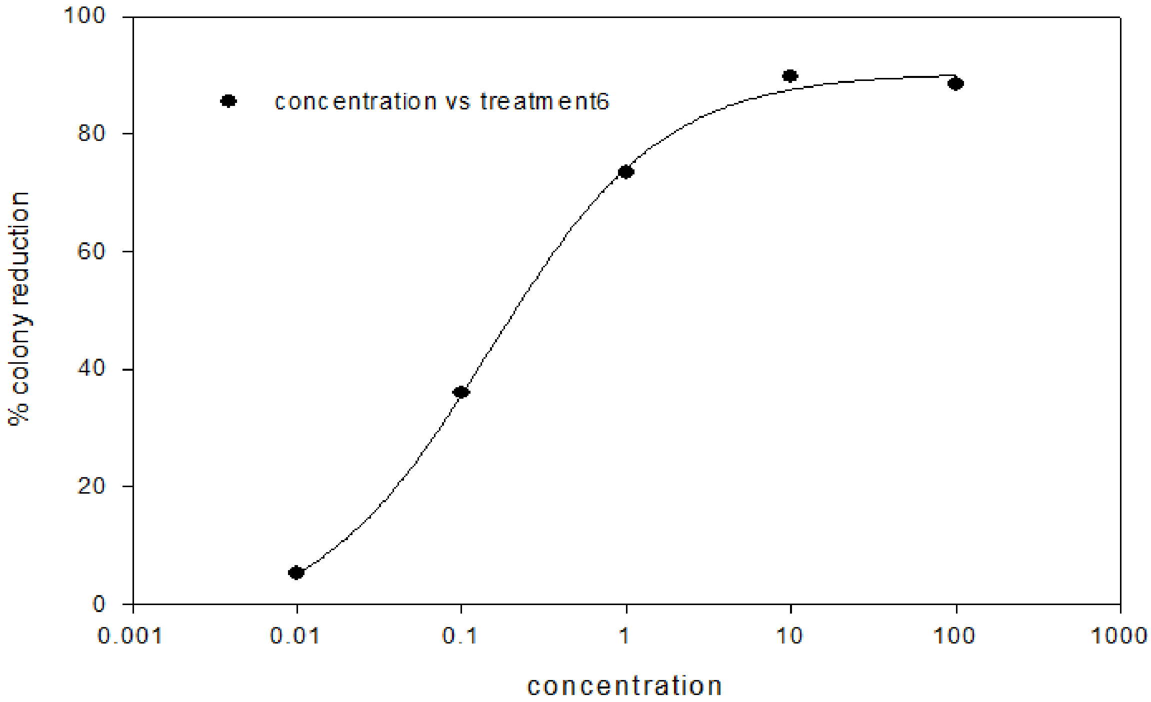


Figure 5. Dose response curve for treatment 6 (HDC F172).

Examination of overall results, 2011-2013

Overall cavity spot control

SL567A resulted in the lowest cavity spot incidence on average over all sites and seasons, with Limex also offering very good control in a number of experiments. When Limex at 10 t/ha was included with SL567A in 2013, at both sites the combination appeared to perform better than either product alone but efficacy was not significantly improved. A cross-site analysis confirms the significant differences between sites and years as expected (Figure 6). There is a significant difference in treatments, and this is probably due to the consistent performance of SL567A.

