Contract report for the
Horticultural Development Council

Asparagus: management of phytophthora rot

FV 246a

August 2006

Project title:	Asparagus: Management of *Phytophthora* rot
Project number:	FV 246a
Report:	Final report, August 2006
Previous reports:	FV 246 Final report, September 2002 FV 246a Annual report, June 2005
Project leader:	Dr K R Green ADAS Arthur Rickwood
Key workers:	Mr J Carpanini
Locations of project:	• ADAS Arthur Rickwood • ADAS Terrington • Field site (on a grower's holding) in Cambridgeshire
Project co-ordinator:	Mr Philip Langley
Date project commenced:	1 April 2004
Date completion due:	31 August 2006
Key words:	Asparagus, *Phytophthora*, spear rot, fungicides, Metalaxyl-M, potassium phosphate, disease, Amistar, azoxystrobin, Shirlan, DP 98, fluazinam, consento, fenamidone, propamocarb hydrochloride, Aliette, fosetyl-aliminium, dimethomorph

AUTHENTICATION

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

Dr K R Green
Research Scientist
ADAS Arthur Rickwood

Signature ..... Date .....

Report authorised by:

Dr W E Parker
Crop Protection Research Manager
ADAS Wolverhampton

Signature ..... Date .....

TABLE OF CONTENTS

FV 246a

Asparagus: management of phytophthora rot

1. GROWER SUMMARY

1.1 Headline

In an inoculated field trial, *Phytophthora* sp. had a deleterious effect on crop establishment over two seasons. The pathogen was most effectively controlled using a soil drench of SL567A (0.65 L/ha) applied to re-filled gulleys immediately after crown planting.

An inoculated seedling bioassay confirmed that SL567A was the most effective fungicide (out of eight tested) for control of phytophthora rot on asparagus.

1.2 Background and expected deliverables

Symptoms of *Phytophthora* on asparagus were widespread in the UK for the first time in 2002. The disease is known to have become a major production constraint in New Zealand and the USA (California), with yield losses in excess of 50%. Losses may occur at crop establishment and in mature crops. There is now an off-label approval for use of metalaxyl-M as SL567A on asparagus. Despite the reported effectiveness of this product for control of *Phytophthora* in the short-term, there are reports of a reduction in efficacy over time due to microbial degradation in soil. In addition, growers may be wary of using the product on a routine basis on established crops, because of the cost involved.

The overall aim of the project is to develop integrated strategies for the management of *Phytophthora* rot on asparagus.

The specific objectives of the project are:

- Confirm the species of *Phytophthora* causing asparagus rot and determine the extent of the disease in the UK.
- Collate information on disease spread and develop a quantitative method for determining levels of *Phytophthora* inoculum in soil.

- Provide recommendations and raise grower awareness of pre-planting measures necessary to reduce the risk of developing asparagus *Phytophthora* and other diseases.
- Determine the efficacy of metalaxyl for control of *Phytophthora* during crop establishment
- Produce a Factsheet update to summarise available information on the use of metalaxyl for control of asparagus rot.
- Evaluate the use of phosphite fertiliser for its incidental effect against asparagus *Phytophthora* and do a cost-benefit analysis on use of this product compared with metalaxyl and an untreated control
- Evaluate two fungicides for control of *Phytophthora* in asparagus, in an inoculated pot trial (year 2).

1.3 Summary of the project and main conclusions

HDC Factsheet no. 06/04 was written as part of this project to alert growers to the problem of *Phytophthora* rot on asparagus, and to summarise available knowledge of the disease and potential management strategies, including the use of SL567A (metalaxyl-M).

1.3.1 Pathogen identification

- The pathogen causing spear and root rot of asparagus in the UK was confirmed by analysis of the rDNA ITS sequence as the same species of *Phytophthora* that is pathogenic on asparagus in other countries (proposed name *P. asparagi*).

1.3.2 Occurrence of phytophthora rot on asparagus in the UK and worldwide

- Phytophthora rot on asparagus was confirmed in the UK in 2004 (five counties), 2005 and 2006. The disease was more prevalent in 2004 and 2006, following heavy rainfall in both harvest seasons, compared with 2005.
- The disease continues to be a problem worldwide, with new reports of its occurrence in Michigan, USA and Canada.

1.3.3 Pathogen detection

- A seedling baiting technique was successfully used to test soil for the presence of *Phytophthora* pathogenic on asparagus.
- A PCR-based molecular diagnostic test for *P. asparagi*, developed on the basis of ITS sequence variation, was developed by SCRI. This was validated using asparagus spears, roots, stem bases and soil.
- An advantage of the baiting technique was that it was simple and relatively quick (3-4 days, assuming seedlings were available) although the microscopic examination of seedlings to check for sporangial development was laborious. The technique also enabled use of larger soil samples than would be possible for molecular diagnostics. To date, the PCR-based technique has been used only for research purposes. There is potential for the test to be developed for commercial use, either pre-planting for detection of the pathogen in soil, or to determine whether batches of planting material (crowns) were free of *Phytophthora* sp.. Further development work would, however, be required to optimise the diagnostic technique and also to determine optimum sampling strategies. There is scope to combine the two strategies, for example using conventional baiting from relatively large soil samples, followed by molecular diagnostics on the seedling samples to confirm pathogen presence.
- The baiting method and the PCR-based molecular method indicate pathogen presence or absence, rather than giving an estimate of inoculum levels in soil. However, the relationship between inoculum density and subsequent disease development in a crop is likely to be extremely complex, dependent on time of sampling, soil temperature, soil type, and soil water content (Falloon, 1982). Quantitative methods of detection are therefore likely to produce results that are difficult to interpret.

1.3.4 Management of phytophthora at crop establishment

- The impact of *Phytophthora* sp. in soil on asparagus crop establishment was demonstrated in an inoculated field trial, with plant stand reduced by 27% in untreated inoculated plots in year 1 and by almost 50% in year 2.
- Poor crop establishment also occurred in inoculated plots that received a crown drench of SL567A (metalaxyl-M) at the time of planting, due to inadequate

phytophthora control using a low application rate (75 ppm a.i) and phytotoxicity with medium and high application rates (150 and 300 ppm a.i., respectively).

- Applications of SL567A to soil immediately after planting resulted in good crop establishment in 2004, equivalent to the uninoculated control treatment, with no evidence of phytotoxicity. Among the inoculated treatments in 2005, crop growth was best overall in plots that had received the medium soil application rate (0.65 L of product/ha) at planting. However, a reduction in fern biomass compared to the uninoculated control demonstrated that as for the other inoculated treatments, *Phytophthora* sp. was having a deleterious effect on crop development in the second year of the experiment. In a commercial situation, this would have necessitated the use of a pre-emergence application of SL567A in April 2005 to maintain effective disease control in the 2nd year of crop establishment.
- Soil baiting six months after inoculation confirmed the presence of *Phytophthora* sp. pathogenic to asparagus in the majority of plots, including the uninoculated control plots, demonstrating movement of the pathogen through a field.
- Application of SL567A to soil immediately after asparagus planting is within the current SOLA conditions of use.
- To date, there have been no reports of asparagus crop establishment failures due to *Phytophthora* sp. in the UK, and so the economic benefit of fungicide treatment at planting would need to be assessed for a particular situation. However, since there is a direct relationship between yield and plant population, any minor loss of plants during the establishment years will have an effect on yield for the rest of the life of the crop. This cumulative effect on yield can be large.

1.3.5 Management of phytophthora in established crops

- In an experiment sited in a mature crop (2004), a pre-harvest treatment with SL567A (1.3 L of product/ha) delayed appearance of spear rot due to *Phytophthora* sp. by 3 weeks compared with the untreated control. The fungicide was effective for approximately 6 weeks after pre-harvest application to the soil.
- These results could not be confirmed in 2005, due to low incidence of disease in the experimental area.
- An inoculated seedling bioassay confirmed that out of eight products tested, SL567A (metalaxyl-M) was the most effective fungicide for control of

phytophthora rot on asparagus, resulting in significantly higher seedling emergence (Figure 1) and reduced development of phytophthora symptoms, compared with the inoculated control treatment. Moderate control was also obtained with Amistar and Shirlan, but neither of these products currently has approval for pre-harvest use on asparagus.