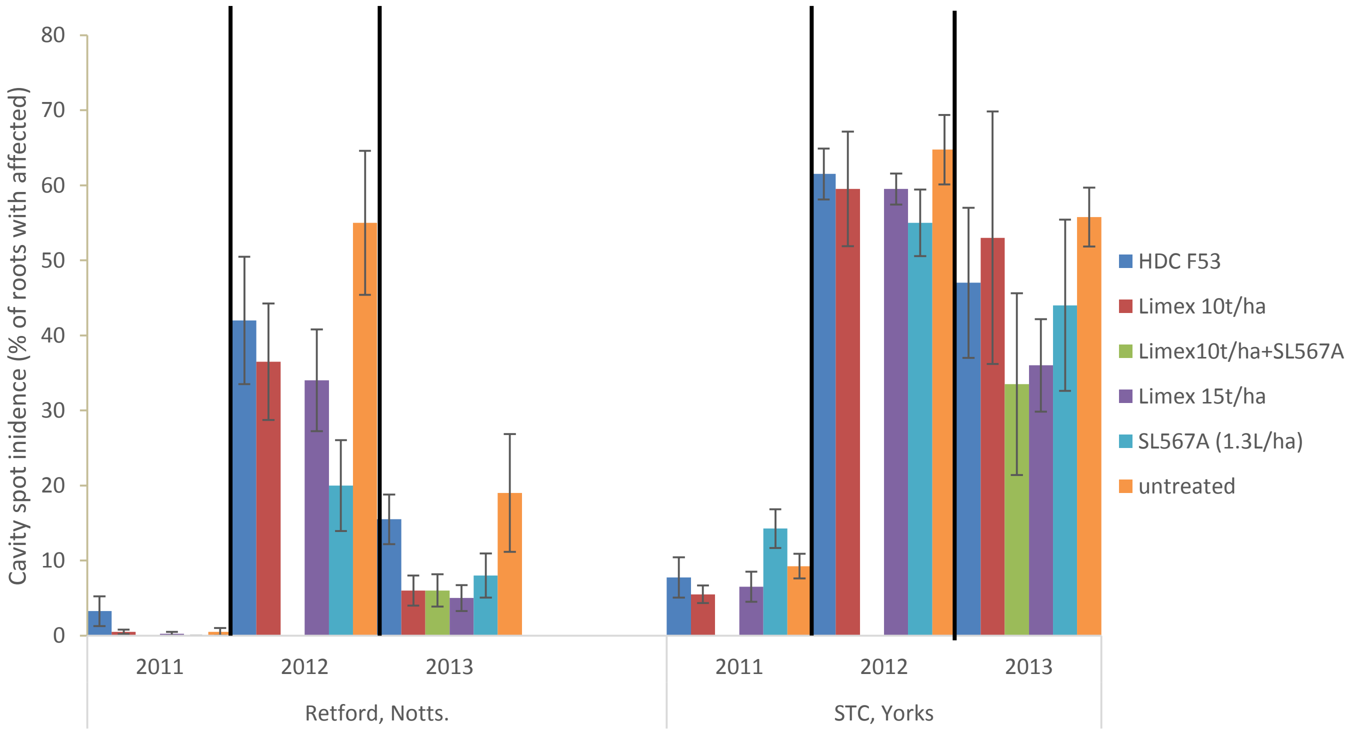


Figure 6. Cavity spot incidence (% of roots affected) across all site seasons, showing results for treatments which were present in all 3 years of the project (2011-2013). Error bars represent standard error.

Severity scores (% root area affected) were low across all sites and seasons, with the Notts sites having noticeably lower severity (Figure 7).

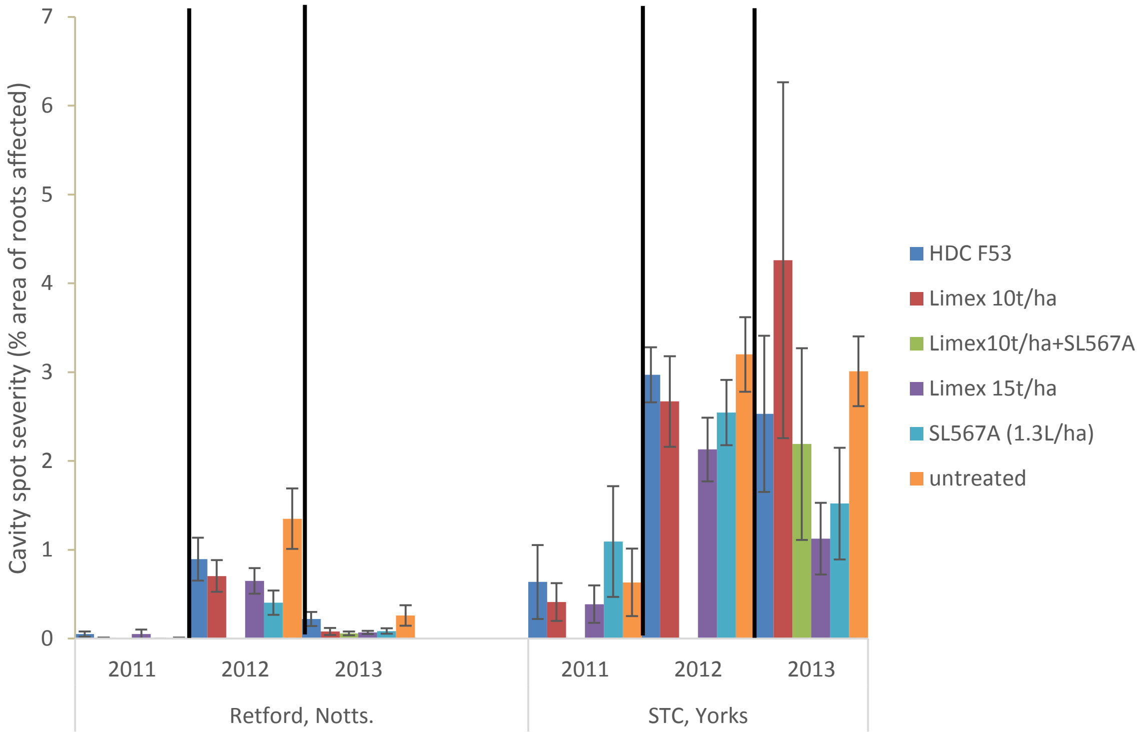


Figure 7. Cavity spot severity (% area of roots affected) across all site seasons, showing results for treatments which were present in all 3 years of the project (2011-2013). Error bars represent standard error.

Due to the changes in treatment programmes between project years, it was necessary to do the cross-site season analysis using REML (restricted maximum likelihood). Disease incidence was identified as being significantly affected by Limex, with higher rates reducing the incidence of cavity spot (P<0.001). A rate response was identified (Table 11), with the 15 t/ha resulting in greater cavity spot control than the 10 t/ha treatment. Despite significant treatment effects, site and year were identified as being the most important determinant of disease incidence.

Table 11. Cross site/season analysis of Limex effects upon cavity spot incidence, as calculated by REML analysis.

Limex Rate	% roots affected by cavity spot
Untreated	23.9
Limex 10 t/ha	16.5
Limex 15 t/ha	12.9

When assessing the severity data through REML, Limex effects and the effect of SL567A were only found to have small effects on disease severity overall. This result is thought to be due to the low levels of disease severity observed throughout.

Effect of season

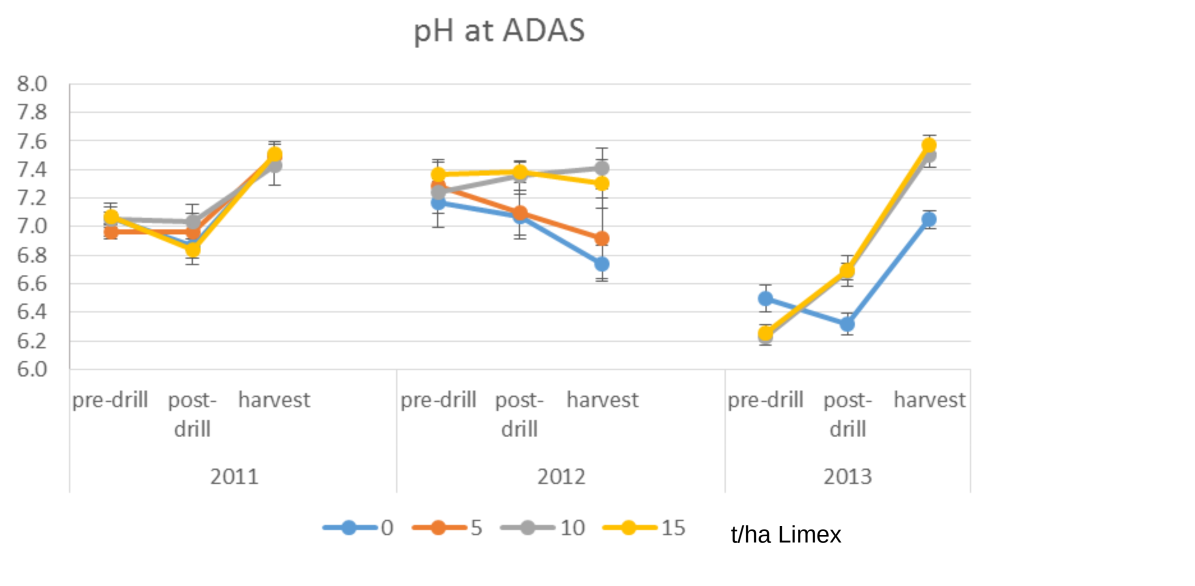
In 2011, cavity spot levels were low because of the dry spring conditions and no significant treatment differences were observed in cavity spot incidence, severity or yield in the two field experiments. At the Notts site, <1% of untreated roots were found to show cavity spot symptoms. At the Yorks site, neither the standard fungicide metalaxyl-M (SL567A) nor the other treatments decreased cavity spot, where 9% of carrots were affected in untreated plots. At both sites, the calcium treatments (as Limex) showed trends for decreased cavity spot and higher yields at the higher rates of application.

In 2012 the standard fungicide metalaxyl-M (SL567A) was the most effective fungicide at the Notts site where it gave 64% control. There was no significant control of cavity spot with any of the treatments at the Yorks site. None of the experimental fungicides applied at standard rates of application (for foliar disease) decreased cavity spot incidence. At both sites, the calcium treatments (Limex) showed trends for decreased cavity spot at the higher rates of application. At the Notts site 15 t/ha of Limex was more effective than most of the foliar treatments apart from SL567A. Perlka resulted in significantly higher cavity spot incidence than the untreated control at the Notts site so this treatment was dropped from the final year experiments.

In 2013 rates of novel products were increased. Most treatment programmes had lower cavity spot incidence than the untreated control at the Notts site, with five treatments resulting in significantly less disease than the untreated. The most effective was Tr 4, which contained SL567A metalaxyl 0.65L/ha followed by Switch 0.8 L/ha applied twice, which had just 4.8% cavity spot incidence. The second most effective treatment was the Limex treatment at 15 t/ha, which had 5% cavity spot incidence. At the STC (Yorks) site cavity spot incidence was not significantly different between treatments, however there was a trend for disease severity to differ. Limex at 15 t/ha had the lowest cavity spot severity overall (0.23% area affected), with the SL567A treatment having a similar level (0.29% area affected). Two of the experimental treatments resulted in greater cavity spot severity than the untreated control. These were HDC F53, followed by Nativo 75WG or by Nativo 75WG + Rudis.

Soil pH

Soil pH results from across the 3 years and 2 sites were variable (Figure 8). 2011 saw pH increase significantly between the summer and harvest sample timings at both sites, however differences between Limex doses were not apparent at the Notts site and differences were not consistent at the Yorks site. 2011 was a particularly dry year, so it is thought that the increases in pH over the season are linked to the changes in soil moisture. 2012 had a very wet summer (Appendix 5) which appeared to reduce the pH as the summer went on. At both sites there were significant effects of increasing the Limex dose, with the Yorks site having significant effect of Limex dose, sample timing and also a Limex dose x sample timing interaction. This is most likely due to the higher rates of Limex increasing the pH over the season, the lower rate (5 t/ha) staying at a similar level at each sample timing and the untreated pH dropping. Results from 2013 are consistent across both sites, with significant Limex dose effects and also sample timing effects, with pH increase from sowing until harvest. Cross-site analysis confirms significant differences between sites, years, Limex dose and sample date depending on site or year.