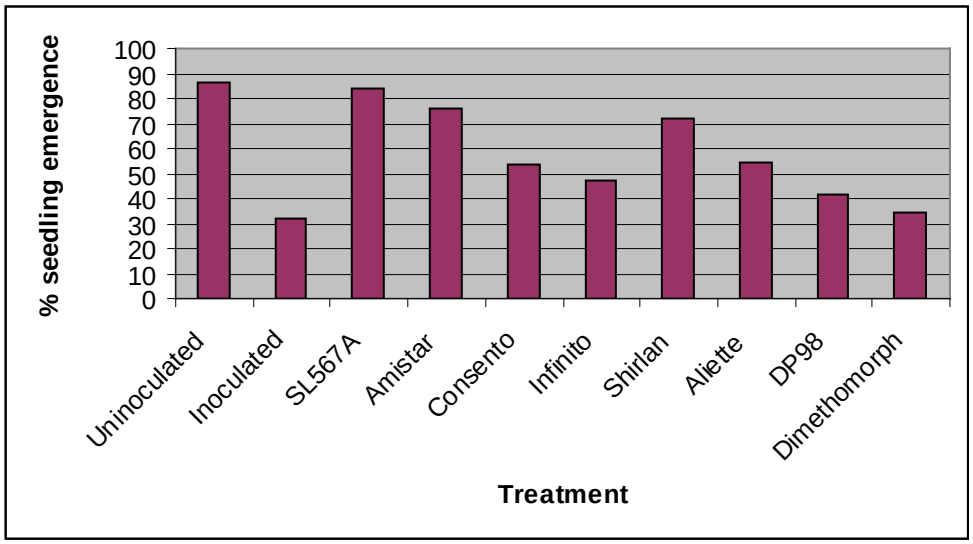

Figure 1. Effect of soil treatments on emergence of asparagus seedlings

1.4 Financial benefits

Assuming a UK area of 856 ha and yield of 2.2 t/ha, returning £2,600 per tonne, the annual value of the crop is approximately £4.95 million. Yield losses in excess of 50 % have been reported in New Zealand and California. Results from this project have confirmed that the disease poses a risk in the UK since it is widespread, occurs annually particularly after heavy spring rain, and can reduce plant stand by 50% during crop establishment. The project has developed guidelines for minimising risk of disease development, including pre-planting recommendations, initial studies on pathogen detection (further development required), and management of the disease during crop establishment and in an established crop.

1.5 Action points for the industry

Confirmation of phytophthora rot on asparagus at several locations in the UK in 2004, 2005 and 2006 means that development of phytophthora on asparagus is a real risk, particularly when symptoms have previously been observed in a field and following heavy spring rainfall (as in 2004 and 2006). For a particular farm, one asparagus field may be affected, while others may be disease-free. Growers need to be aware of typical symptoms of spear rot as shown in Factsheet 06/04. During the harvest season, it is important to monitor each field for symptoms of spear rot, and send suspect symptoms for laboratory confirmation of *Phytophthora* sp. This will enable an appropriate disease management strategy to be formulated for each crop the following season.

1.5.1 Pre-planting recommendations

1.5.1.1 Recommendations to UK crown producers

- Choose fields where the soil is well drained with a sand or sandy loam texture. Fields where water lies for several days after winter rains should be avoided.
- Do not raise crown transplants in fields that are adjacent to asparagus fields as *Phytophthora* sp. can be moved on cultivation equipment from the production field to the crown nursery.
- Apply SL567A to the nursery (following the SOLA conditions of use) prior to emergence (one application per year permitted), to control *Phytophthora* sp. that may have been introduced to the nursery site.

1.5.1.2 *Recommendations to* UK asparagus growers.

- Due to the ability of *Phytophthora* sp. to survive in soil and the perennial nature of asparagus, it is difficult to eliminate the disease once it is present in a crop. Avoidance is the best management strategy.
- Avoid planting new fields where there have been symptoms of phytophthora on a previous crop (e.g. strawberry). Even if symptoms were not due to a species of *Phytophthora* pathogenic to asparagus, a history of the disease on a previous crop indicates that soil conditions may be conducive for development of phytophthora rot in that field.

- Phytophthora rot is more severe when the soil is saturated with water. Always select fields that are well drained for planting asparagus. This will minimize the impact of the disease should it spread into the field after planting.
- Phytophthora rot is worse when soil conditions are cool and wet. To avoid these conditions, cool storage of crowns until field conditions are conducive to rapid growth of the crowns is recommended.
- Avoid introduction of *Phytophthora* sp. on planting material. Obtain planting material from reliable suppliers that have a scheme for production of high health status crowns or transplants. For example, in the Netherlands, asparagus planting material with the Select Plant® label is certified by the Netherlands Inspection Service for Horticulture (Naktuinbouw). A list of Select Plant® suppliers can be obtained from *www.naktuinbouw.com*. A similar scheme is available in France. While monitoring for diseases such as fusarium and viruses tend to be standard within these schemes, monitoring for phytophthora may not be. Enquire from the crown supplier what measures have been taken to eliminate or avoid phytophthora during crown production.
- Seedling transplants, which are usually transplanted later in the spring when phytophthora rot is less likely to be a problem, are more likely to establish without severe phytophthora infection.

1.5.2 Establishing crops

- Growers should be aware that in an establishing crop, symptoms of phytophthora infection are more likely to be apparent as reduced plant stand and vigour, rather than visible lesions on emerging spears and ferns.
- If phytophthora has been confirmed in another field, wash down machinery between operations to minimise soil spread to the establishing crop.

1.5.3 Established crops

- Factsheet 06/04 provides guidance on cultural practices to avoid or reduce the risk of disease development and best-practice guidelines for chemical control.
- If there is poor drainage in an established crop, take action to remedy the problem.
- SL567A (metalaxyl-M) is approved for use as a soil drench prior to asparagus spear emergence (SOLA 1502/05). In crops where the soil is infested with *Phytophthora* sp. pathogenic to asparagus, this fungicide can delay the development of spear rot, by up to six weeks. The fungicide should be applied as

close as possible to the start of harvest, following the SOLA conditions of use (a minimum of 7 days prior to harvest).

- SL567A was shown to be the most effective available fungicide versus phytophthora rot. Post-harvest fungicides applied to the fern in summer and autumn for control of rust and stemphylium will not provide adequate protection against phytophthora rot.
- If phytophthora was not observed in a crop in the previous season, treatment of that field with metalaxyl-M is unlikely to be economic.
- If symptoms of spear rot due to phytophthora were confirmed in a field in the previous harvesting season, an application of SL567A (metalaxyl-M) in that field prior to spear emergence may be warranted (following the SOLA conditions of use).
- Because of the potential for spread of *Phytophthora* sp. within a field between harvest seasons (e.g. in soil water), spot spraying areas only the areas of a crop that were affected in the previous season, is unlikely to provide effective disease control.
- Spears found with phytophthora rot in the packhouse should be discarded, ensuring that waste is not returned to cropped areas.

1.5.4 Use of metalaxyl-M

- There are concerns about the development of resistance to metalaxyl in *Phytophthora* populations, particularly after repeated use of the fungicide over several years. Adhere to the recommended dose on the off-label approval. One spray application is permitted per season and this must be applied only to soil.
- Metalaxyl degrades in soil due to the activity of soil micro-organisms. The rate of degradation varies greatly but can reduce fungicide efficacy. A soil test to determine metalaxyl degradation rate is available at Warwick HRI, Wellesbourne (www.warwick.ac.uk) and may be warranted prior to metalaxyl use in established crops and in new crops.

2. SCIENCE SECTION

2.1 Introduction

Phytophthora rot of asparagus is characterised by soft, watersoaked, slightly sunken lesions on spears at, or just above soil-level. Under wet conditions, the lesions become slimy because of secondary invasion by saprophytic bacteria. Spears usually have a crooked appearance with lesions on the inside of the crook. Under dry conditions, the whole lesion may become light brown and the spear may finally shrivel up. Because severe infection may affect buds and spears before they emerge from the soil, yield losses due to phytophthora rot are often underestimated (P. Falloon, pers. comm). The disease can cause establishment failures (plant losses up to 80%), reduce yields in an established crop (40-70%), and can also cause post-harvest losses if infected spears are packed together with healthy spears.

The disease is common in New Zealand and also California, USA and most research on the biology and control of the disease has been carried out in these countries. The disease causes sporadic problems in France (e.g. in 2003) and Spain, and is endemic in the Netherlands and Germany. Up until 2002, reports of the disease on asparagus in the UK were rare. In 2002 and 2003, however, the disease was more widespread.

While phytophthora rot in asparagus crops had been confirmed on two farms in the UK at the beginning of this project, there were several farms where although possible symptoms had been observed, the disease had not been confirmed. Further information was needed to determine the extent of the disease in the UK and to confirm the species of *Phytophthora* causing the disease. In New Zealand and California, the species most commonly associated with the disease is *P. megasperma* var *sojae*.

Until the start of this project, there were no fungicides approved specifically for the control of asparagus phytophthora either in UK or the rest of Europe (HDC, 2002). SL567A (metalaxyl-M) now has a specific off-label approval for pre-harvest use on asparagus in the UK. However, routine use of metalaxyl-M will be a costly control option (£185-240/ha for a single treatment). Metalaxyl has been used successfully for control of asparagus phytophthora in New Zealand and California for the past 15

years (Falloon *et al*., 1985). In some areas, however, the efficacy of the chemical against phytophthora rot is now decreasing, due largely to the problem of microbial degradation in the soil. Asparagus growers in these regions are now looking for alternative management options, such as the use of phosphite fertiliser, which is reported to have incidental activity against oomycete fungi on other crops (eg onion downy mildew, and *Phytophthora* species on peppers and avocados). Published trial results for control of phytophthora rot on asparagus are not available, although there are reports of moderate control (P. Falloon, pers. comm.). Recent research efforts in New Zealand have focused on developing hybrids with durable resistance to phytophthora rot (Falloon *et al*., 2001).

This project aims to provide recommendations to growers on the integrated management of asparagus phytophthora, from crown production through to the established crop, both by continued compilation and presentation of available knowledge of the disease, and by experimental work on the biology and control of the disease, to fill knowledge gaps.

2.2 Occurrence of phytophthora rot on asparagus in the UK and worldwide

The pathogen causing spear and root rot of asparagus in the UK was confirmed as the same species of *Phytophthora* that is pathogenic on asparagus in other countries. *Phytophthora* isolates and spears with symptoms due to *Phytophthora* sp. were examined by Scottish Crop Research Institute (SCRI) using PCR amplification and DNA sequencing of the internal transcribed spacers (ITS) of rDNA (Cooke *et al*., 2000). The ITS sequences of the UK isolates were identical to those from diseased asparagus in New Zealand, France and Italy confirming that the disease was caused by the same pathogen. The sequence data also confirmed that this is related to but clearly distinct from *P. megasperma,* which has previously been reported as the causal organism of spear rot. A re-description of this species as *Phytophthora asparagi* has been proposed (D. Cooke pers. comm., 2005). Further details of pathogen identification are provided in the year 1 Annual Report.

During the 2004 asparagus harvest season, weather conditions were conducive for the development of phytophthora rot on asparagus with, for example, 38 mm rain in the first two weeks of the harvest season at one Cambridgeshire farm. Spear rot on asparagus was widespread with typical symptoms reported by five growers each from a different county of the UK: Cambridgeshire, Cornwall, Northamptonshire, Warwickshire and West Sussex. *Phytophthora* sp. was confirmed as the cause of spear rot at each of the five farms. The disease was also observed but not confirmed at a farm in Lincolnshire. Phytophthora rot was particularly severe in crops where it had been observed in previous seasons, with one grower observing symptoms of the disease on spears in packed produce.

The severity of the disease in 2004 prompted more growers to apply a pre-harvest application of metalaxyl-M in 2005, particularly on fields where the crop had a history of the disease. One grower who applied metalaxyl-M in 2005 had less symptoms of phytophthora rot during the harvest season, however, it should be noted that environmental conditions were less conducive for disease development, compared with 2004 (lower rainfall).

In 2006, there was a cool wet start to the harvest season with above average rainfall recorded across England in May, followed by mainly warm dry weather in June. Following heavy rainfall, phytophthora rot on asparagus was reported by two growers

in West Sussex and one grower in Cambridgeshire, on crops where the disease had been confirmed in previous seasons. The disease was also confirmed in a young crop in Norfolk where it had not previously been observed. Many growers are still unfamiliar with typical symptoms of the disease, and it is likely that the disease remains undiagnosed in some crops.

Prior to project commencement, yield losses due to phytophthora rot on asparagus had been reported mainly from New Zealand and California, USA. More recently, there have been new reports of the disease worldwide. A first report of phytophthora root rot on asparagus in Canada (Quebec) was published in 1993 (Vujanovic, 2003) in which the disease was confirmed on the cultivar Guelph Millenium. The disease was first reported from Michigan State, USA in 2004 (Saude *et al.*, 2005). The occurrence of excessive rainfall in the spring of 2004 was thought to have resulted in widespread disease and considerable yield losses in production fields. Phytophthora rot has been observed on green asparagus in France in recent seasons, with consultants observing that the use of plastic covers for production can reduce disease incidence because of drier soil conditions. There have been no reports of phytophthora rot on asparagus from The Netherlands, although the disease is thought to be endemic there (P. Falloon, pers. comm.).

2.3 Pathogen detection

Two methods were developed during the project to enable detection of *Phytophthora* sp. pathogenic to asparagus.

2.3.1 Soil baiting

A seedling baiting technique (based on the method of Falloon, 1982) was used to test soil samples for the presence of *Phytophthora* sp. Asparagus seedlings grown in sterile sand were used to bait phytophthora from soil samples flooded with water. The seedlings served as an effective bait with symptoms typical of phytophthora rot developing in 3-4 days. Presence of sporangia typical of *Phytophthora* sp. on the seedlings was confirmed by microscopic examination. Full details of the method are provided in the year 1 Annual Report.

This technique was used successfully throughout the project to confirm or otherwise the presence of *Phytophthora* sp. pathogenic to asparagus in field soil from

commercial fields (natural infestation) and experimental sites (artificial infestation) (see Sections 2.4 and 2.5).

2.3.2 PCR-based molecular diagnostics

Further to detection of *Phytophthora asparagi* in asparagus spears with typical spear rot symptoms in 2004 (Year 1 Annual Report), a PCR-based molecular diagnostic test for *P. asparagi* was developed by SCRI. Soil, roots and stem bases were tested with an ITS-based *P. asparagi*-specific real time PCR assay. This was done in either a single or nested format (to increase sensitivity) and together with a universal real-time assay that checked whether the extraction method had worked.

Soil samples were sent from two asparagus fields where phytophthora rot had been confirmed (sites E1 and S2) and from one establishing crop where the disease had not been observed (site E2). *P. asparagi* was confirmed in the sample from E1 using the single format, and in the sample from S2 using the nested format. The pathogen was not detected in the sample from E2.

Asparagus root samples were also sent from sites E1, E2 and S2. These were processed using two different grinding and extraction procedures (liquid nitrogen grinding, versus squeezing through a Pollahne press and extraction from the sap). Universal primers showed the DNA from all the samples was of PCR quality. With single round real-time *P. asparagi* primers there was no signal from any sample. The nested PCR showed one positive root sample from site S2 but not from the other sites.

Emerging ferns with stem base lesions (Fig. 1) were collected in July 2005 from E1 and sent for analysis. *P. asparagi* was detected in sub-samples using single round PCR.

The results demonstrated that the PCR test can be used to confirm the presence of *Phytophthora* sp. pathogenic to asparagus in spears, soil, roots and stem base material. The test has now been modified to further improve the sensitivity of the nested PCR assay.

Figure 1. Stem base lesion due to *Phytophthora* sp. on emerging asparagus fern

2.3.3 Summary

An advantage of the baiting technique was that it was simple and relatively quick (3-4 days, assuming seedlings were available) although the microscopic examination of seedlings to check for sporangial development was laborious. The technique also enabled use of larger soil samples than would be possible for molecular diagnostics. To date, the PCR-based technique has been used only for research purposes. There is potential for the test to be developed for commercial use, either pre-planting for detection of the pathogen in soil, or to determine whether batches of planting material (crowns) were free of *Phytophthora* sp.. Further development work would, however, be required to optimise the diagnostic technique and also to determine optimum sampling strategies. There is scope to combine the two strategies, for example using conventional baiting from relatively large soil samples, followed by molecular diagnostics on the seedling samples to confirm pathogen presence.