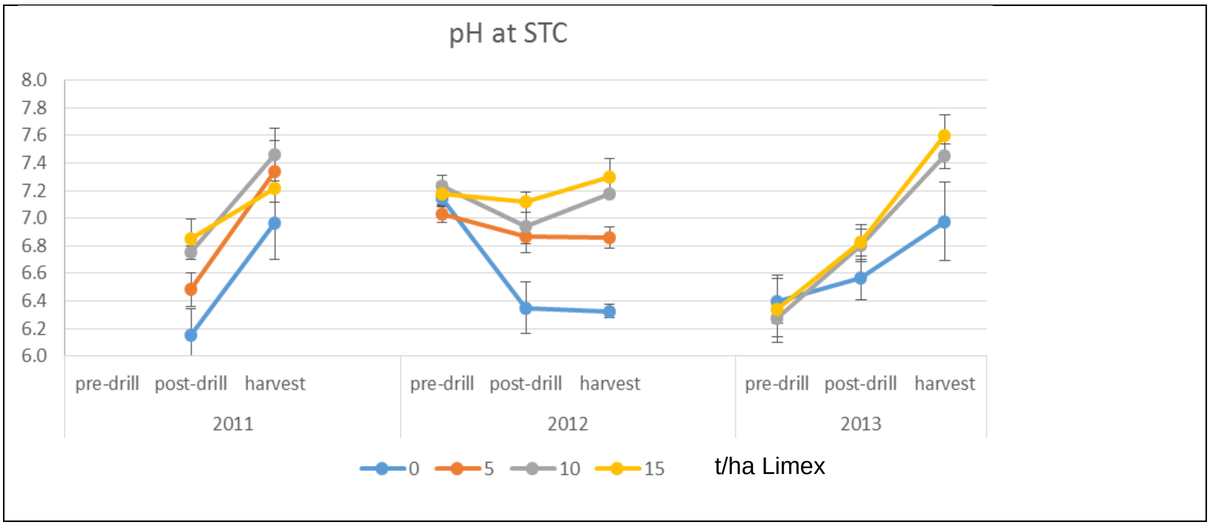
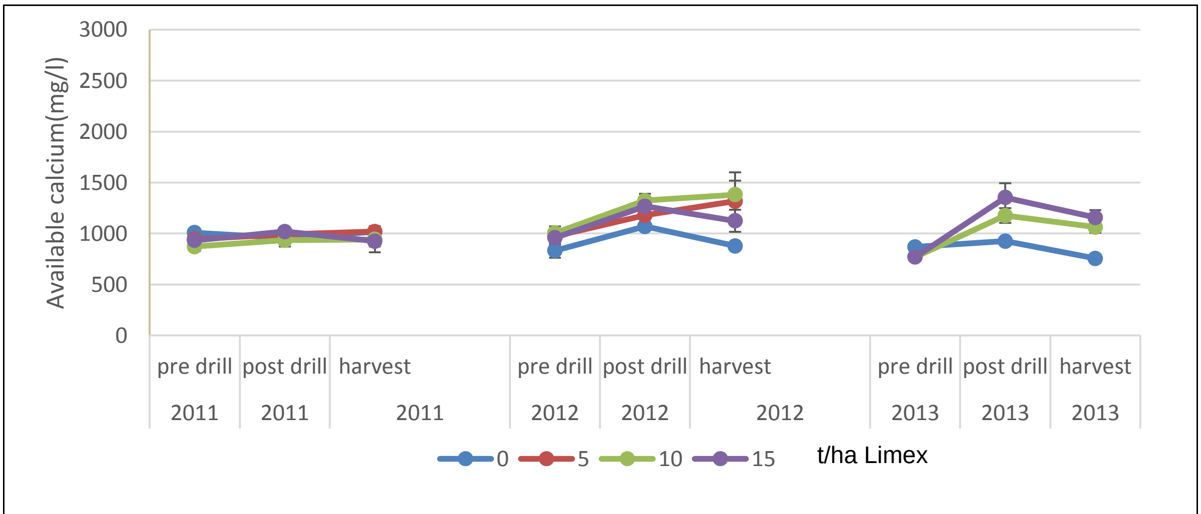


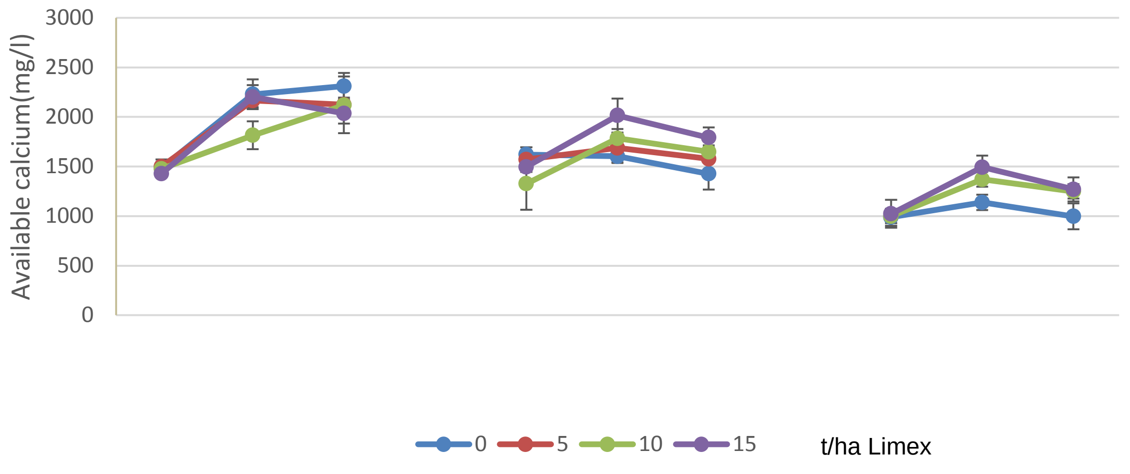
Figure 8. pH levels at the Notts and Yorks site from 2011-13