The baiting method and the PCR-based molecular method indicate pathogen presence or absence, rather than giving an estimate of inoculum levels in soil. The relationship between inoculum density and subsequent disease development in a crop is likely to be extremely complex, dependent on time of sampling, soil temperature, soil type, and soil water content (Falloon, 1982). Quantitative methods of detection are therefore likely to produce results that are difficult to interpret.

2.4 Effects of metalaxyl-M (SL567A) on asparagus crop establishment in a field inoculated with *Phytophthora* sp.

The aim of this experiment was to determine the effects of metalaxyl-M, on crop establishment and phytophthora development over two seasons when applied by two different techniques at crown planting. The work was done in part of a field artificially inoculated with *Phytophthora* sp. The experiment commenced in May 2004 and was completed in October 2005.

2.4.1 Methods

(See Appendix 1 for Experiment Diary)

SL567A (metalaxyl-M, 480 g/L a.i.) was applied either as a drench to asparagus crowns planted in gulleys, or as a soil application immediately after crown planting to re-filled gulleys, at three different rates. The full list of treatments is given in Table 1.

The experiment was laid out in a randomised complete block design, with four replicates of eight treatments. Plots were 6 m long, containing a row of 20 plants, separated by 1.5 m (five guard plants). Plots were 1.8 m wide, containing one row of plants, separated by a single (shared) guard row (1.8 m). Plant spacing along the row was at 30 cm. Treatments were applied to the central row only in each plot. Assessments were done on the 20 plants in the central rows of each plot.

Table 1. SL567A treatments applied in the inoculated field experiment.

Treatment no.	Method of SL567A application	Inoculated soil	SL567A application rate (L product/ha)*	Crown drench concentration (ppm a.i.)*
1	-	No	-	
2	-	Yes	-	
3	Crown drench	Yes	0.25	300
4	Crown drench	Yes	0.125	150
5	Crown drench	Yes	0.0625	75
6	Soil application	Yes	1.3	
7	Soil application	Yes	0.65	
8	Soil application	Yes	0.325	

*Applied in 400 L water/ha

The trial was planted on 27 May 2004 at ADAS Terrington on a silt soil, previously cropped to ryegrass. Results of soil pH and nutrient analyses were:

pH = 7.9,
P = 89 mg/L (index = 5)
K = 528 mg/L (index = 4)
Mg = 227 mg/L (index = 4)

After preparation of a clean seed bed, fertiliser was applied prior to cultivation (N at 50 kg/ha, P at 150 kg/ha and K at 150 kg/ha). Nitrogen was applied as a liquid fertiliser (37%); P and K were applied as 0:24:24 granular fertiliser. The land was cultivated with a power harrow to provide loose soil underneath the planted crowns. Nine gulleys 1.8 m apart, and 65 m long, were prepared with a potato ridger, aiming for a gulley width of 40 cm and a depth of 10 cm.

Dutch Grade B asparagus crowns (var. Geynlim) were obtained from Teboza's in The Netherlands via a UK supplier, and were stored in the cold store at ADAS Terrington until required. Crowns were planted at the base of the gulleys at a spacing of 30 cm, ensuring that the bud was placed upwards, and that the roots were spread evenly across the gulley base. Twin ridging bodies were used to fill in the gulleys.

Fungicide treatments were applied in a 50 cm band using an Oxford Precision sprayer with 03F110 nozzle at 2 bar pressure. Treatments 1 and 2 remained untreated. For treatments 3, 4 and 5, crowns planted in the gulleys were band-sprayed (0.5 m width) with SL567A at the rates shown in Table 1. For treatments 6, 7 and 8, once crowns had been planted in the gulleys and infested soil applied (see below), the gulleys were refilled with soil and SL567A applied as a soil drench (0.5 m width) at the rates shown above.

Soil to be used as artificial inoculum was collected from a commercial asparagus field (Cambridgeshire) where symptoms of *Phytophthora* had been confirmed in 2004. In addition, samples of spears collected from the field with typical symptoms of *Phytophthora* rot were chopped and macerated, then mixed evenly into the soil.

Treatment 1 plots and the guard rows remained uninoculated. For inoculated treatments (2 to 8), infested soil was spread evenly to the sides of the gulleys at a rate of approximately 3.8 kg soil per 6 m plot length. For treatments 3, 4 and 5, infested soil was applied after the crowns had been drenched and prior to re-filling gulleys. For treatments 6, 7 and 8, infested soil was applied prior to re-filling gulleys

and the soil application of SL567A. The procedures for inoculating and applying SL567A are summarized in Table 2.

Table 2. Summary of inoculation and treatment procedures

Treatment 1	Treatment 2	Treatments 3-5	Treatment 6-8
Plant crowns	Plant crowns	Plant crowns	Plant crowns
↓	↓	↓	↓
Re-fill gulleys	Add soil inoculum	Apply SL567A	Add soil inoculum
↓	↓	↓	↓
Level off	Re-fill gulleys	Add soil inoculum	Re-fill gulleys
	↓	↓	↓
	Level off	Re-fill gulleys	Level-off
		↓	↓
		Level off	Apply SL567A

To provide conditions conducive for *Phytophthora* development, the plot was irrigated regularly for two 1.5 h periods per day using Wright Rain misting equipment, for 7 weeks after planting (2004) and during June and July in 2005.

In 2004, the herbicide Simazine 90WG was applied at 3 L/ha in 225 L water/ha after crown planting, and before spear emergence. The experimental area was hand-weeded during July and August as necessary. Metaldehyde pellets were applied in mid-July and early August and mid-September for slug control. Senesced fern was removed from the trial area in December 2004. Trial management for 2005 is summarised in the experiment diary (Appendix 1).

The following crop assessments were done during 2004:

- Number of plants emerged (1, 2, 3 and 5 months after planting)
- Incidence of *Phytophthora* rot and other pests/diseases on emerging plants (1 and 2 months after planting)
- Incidence of fern diseases (5 months after planting)
- Plant vigour (0 to 10 index, 2 and 3 months after planting)
- Fern numbers per plant (5 months after planting)

- Fern height (tallest fern per plant in cm, 5 months after planting)

In 2005, crop assessments were as follows:

- Number of plants present (14 and 16 months after planting)
- Incidence of phytophthora rot (May/June 2005) and fern diseases (September 2005)
- Plant vigour (0 to 10 index, 14 and 16 months after planting)
- Fern numbers per plant (16 months after planting)
- Fern height (tallest fern per plant in cm, 16 months after planting)
- Fern biomass as dry weight per plot (18 months after planting)

Soil from each plot was tested for the presence of *Phytophthora* sp. pathogenic to asparagus in November 2004 (see Section 2.3.1). In October 2005, crowns were dug from inoculated untreated plots (Treatment 2) and roots plated onto selective agar media (P_{10}ARP), to check for the presence of *Phytophthora* sp.

Data were analysed by analysis of variance (for number of ferns and fern height), generalised linear models (for plant counts) or by Friedman's test for non-parametric data (fern vigour scores).

2.4.2 Results and discussion

Results for the first year of the experiment (2004) are presented in the Year 1 Annual Report for year 1. Results for the second year of the experiment (2005) are summarised below.

No rust was observed on the fern in 2005, however, stemphylium lesions on stem bases and mid-stems were present on plants in all plots in September 2005.

As in 2004, no symptoms of phytophthora rot were observed either on emerging spears or fern stem bases during 2005. However, the significant treatment effects on crop establishment recorded in 2004 became further accentuated in 2005. At 14 months after planting, percentage plant survival was significantly lower for the untreated inoculated control and the three crown drench treatments, compared with the uninoculated control (Table 3). Percentage plant survival for the soil application treatments was, however, not significantly different from the uninoculated untreated control. At 16 months after planting, there was a significant treatment effect on plant vigour with poorest plant growth for the untreated inoculated control and the high and

low rate crown drench treatments (Table 4). There was no effect of treatment on the number of ferns per plant (Table 5) but fern height for the uninoculated untreated control was significantly higher than each of the other treatments except the medium rate soil application (Table 6). At the end of the experiment, fern biomass was highest for the uninoculated control treatment ($P<0.01$) and was approximately six times higher than that obtained for the inoculated control (Table 7). Among the inoculated treatments (T2 – T8), fern biomass for the medium rate soil application plots was significantly higher than the untreated control and the crown drench treatments ($P=0.059$).

In November 2004, soil baiting was used to confirm that *Phytophthora* sp. pathogenic to asparagus was present in the soil in the trial area. The pathogen was baited from 29 out of 32 plots. The presence of *Phytophthora* sp. in three of the uninoculated untreated control plots demonstrates the potential for pathogen spread in a field, for example during waterlogged conditions that occurred on the trial area in November 2004.

Crowns dug from the inoculated untreated control plots (T2) were small and rotted, with mainly rotted and hollow roots, in comparison with crowns from the uninoculated untreated control plots (T1) that had a larger, mainly healthy, root mass. On partially rotted roots from T2 crowns, superficial dark brown lesions and vascular staining due to *Fusarium* sp. were present. *Phytophthora* sp. was isolated on selective agar media from the tips of visibly healthy roots growing from rotting crowns. When plugs of mycelium were floated in distilled water, sporangial formation typical of *Phytophthora* sp. *ex* asparagus was observed.

The consistently poor results obtained for the inoculated untreated control plots in 2004 and 2005 confirms the deleterious effect that *Phytophthora* sp. present in soil can have on asparagus crop establishment. The plant population (number of established plants) was reduced by 27 % in 2004 and by almost 50% in 2005. Fern biomass was also reduced by approximately six times. Poor crop establishment also occurred in plots that received a crown drench at the time of planting. In 2004, it was the plots receiving the medium and high rate crown drenches (150 and 300 ppm a.i., respectively), that were worst affected suggesting a phytotoxic effect. Crop establishment results were better following the low rate crown drench in 2004 (75 ppm a.i.), suggesting adequate pathogen control without phytotoxicity. However, control was no longer effective in 2005. Similar effects were reported by Falloon &

Fraser (1990) in New Zealand indicating that optimising application rate to achieve pathogen kill without phytotoxicity can be problematic with asparagus crown drenches or dips. In comparison, the soil application of SL567A has the advantage that there is less chance of phytotoxicity, and less health and safety risk to operators. Application of SL567A to re-filled gulleys immediately after planting provided effective control of *Phytophthora* sp., with crop establishment results similar to those obtained for the uninoculated control treatment in 2004, particularly for the medium rate soil application (0.65 L product/ha). In 2005, the medium rate soil application remained as the most effective treatment. However, a 50% reduction in fern biomass compared with the uninoculated control, suggests that as for the other inoculated treatments, *Phytophthora* sp. was having a deleterious effect on crop development in the second year of the experiment. Soil baiting in November 2004 confirmed the presence of *Phytophthora* sp. pathogenic to asparagus in the majority of plots; in a commercial situation, this would have necessitated the use of a pre-emergence application of SL567A in April 2005 to maintain effective disease control in the 2nd year of crop establishment.

Table 3. Effect on percentage plant survival (14 months after planting) of SL567A treatments applied immediately after asparagus crown planting in *Phytophthora*-infested soil

Treatment	% plant survival
1. Untreated – uninoculated	75.0
2. Untreated – inoculated	40.0
3. Crown drench high rate	38.8
4. Crown drench medium rate	47.5
5. Crown drench low rate	38.8
6. Soil application high rate	58.8
7. Soil application medium rate	75.0
8. Soil application low rate	68.8
SED	2.429
d.f.	21
P	0.012

Table 4. Effect on plant vigour (16 months after planting) of SL567A treatments applied immediately after asparagus crown planting in *Phytophthora*-infested soil

Treatment	Vigour (0-10 index) – estimated median
1. Untreated – uninoculated	6.16
2. Untreated - inoculated	4.06
3. Crown drench high rate	3.97
4. Crown drench medium rate	4.58
5. Crown drench low rate	3.97
6. Soil application high rate	4.86
7. Soil application medium rate	5.37
8. Soil application low rate	4.93
d.f.	7
P	0.044*

(Data analysed by Friedman's non-parametric test)

Table 5. Effect on the number of ferns per plant (16 months after planting) of SL567A treatments applied immediately after asparagus crown planting in *Phytophthora*-infested soil

Treatment	Mean number of ferns per plant
1. Untreated – uninoculated	6.8
2. Untreated – inoculated	4.6
3. Crown drench high rate	4.5
4. Crown drench medium rate	5.6
5. Crown drench low rate	5.4
6. Soil application high rate	5.9
7. Soil application medium rate	5.6
8. Soil application low rate	5.5
SED	0.704
d.f.	21
P	0.091

Table 6. Effect on fern height (16 months after planting) of SL567A treatments applied immediately after asparagus crown planting in *Phytophthora*-infested soil

Treatment	Mean height of fern (cm)
1. Untreated – uninoculated	120.7
2. Untreated – inoculated	83.5
3. Crown drench high rate	80.3
4. Crown drench medium rate	94.1
5. Crown drench low rate	83.6
6. Soil application high rate	96.0
7. Soil application medium rate	105.3
8. Soil application low rate	96.9
SED	10.86
d.f.	21
P	0.023

Table 7. Effect on plant biomass (18 months after planting) of SL567A treatments applied immediately after asparagus crown planting in *Phytophthora*-infested soil

Treatment	Mean total dry matter per plot (g)
1. Untreated – uninoculated	1828.8
2. Untreated – inoculated	321.8
3. Crown drench high rate	196.6
4. Crown drench medium rate	412.0
5. Crown drench low rate	311.1
6. Soil application high rate	655.0
7. Soil application medium rate	861.0
8. Soil application low rate	622.3
SED	209.9*
d.f.	18*
P	0.059*

*analysis excluded untreated uninoculated control (Treatment 1)

2.5 Effects of metalaxyl-M (SL567A) and potassium phosphite (DP98) on asparagus Phytophthora

The aim of this experiment was to determine the effects on the incidence of spear rot and spear yield of metalaxyl-M (SL567A) and potassium phosphite treatments over two seasons, in an established asparagus crop known to be affected with *Phytophthora* sp. The experiment commenced in 2004 with results presented in the year 1 Annual Report). Due to poor plant stand in the experimental area, plots were re-located to a different area of the field in 2005 and treatments modified.

2.5.1 Methods

(Experiment diary in Appendix 1)

Treatments in 2005 (Table 8) were applied using an Oxford precision sprayer with 3 m boom and medium flat fan nozzle (03F110).

Table 8. Product application rates of SL567A and DP98 (potassium phosphite) used in the established crop field experiment.

	Product	Active ingredient	Product rate (L/ha)	Water volume (L/ha)	Spray timing
1	Untreated	-	-	-	-
2	SL567A*	Metalaxyl-M	1.3	400	Pre-harvest only
3	DP98**	-	4.0	400	Pre-harvest only
4	SL567A* DP98**	Metalaxyl-M -	1.3 4.0	400 400	Pre-harvest 4 weeks after 1st harvest

*SOLA 1502/05

**Potassium phosphite supplied by Omex

The experiment was sited in an established asparagus crop (Cambridgeshire, UK). Presence of *Phytophthora* sp. pathogenic to asparagus had been confirmed at the field site as follows:

- Typical symptoms of phytophthora spear rot were observed on spears in 2004 and confirmed by PCR as *P. asparagi* (Year 1 Annual Report).
- Symptom distribution was apparently random rather than aggregated, although some areas of the field were more severely affected.

- *Phytophthora* sp. was baited from soil samples collected from the field site in March 2004, using asparagus seedlings and also confirmed as *P. asparagi* by PCR (Year 1 Annual Report).

The experiment was laid out in a randomised block design, with six replicates of each treatment. Each plot was 12 m in length and four rows wide (6 m). Plants were originally established at a spacing of 30 cm between plants, and 1.5 m between rows. Treatments were applied to whole plots but assessments were done on plants in the central 6 m of the central two rows of each plot only. The pre-harvest treatments were applied prior to spear emergence and 8 days before the first harvest.

The grower was responsible for the following field operations:

- Land preparation prior to harvesting (ridge formation, fertiliser and herbicide application)
- Subsequent herbicide applications
- Spear harvest except on assessment days

From the start of spear harvest, yield assessments were made twice per week until the end of the harvest period (as decided by the grower). In each plot, only spears from the centrally marked out area were harvested and assessed. Apart from these assessments, the experiment area was harvested by the grower.