Calcium levels in soil

Analysis of available calcium was completed across all 3 years of the project and both sites (Figure 9. In most site and seasons there was a trend for available calcium to increase between the pre drilling sample and the summer sample, and then for available calcium levels to decrease in most cases by the harvest assessment. Significant differences were found between dose of Limex application and also timing of sample for both sites in 2013 and the Notts site in 2012, with no significant effects of Limex dose being identified for the Yorks site in 2012. The 2011 growing season was very dry overall, which resulted in inconsistent results at the Yorks site and no effects of Limex at the Notts site. A cross-site analysis identified site and season as significant factors as expected, as well as significant differences caused by Limex dose.



Available calcium at the Retford site, Notts.



Available calcium at the STC site, Yorks.

Figure 9. Effect of Limex application at different rates on available calcium in soil from 2011-2013.

Metalaxyl-M degradation study

In 2011, soil from 32 fields (including the two fungicide trial sites) was assessed for the persistence of metalaxyl-M. In 15 soils the half-life was less than the 10 days, a breakdown rate previously associated with control failure. In 12 soils the half-life was greater than 20 days. The remaining 5 soils fell between 10 and 20 days. There was some evidence of correlation between half-life and pH with half-life appearing to diminish with increasing pH (Figure 10). The effect of organic matter was weak. The Notts site was identified as being a fast degrading soil, with a half-life of 5.2 days, and the Yorks site had a slow degrading soil with a half-life of 38.5 days. Due to the low levels of disease in 2011 it is not possible to comment on how this relates to SL567A disease control at each site.

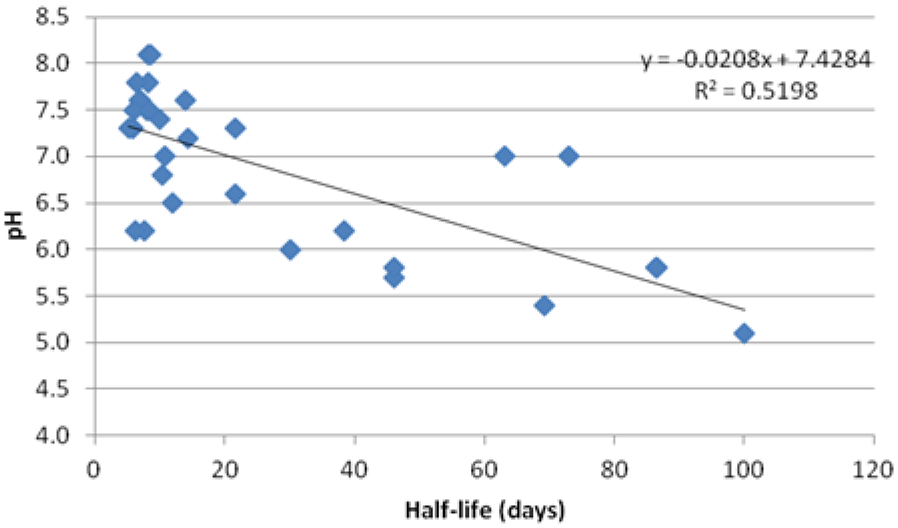


Figure 10. Relationship between soil pH and metalaxyl-M half-life, for 32 soils, sampled in 2011.

In 2012 none of the soils sampled showed very rapid degradation (half-life less than 10 days) compared with 50% of samples from different fields in 2011. A total of nine soils had half-life values of between 10 and 13 days and 11 soils had a half-life greater than 20 days. Metalaxyl-M treatments are likely to be more effective in soils with slower rates of degradation. The slower rates of degradation in 2012 may be due to effects on soil microbial populations in dry conditions that were evident up to the end of March 2012. In 2013 both the Notts and Yorks site had a half-life less than 10 days, so both soils would be classed as fast degrading. Even so, SL567A still provided a significant reduction up to 67% disease incidence at the Notts site and appeared to be reducing disease incidence at the Yorks site. Possibly greater control would have been achieved on a non or a slow degrading site.

Occurrence of Pythium DNA in soil

During 2012, soil samples were sent for *Pythium* analysis, using a PCR test for the presence or absence of *P. violae* DNA in extracts of total DNA from soil samples. *P. violae* was not detected in any samples at the earlier assessment timing (11 June), but at the 6 August assessment, *Pythium* DNA was identified in many of the plots and treatment differences approached significance (P=0.089). The greatest number of positive results were found in the untreated, HDC F50, HDC F53, Limex 15 t/ha and the HDC F125 treatments. The treatments which had a lowest level of *Pythium* were single applications of SL567A (Tr 2), HDC F52 (Tr 4), and Limex 10 t/ha, all of which were treatments that reduced, or appeared to reduce the level of cavity spot in carrots. The inconsistency in the results (e.g. Limex 10 t/ha compared to Limex 15 t/ha) is thought to be related to the specificity of the test, with variation likely to be reduced if *P. violae* could be quantified within samples rather than just the presence or absence of disease.