At each assessment time, the following were recorded for each plot:

- The total number of spears and weight
- Number and weight of spears with symptoms of phytophthora rot
- Number and weight of spears with damage other than phytophthora symptoms
- Number and weight of marketable spears in the following categories:
  - spears <10 mm diameter
  - spears >10 mm diameter
  - blown and twisted spears

Statistical analyses were by analysis of variance. Because the plots were harvested by the grower in between our assessment times, the data could be compared at a

particular assessment time but not across sampling times.

2.5.2 Results and discussion

In contrast to the 2004 harvest season, which commenced with heavy prolonged rain, weather conditions during the 2005 asparagus season were not conducive for the development of spear rot, with more sporadic rainfall. Harvest commenced on 29 April 2005. Spear rot was confirmed 1 week later for three out of four treatments, and subsequently occurred at very low incidences throughout the experimental area (Table 9). At least one infected spear was confirmed for each treatment during the harvest period. There was no effect of treatment on either the numbers or weight of marketable spears at any of the individual assessment dates or on cumulative data (data not shown). Given the low incidence of disease during the 2005 harvest season, no conclusions can be drawn regarding the effectiveness of the treatments against *Phytophthora* sp. The results are in contrast to findings from 2004 when in the same crop (different area of the field), a pre-harvest treatment with SL567A (1.3 L of product/ha) delayed appearance of spear rot due to *Phytophthora* sp. by 3 weeks compared with the untreated control. The fungicide was effective for approximately 6 weeks after pre-harvest application to the soil.

Table 9. Incidence of spears with symptoms due to *Phytophthora* sp. in an established asparagus crop (Cambridgeshire, 2005)

	No. of infected spears per treatment			
Date (2005)	Untreated	SL567A	DP98	SL567A followed by DP98
29 April	0	0	0	0
3 May	0	0	0	0
6 May	1	0	1	1
11 May	0	0	0	0
16 May	0	0	2	0
20 May	0	0	0	0
25 May	0	0	0	0
31 May	0	0	0	0
3 June	0	0	1	0
7 June	0	0	0	0
14 June	1	2	3	2
17 June	0	2	0	1
21 June	0	0	0	0
Total	2	4	7	4

In August 2005, stem base lesions were observed on emerging ferns, irrespective of treatment. *Phytophthora* sp. was consistently isolated from the stem base lesions and oospores were observed microscopically in the plant tissue, indicating that infected crop debris could provide a source of inoculum for the disease. Presence of *P. asparagi* was confirmed by PCR.

Despite confirmation of asparagus phytophthora in this field since 2002, the grower continues to obtain good yields. However, there are areas of the crop where plant stand (and spear emergence) is particularly poor, due perhaps to crown infection by *Phytophthora* sp.. The effect of phytophthora rot on yield has proved difficult to quantify in the experiments conducted in this field in 2004 and 2005, because even in a season favourable to phytophthora development (e.g. 2004), the proportion of emerging spears showing spear rot symptoms is relatively low. It is predicted that unseen yield losses are occurring, due to i) lower numbers of spears produced from infected crowns, and ii) infection and death of developing spears prior to emergence above the soil (P. Falloon, pers. comm.).

2.6 Effect of fungicides on phytophthora rot of asparagus

2.6.1 Introduction

SL567A (metalaxyl-M) is currently the only fungicide approved (SOLA 1502/05) for treatment of phytophthora rot on asparagus. Despite the reported effectiveness of this product for control of *Phytophthora* in the short-term, there are reports from New Zealand and California of a reduction in efficacy over time, due to microbial degradation in soil. In addition, growers may be wary of using the product on a routine basis on established crops, because of the cost involved. The aim of this experiment was to evaluate a range of fungicides for their efficacy against phytophthora rot on asparagus. The experiment was designed as an assay in which asparagus seedlings were grown in compost artificially inoculated with *Phytophthora* sp. *ex* asparagus. The range of products to be evaluated was selected based on previous evidence of activity against oomycete fungi, and discussions with agro-chemical company technical managers and V. Powell of HDC.

2.6.2 Methods

(Experiment diary in Appendix 1)

Treatments were applied as follows:

	Inoc.	Product	Active ingredient	Product rate	Product rate per m^2 (in 2500 L water/ha or 250 ml/m^2)
1	No	Nil	-	-	-
2	Yes	Nil	-	-	-
3	Yes	SL567A	Metalaxyl-M	1.3 L/ha	0.13 ml
4	Yes	Amistar	Azoxystrobin	1.0 L/ha	0.10 ml
5	Yes	Consento	Fenamidone + Propamocarb hydrochloride	2.0 L/ha	0.20 ml
6	Yes	Infinito	Fluopicolide + Propamocarb hydrochloride	1.6 L/ha	0.16 ml
7	Yes	Shirlan	Fluazinam	3.0 L/ha	0.30 ml
8	Yes	Aliette	Fosetyl aluminium	5.6 kg/ha	0.56 g
9	Yes	DP98	-	4.0 L/ha	0.40 ml
10	Yes	Experimental 1	Dimethomorph	0.3 ml/m^2	0.30 ml

Notes:

SL567A	SOLA 1502/05
Amistar	Administrative Experimental Approval
Consento	Administrative Experimental Approval
Infinito	Administrative Experimental Approval
Shirlan	Administrative Experimental Approval
Aliette	Administrative Experimental Approval
DP98	Potassium phosphite
Dimethomorph	Administrative Experimental Approval

A plot comprised a seedling tray containing 30 asparagus seedlings. The trial was laid out in a randomised block design in a controlled temperature store, with four replicates of the ten treatments. Statistical analyses of the proportion of plants emerged and the proportion or emerged seedlings with symptoms of phytophthora rot, was by generalised linear models in Genstat.

Inoculum was prepared as follows. A pure culture of *Phytophthora* sp. *ex* asparagus was sub-cultured onto ten plates of potato dextrose agar (PDA). The plates were incubated at 18^{o}C in the dark. V8 juice broth was prepared using a 1:4 dilution of V8 juice to distilled water and adjusted to pH 5.5 with calcium carbonate. One litre of vermiculite was measured into each of ten autoclave bags. V8 juice broth (500 ml) was added to each bag, sufficient to wet the vermiculite without excess broth draining to the base of the bags. Each bag was sealed across the top with masking tape and autoclaved in an upright position for 60 minutes. After cooling in a laminar flow hood, one bag was put aside to use for the uninoculated control plots (Treatment 1). For each of the remaining bags, sterile technique was used to cut an actively growing colony of *Phytophthora* sp. *ex* asparagus on one plate into approximately 0.5 cm^{2} pieces, which were then added to a bag. The corner of the bags was re-sealed with new masking tape and the bags were shaken gently to distribute the mycelial pieces within the vermiculite. Both the uninoculated and inoculated bags were placed in an incubator in the dark for 4 weeks (18-20^{o}C). After 3 weeks, development of *Phytophthora* sp. was confirmed by sampling vermiculite at random from an inoculated bag and sprinkling it on PDA plates incubated for 5 days at 18^{o}C in the dark. Resulting mycelial growth was floated in sterile distilled water to check for sporangial development typical of *Phytophthora* sp. The inoculum was ready for use after approximately 4 weeks. The vermiculite was crumbled apart and mixed by shaking before use.

For each seedling tray required for Treatments 2-10, 250 ml inoculated vermiculite was mixed thoroughly with 2250 ml F1 compost. Trays for Treatment 1 were made up in the same way but using uninoculated vermiculite. Care was taken to avoid contamination between inoculated and uninoculated trays. Each tray was placed in an individual gravel tray containing water (to ensure the compost was always moist).

After 5 days, treatments were applied to the trays using an Oxford Precision Sprayer set at 2 Bar pressure with a single nozzle boom attached. Spray quality was fine (02F110 nozzle). Each treatment was applied in a volume equivalent to a field

application of 2500 L/ha. After this spray application, the trays were left for 1 day, then overhead watered.

The trays were left for a further 5 days before 30 asparagus seeds (cv. UC157 F1) were sown in each tray. The trays were then placed in a controlled environment store in the dark at 18-20^{o}C. The compost was kept continually moist by watering into the gravel trays as required, being careful to avoid cross-contamination. The trays were inspected at least three times a week until emergence took place. Assessments were made 1-2 times a week until no further plants emerged. The trays were assessed for number of emerged seedlings and number of wilted seedlings. When seedling wilting was first observed, seedlings with typical symptoms were uprooted (after assessment), washed under tap water to remove compost, then floated in sterile distilled water in a Petri dish. The seedlings were examined after 3-4 days using an inverted microscope to check for the development of sporangia typical of *Phytophthora* sp.