Discussion

This project tested a range of products across three seasons with extremes of weather. Year one of this project (2011) was a particularly dry year which limited both cavity spot expression and soil fungicide activity. Year two was another unusual year, with drought until spring, and then above average rainfall until harvest. Sunlight was a major factor affecting crops in 2012, with this being notably lower than average. Year three of this project saw the closest year to normal in terms of weather, with average rainfall in May, however this was followed by below average rainfall in June until September, followed by above average rainfall from October onwards.

In 2012 HDC F53 was found to be the most effective foliar applied experimental product, showing evidence of carrot cavity spot control at both sites, although effects were not statistically significant. No past research has considered this compound for use in carrot crops, so it was retained in the 2013 trials, with the dose increased, seeking to improve cavity spot efficacy. In 2013 at the Notts site HDC F53 appeared to reduce cavity spot when used solely at 4 weeks post drilling, although less so when the application was split across two timings. At the Yorks site in 2013, two F53 treatments significantly increased cavity spot severity. Overall, the treatment was not significantly different from the untreated.

Over the entire project, SL567A (metalaxyl-M) resulted in the best cavity spot control at both sites, although there are well documented cases of reduced persistence of this chemical (Davison and McKay, 1999) and reduced persistence (fast degradation) was detected at both sites in 2013. Fungicides often require moisture to move within the soil profile and within plants. Metalaxyl-M is highly soluble and moist soil conditions during the early growing seasons of 2012 and 2013 may have positively affected the fungicides performance. Weather conditions can play a big part in pesticide degradation with degradation rates increasing with soil moisture content and temperature, with very wet soils likely to decrease metalaxyl persistence.

The use of Limex (calcium) treatments just before sowing in 2011 showed some promising trends, and in the 2012 and 2013 experiments Limex stood out at both sites compared to the experimental fungicide products. In the 2013 experiments Limex offered equal or greater control than the SL567A (metalaxyl-M) treatments, providing 68-74% cavity spot control when compared to the untreated. Rate responses were also identifiable throughout the project, with Limex at 15 t/ha often providing greater levels of control than the 10 t/ha rate. Calcium carbonate is known to have significant effects on cavity spot, probably by inducing a soil microflora inhibitory to filamentous fungi (Hiltunen, L. H. and White, J. G., 2002). This is also confirmed by work completed by Khated *et al* (1996), where applications of Lime (4 t/ha) to a soil significantly increased pH and reduced the incidence of cavity spot disease. The lime treatment was found to increase soil microbial activity (as measured by the hydrolysis of fluorescein diacetate and arginine ammonification). The Lime resulted in a significant increase in the total number of colony forming units, of bacteria, fluorescent pseudomonads, gram negative bacteria, actinomycetes and a significant disease in the amount of filamentous fungi and yeasts compared to the control. Compared to other forms of liming products, Limex is delivered in a fine concentrated powder, so provides a calcium burst during the period when cavity spot infection is likely to take place. In the 2011 and 2012 field experiments, Perlka was also examined. There are claims regarding this compound having bio-control properties, by stimulating soil microbes which interact antagonistically with more pathogenic soil pathogens. However in this project plots receiving Perlka had high levels of both cavity spot on roots and *Alternaria* leaf spot*,* indicating that this product may stimulate *P. violae*, or control its natural antagonists.

Previous work has shown a decrease in carrot cavity spot when levels of exchangeable calcium exceeded 8 milliequivalent / 100g soil (Scaife *et al*, 1983). In our work calcium was measured as mg available calcium / Litre of soil so no direct comparison is possible with the reported study. However, there was an increase in available calcium mid-season from around 750 to 1350 mg/L, following applications of Limex, and also a decrease in cavity spot with these Limex treatments. These results suggest that high calcium levels may be associated with reduced cavity spot.

During the 2012 experiments a *Pythium* soil test was completed at both Notts and the Yorks site, which outputted either a positive or negative result. Results from this were interesting, with some treatments showing promising signs of detection. For example, at Notts all of the untreated and HDC F125 plots were positive, and these also had the highest cavity spot incidence. However some of the other results were not consistent with the level of cavity spot disease recorded. At the Yorks site, where very high levels of cavity spot occurred, none of the plots tested positive for *Pythium* DNA. More work is needed in the future to refine this technique.

The laboratory agar test looked at controlling mycelial growth of *P. violae* using agar plates amended with novel and current fungicides. Single active ingredients were tested, so cannot be directly compared with the field work, where products were often mixtures of two or more actives. SL567A was the most effective at inhibiting mycelial growth, which compared well with the field work. Promising results were produced by HDC F172 which was identified as the most effective experimental product. However this product has not been evaluated in the field yet. Some variation in response between isolates was observed, though the isolates were assumed to be similar as they were isolated from the same field in the same period. The use of multiple isolates contributes to the reliability of this data, as more of the variation in the natural population of *P .violae* has been represented. It is important to note that laboratory tests may not translate to commercial situations perfectly, but those products such as HDC F172 that look promising warrant further testing in the field. Additionally, the median effective dose of a product does not account for potential phytotoxicity or possible negative effects on the environment.

Conclusions

- The wet summer and autumn in 2012 and 2013 allowed the development of cavity spot in crops.
- Site and year had more effect on incidence of cavity spot than any of the treatments tested.
- Significant control of cavity spot was demonstrated in field experiments. No chemical control method was more effective than SL567A. A laboratory based study identified promising new chemistry to test in the field in the future.
- There was no difference in efficacy between a single application of SL567A at 1.5 L/ha and two applications at half rate applied 4 weeks apart soon after drilling
- The most promising of the five novel fungicides tested was HDC F53 in field tests and HDC F172 in laboratory tests (the latter was not tested in the field).
- The biofungicide tested (HDC F166) did not reduce cavity spot.
- Cavity spot incidence was significantly reduced by Limex with a 15 t/ha rate giving greater control than 10 t/ha.
- Metalaxyl-M degradation data was inconclusive, with trials sited in fast-degrading soils still showing good control from SL567A.
- Field diagnosis techniques require further refinement to quantify *P. violae* other than simply by presence or absence of the pathogen.

Future work

- There is some evidence from 2013 to suggest that higher rates of use may be necessary to achieve effective control of cavity spot. In light of the early work with metalaxyl-M where a much higher rate of application was required (8x the rate for blight in potato) to get effective control of this soil-borne pathogen, it is recommended all future studies should explore high application rates relative to foliar disease control. It must be considered though that in the tightening regulatory framework across the EU it may be more difficult to secure approval for such a use in future.
- Test the most successful chemicals from the laboratory study in the field.

Knowledge and Technology Transfer

Horticulture Week (2013) Science Into Practice - Targeting cavity spot on carrots. Available at: http://m.hortweek.com/article/1219544/science-practice---targeting-cavity-spot-carrots [Accessed 29 April 2014].

BCGA meeting to discuss the Cavity Spot R & D Strategy. Peter Gladders and Martin McPherson. 6 June 2013, The Conference Room, Stockbridge Technology Centre, Stockbridge House, Cawood, North Yorkshire, YO8 3TZ.

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Appendices

Appendix 1. Weather conditions at spraying and incorporation, Retford, Notts 2013

Target date (Timing)	Actual Date	Growth Stage	Weather (recorded at time of application)
Timing 1 Pre- drilling	10/05/13	Pre-em	Temp: 14.4-14.6 RH: 71.3-72% Wind Speed: 2.2-6.3kph Cloudy with Drizzle Slight drift
Timing 2 4-6 weeks after Timing 1 spray	27/06/13	Post em	Temp: 20^{O}C RH: 58.6% Wind Speed 1.5 kph Cloudy and Dry Slight Drift
Timing 3 4-6 weeks after Timing 2 spray	27/08/13		Temp: 21 RH: 47-57% Wind Speed: 3.7-7 kph Cloudy Very Slight Drift
Timing 4 4-6 weeks after Timing 3 spray	04/09/13		Temp: 23 RH: 63% Wind Speed: 7.0-8.7 kph Sunny and Cloudy Very Slight Drift

Sprayer: OPS sprayer with 2m boom and 110-03 nozzles operated at 2 bars pressure and applying fungicides in 1000 litres water/ha

Appendix 2. Weather conditions at spraying STC, North Yorkshire 2013

Target date (Timing)	Actual Date	Growth Stage	Weather (recorded at time of application)
Timing 1 Pre- drilling	14/5/13	Pre-drilling	Overcast, gentle breeze, slight drift across plots. Max temp 13.0°C, 17.6mm rainfall post-spraying
Timing 2 4-6 weeks after Timing 1 spray	20/06/13	2-3 TL	Overcast, warm, spots of rain. Light air with very slight drift. Ground damp from irrigation on 18.06.13 Max temp 20.0°C, 5.4mm rainfall post-spraying
Timing 3 4-6 weeks after Timing 2 spray	31/07/13	6-8 TL	Dry, mild, calm, no drift. Ground damp. Max temp 21.3°C, 2.1mm rainfall post-spraying
Timing 4	05/09/13	43	Warm, hazy and calm. Ground damp from irrigation on 03.09.13 Max temp 22.3°C, 3.2mm rainfall same day and 13.5mm following day.

Sprayer: OPS sprayer with 2m boom and 04-F110 nozzles (14.5.13) and 06-F110 nozzles (other applications) operated at 2 bars pressure and applying fungicides in 1000 litres water/ha

Appendix 3. Site details Retford, Notts 2013

Site:	Babworth, nr Retford, Notts		
Field name/ GRef:	SK 66545 79593		
Soil texture:	Loamy sand		
Drainage:	Good		
Previous cropping:	2012 Wheat	2011 Wheat	2010 Sugar beet
Soil analysis:	pH 6.9 Notts Indices – P 39 mg/l (3), K 174 mg/l (2-), Mg 154 mg /l (3) 1.56 % organic matter		
Crop: Carrots	Cultivar	: Chantenay variety	
	Sowing date	: 26 May 2013	
	Seed rate	: 7.7 kg/ha	
Cover crop	Spring barley cv. Tipple (Cover Crop)	50 kg/ha seed rate	
Irrigation	Nill Completed		
Fertilisers	K-salt	658kg/ha	11th March 2013
	33 N 30SO3	106.5kg/ha	8th July 2013
	Manganese	2kg/ha	18th July 2013
	Bittersalz	3.7L/ha	18th July 2013
Farmer applied sprays	Vydate 10g	12.5L/ha	11 May 2013
	Datura	1.2L/ha	16 May 2013
	Sherman	3.5L/ha	16 May 2013
	Datura	1.2L/ha	28 May 2013
	Sherman	3.5L/ha	28 May 2013
	Shogun	0.6L/ha	06 June 2013
	Shogun	0.6L/ha	17 June 2013
	Clayton Divot	1.3L/ha	19 June 2013
	Clayton Divot	1.3L/ha	28 June 2013
	Afalon	1L/ha	08 July 2013
	Life Scientific Lambda-Cyhalothrin	0.075L/ha	02 August 2013
	Life Scientific Lambda-Cyhalothrin	0.075L/ha	20 August 2013
Harvest trial plots			3 December 2013