2.6.3 Results and discussion

Three weeks after inoculation of vermiculite bags, fungal colonies with morphology typical of Phytophthora sp. developed consistently from pieces of vermiculite plated onto PDA. Sporangia typical of *Phytophthora* sp. developed when sections of mycelium were floated in sterile distilled water. After 4 weeks, mycelium could be seen growing throughout the vermiculite. These observations confirmed that *Phytophthora* sp. was actively growing in the vermiculite that was to be used as inoculum.

Asparagus seedlings started to emerge 17 days after sowing. Figure 2 shows seedling emergence for the different treatments over time with more rapid emergence for the uninoculated control, and plots treated with SL567A, Amistar and Shirlan. After approximately 7 weeks, numbers of seedlings reduced in some plots due to death of infected seedlings. At 6½ weeks after sowing (19.04.06), there was a significant effect of treatment on seedling emergence (Table 10). Seedling emergence was significantly reduced in the inoculated control compared to the uninoculated control, from 87 to 32%. Fungicides that resulted in seedling emergence that was significantly higher than the inoculated control, and not significantly different from the uninoculated control treatment were SL567A and Amistar and Shirlan. Emergence in the remaining treatments was not significantly higher than the inoculated control treatment.

Seedlings in the uninoculated control plots remained white/pale green for the duration of the trial. In other plots, seedlings that were translucent in appearance and wilting or collapsed were observed approximately 7 weeks after sowing. Sporangia typical of *Phytophthora* species developed consistently when these seedlings were incubated in float culture, confirming that symptom development was due to infection by *Phytophthora* sp.. At 8½ weeks after sowing, there was a significant effect of treatment on the incidence of phytophthora symptoms (Table 11). The incidence of symptoms was significantly higher for the inoculated control (71%) compared to the uninoculated control (3%). Symptom development for SL567A was significantly lower than for the inoculated control and not significantly different from the uninoculated control treatment. For Amistar and Aliette there was a trend for lower percentage symptom development than for the inoculated control but this was not statistically significant. For the remaining fungicides, percentage symptom development was not significantly different from the inoculated control treatment.

In summary, the results of the asparagus seedling bioassay confirmed that inoculation of compost with *Phytophthora* sp. *ex* asparagus resulted in reduced seedling emergence and increased seedling wilting compared with the uninoculated control. A compost drench with SL567A (metalaxyl-M) gave control of phytophthora rot equivalent to the uninoculated control. Despite the selection of a wide range of fungicide actives (that are available for control of phytophthora diseases on other crops) for evaluation in this experiment, none were as effective as SL567A in controlling phytophthora rot. The results confirmed that this fungicide is currently the best available product for control of phytophthora rot on asparagus. Medium control was also obtained with Amistar (azoxystrobin) and Shirlan (fluazinam). Amistar currently has off-label approval for use on asparagus, but not as a pre-harvest soil treatment. Shirlan is not approved for use on asparagus. The results for DP98 (potassium phosphite) confirmed the results from year 1 of the established crop experiment (Section 2.5) that this product is not effective for control of phytophthora root rot on asparagus.

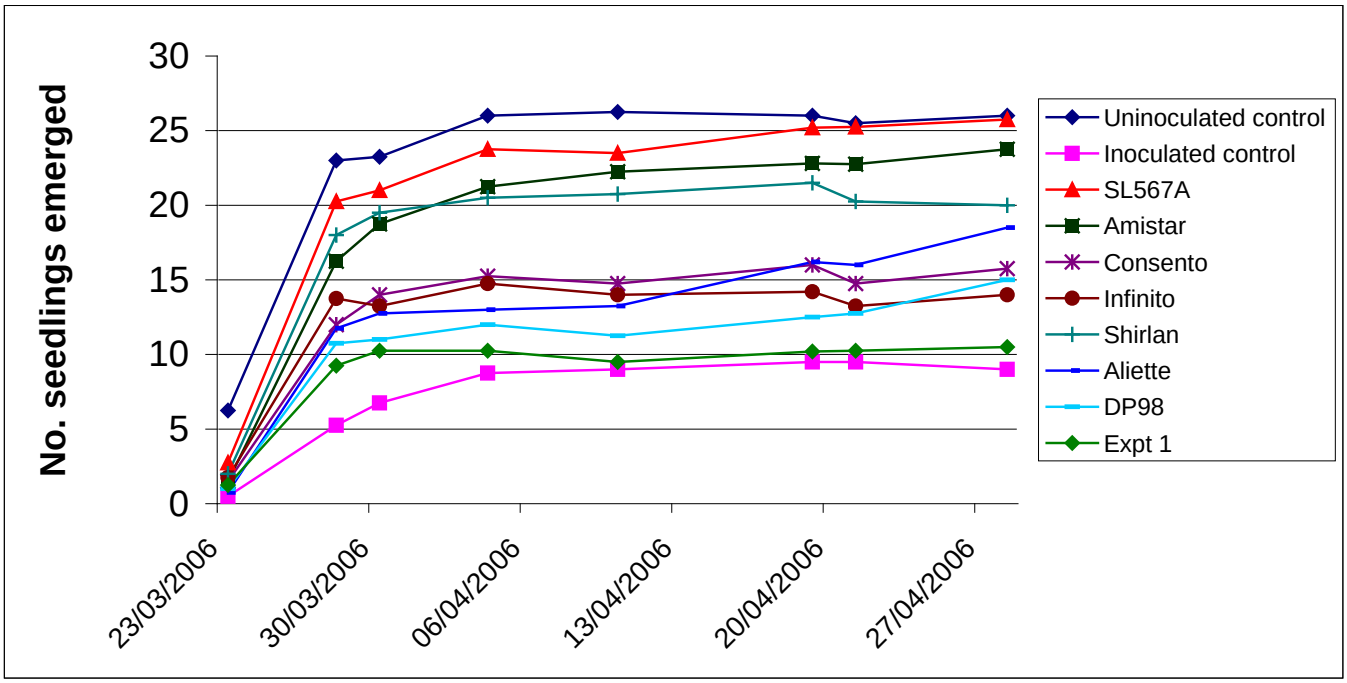

Figure 2. Effect of fungicide treatments on emergence of asparagus seedlings over time

Table 10. Effect of fungicide treatments on percentage emergence of asparagus seedlings grown in compost inoculated with *Phytophthora* sp. *ex* asparagus (6½ weeks after sowing)

	Inoculation	Product	Mean % seedling emergence
1	No	Nil	*86.7
2	Yes	Nil	31.7
3	Yes	SL567A	*84.2
4	Yes	Amistar	*75.8
5	Yes	Consento	53.3
6	Yes	Infinito	47.5
7	Yes	Shirlan	*71.7
8	Yes	Aliette	54.2
9	Yes	DP98	41.7
10	Yes	Experimental 1	34.2
		D.f.	39
		F. Probability	0.007

*Mean % seedling emergence significantly higher than the inoculated control (treatment 2)

Table 11. Effect of fungicide treatments on percentage of emerged asparagus seedlings with symptoms of phytophthora rot when grown in compost inoculated with *Phytophthora* sp. *ex* asparagus (8½ weeks after sowing)

	Inoculation	Product	Mean % emerged seedlings wilted
1	No	Nil	*2.8
2	Yes	Nil	71.3
3	Yes	SL567A	*13.5
4	Yes	Amistar	37.1
5	Yes	Consento	66.1
6	Yes	Infinito	80.5
7	Yes	Shirlan	61.9
8	Yes	Aliette	36.3
9	Yes	DP98	51.9
10	Yes	Experimental 1	74.0
		D.f.	39
		F. probability	<0.001

*Mean % emerged seedlings wilted significantly lower than the inoculated control (treatment 2)

2.7 Overall conclusions (2004 – 2006)

2.7.1 Pathogen identification

- The pathogen causing spear and root rot of asparagus in the UK was confirmed by analysis of the rDNA ITS sequence, as the same species of *Phytophthora* that is pathogenic to asparagus in other countries; this has previously been named *P. megasperma* var. *sojae*. The proposed name new name is *P. asparagi*. Other species of *Phytophthora* known to infect asparagus worldwide include *P. cryptogea*, *P. cactorum* and *P. richardiae*.