Appendix 4. Site details Stockbridge Technology Centre 2013

Site:	Field L, Stockbridge Technology Centre, Cawood, YO8 3TZ		
Field name/ GRef:	SE558366		
Soil texture:	Sandy loam		
Drainage:	Good		
Previous cropping:	2012 W. wheat	2011 S. Barley	2010 W. wheat
Soil analysis:	pH 6.0 P 32.0 mg/l K 261 mg/l Mg 158 mg/l 2.2 % organic matter		
Crop: Carrots	Cultivar	:	Confidential, susceptible variety
	Sowing date	:	21 May 2013
	Seed rate	:	200 seeds/m^2
Irrigation	Prior to treatment applications when required.		
Fertilisers	Muriate of Potash 60%	208kg/ha (125kg/ha K)	15 May 2013
	Nitram	232kg/ha (80kg/ha N)	15 May 2013
Herbicides	Alpha Linuron	1.1l in 600l water/ha	22 May 2013
Insecticides	Biscaya	0.4l in 200l water/ha	20 June 2013
	Hallmark Zeon	150ml/200l water/ha	26 July 2013
	Hallmark Zeon	150ml/200l water/ha	10 August 2013
Harvest trial plots			27 November 2013

Appendix 5. Site details Retford, Notts 2013

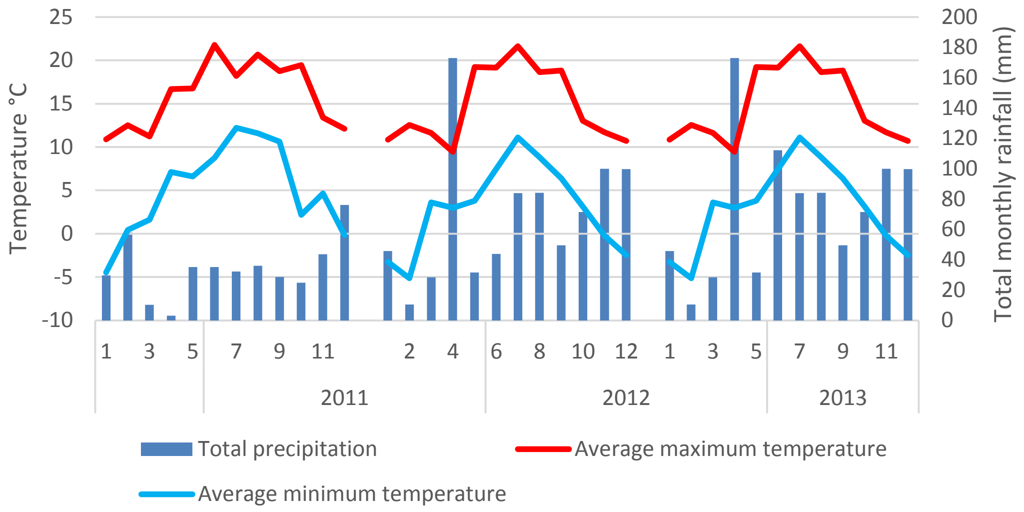

Figure 11. Monthly temperature and rainfall for the Notts site, 2011 – 2013

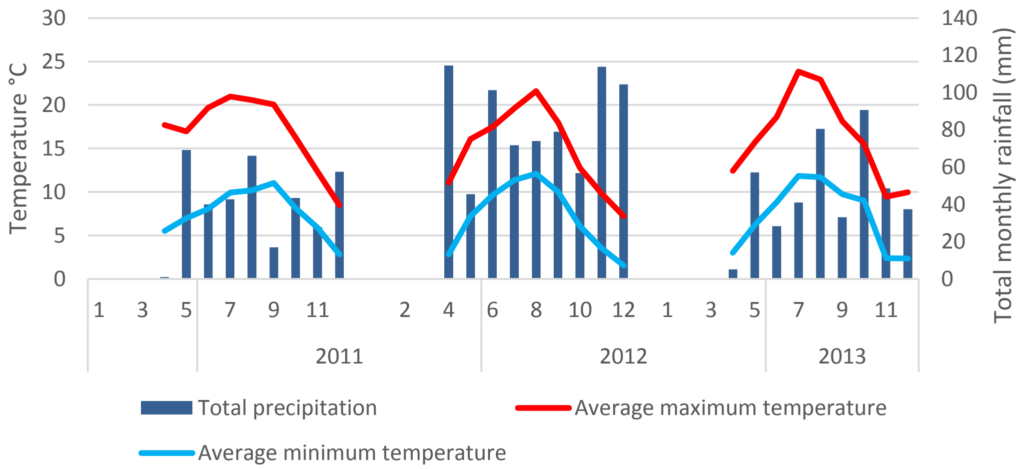

Figure 12. Monthly temperature and rainfall for the Yorks site, 2011 – 2013