2.7.2 Occurrence of phytophthora rot on asparagus in the UK and worldwide

- Phytophthora rot on asparagus was confirmed in the UK in 2004 (five counties), 2005 and 2006. The disease was more prevalent in 2004 and 2006, following heavy rainfall in both harvest seasons, compared with 2005.
- The disease continues to be a problem worldwide, with reports of its occurrence in Michigan, USA and Canada.

2.7.3 Pathogen detection

- A seedling baiting technique was successfully used to test soil for the presence of *Phytophthora* pathogenic on asparagus.
- A PCR-based molecular diagnostic test for *P. asparagi*, developed on the basis of ITS sequence variation, was developed by SCRI. This was validated using asparagus spears, roots, stem bases and soil. There could be potential for the test to be developed for commercial use, either pre-planting for detection of the pathogen in soil, or to determine whether batches of planting material (crowns) were free of *Phytophthora* sp.. Further development work would, however, be required to optimise the diagnostic technique and also to determine optimum sampling strategies.

2.7.4 Management of phytophthora at crop establishment

- The impact of *Phytophthora* sp. in soil on asparagus crop establishment was demonstrated in an inoculated field trial, with plant stand reduced by 27% in untreated inoculated plots in year 1 and by almost 50% in year 2.

- Poor crop establishment also occurred in inoculated plots that received a crown drench of SL567A (metalaxyl-M) at the time of planting, due to inadequate phytophthora control using a low application rate (75 ppm a.i) and phytotoxicity with medium and high application rates (150 and 300 ppm a.i., respectively).
- Applications of SL567A to soil immediately after planting resulted in good crop establishment in 2004, equivalent to the uninoculated control treatment, with no evidence of phytotoxicity. Among the inoculated treatments in 2005, crop growth was best overall in plots that had received the medium soil application rate (0.65 L of product/ha) at planting. However, a reduction in fern biomass compared to the uninoculated control demonstrated that as for the other inoculated treatments, *Phytophthora* sp. was having a deleterious effect on crop development in the second year of the experiment. In a commercial situation, this would have necessitated the use of a pre-emergence application of SL567A in April 2005 to maintain effective disease control in the 2nd year of crop establishment.
- Soil baiting six months after inoculation confirmed the presence of *Phytophthora* sp. pathogenic to asparagus in the majority of plots, including the uninoculated control plots, demonstrating movement of the pathogen through a field.
- To date, there have been no reports of asparagus crop establishment failures due to *Phytophthora* sp. in the UK, and so the economic benefit of fungicide treatment at planting would need to be assessed. However, since there is a direct relationship between yield and plant population, any minor loss of plants during the establishment years will have an effect on yield for the rest of the life of the crop. This cumulative effect on yield can be large (P. Falloon, pers. comm.).

2.7.5 Management of phytophthora in established crops

- In an experiment sited in a mature crop (2004), a pre-harvest treatment with SL567A (1.3 L of product/ha) delayed appearance of spear rot due to *Phytophthora* sp. by 3 weeks compared with the untreated control. The fungicide was effective for approximately 6 weeks after pre-harvest application to the soil.
- SL567A needs to be applied as close to the start of harvest as possible within the SOLA guidelines for use (a minimum of 7 days prior to harvest).
- These results could not be confirmed in 2005, due to low incidence of disease in the experimental area.
- An inoculated seedling bioassay confirmed that out of eight products tested,

SL567A (metalaxyl-M) was the most effective fungicide for control of phytophthora rot on asparagus, applied as a soil drench treatment. Moderate control was also obtained with Amistar and Shirlan, but neither of these products currently has approval for pre-harvest use on asparagus.

2.8 References

Cooke, D.E.L., Drenth, A., Duncan, J.M., Wagels, G., Brasier, C.M. 2000. A molecular phylogeny of *Phytophthora* and related Oomycetes. *Fungal Genetics and Biology.* **30**: 17-32.

Falloon, P.G. 1982. Baiting, pathogenicity and distribution of *Phytophthora megasperma* var. *sojae* in New Zealand asparagus soils. *New Zealand Journal of Agricultural Research*. **25**: 425-429.

Falloon, P.G., Mullen R.J., Benson, B.L. & Grogan, R.G. 1985. Control of *Phytophthora* rot with metalaxyl in established asparagus. *Plant Disease*. **69**: 921-923.

Falloon, P.G., Fraser, H.A. 1990. Control of establishment failures in asparagus (*Asparagus officinalis* L.) caused by Phytophthora rot. *New Zealand Journal of Crop and Horticultural Science*. **19**:47-52.

Falloon, P.G., Falloon, L.M. & Anderson, A.M. 2001. Breeding asparagus varieties resistant to *Phytophthora*. *Proceedings of the Xth International Asparagus Symposium, Japan, August 2001.*

HDC. 2002. Asparagus: control of *Phytophthora* rot. FV 246 Final Report. Horticultural Development Council.

Saude, C., Hausbeck, M.K., Hurtado-Gonzales, O. & Lamour, K.H. 2005. Detection of a *Phytophthora* sp. causing asparagus spear and root rot in Michigan. *Plant Disease* **89**: 1011.

Vujanovic, V. 2003. First report of root rot on asparagus caused by *Phytophthora megasperma* in Canada. *Plant Disease* **87**:447.

2.9 Technology transfer (2004-2006)

Phone advice to growers and consultants on management of *Phytophthora* on asparagus in 2004, 2005 and 2006.

2.9.1 Articles in HDC News

- Article on ADAS/Syngenta Vegetable Conference in HDC News (March 2006) including results from FV 246a.
- Feature article on asparagus research in HDC News (May 2006) including results from FV 246a.

2.9.2 Publications

Chimento, A., Scibetta, S., Schena, L., Cacciola, S.O., Green, K.R., Cooke, D.E.L.. 2005. The development of a real-time PCR assay for the detection of *Phytophthora* in asparagus. XII Congress of S.I.Pa.V., Reggio Calabria, Italy, 29 Sept-1 Oct 2005.

Green, K. & Dyer, W. 2004. Management of *Phytophthora* rot on UK asparagus crops. HDC Factsheet 06/04. East Malling, Kent: Horticultural Development Council. 4 pp.

Green, K.R., Dyer, W., Falloon, P.G., Cooke, D.E.L. & Chimento, A. 2006. Management of *Phytophthora* rot on UK asparagus crops. *Acta Horticulturae (in press).*

2.9.3 Presentations

- 'Asparagus: management of phytophthora rot' Presentation by K. Green to an Open meeting of the Asparagus Growers Association, PGRO, November 2004.
- 'Biology and management of phytophthora diseases on vegetables'. Presentation by K. Green (incorporating results from FV 246a) at HDC Roadshow on Field vegetable research, Kirton, Lincs, March 2005
- 'Management of *Phytophthora* rot on UK asparagus crops'. Poster presentation by K. Green at the XIth International Asparagus Symposium, Horst, The Netherlands, June 2005.
- 'Soil-borne diseases of vegetables: old and new culprits'. Presentation by K. Green (incorporating results from FV 246a) at the ADAS Syngenta Vegetable Conference, February 2006.
- 'Management of phytophthora rot on asparagus'. Presentation by K. Green at the Annual Conference of the Asparagus Growers' Association, Peterborough, March 2006.

2.10 Acknowledgements

Assistance from the following is gratefully acknowledged:

- H.V. Aveling (provision of field site).
- D. Cooke and colleagues at SCRI (PCR-based diagnostics).
- Asparagus growers (provision of soil and spear samples).
- W. Dyer (asparagus consultant, Suffolk UK) and P. Falloon (Aspara Pacific, New Zealand) for technical expertise.
- B. Benson for provision of asparagus seed

3. APPENDIX 1: EXPERIMENT DIARIES

Effects of metalaxyl-M (SL567A) on asparagus crop establishment in a field inoculated with phytophthora

Date	Activity
26.05.04	Land culivated with a power harrow
27.05.04	Ridges formed, trial planted, sprays applied
28.05.04	Logger set up. Mist irrigation commenced
08.06.04	Pre-emergence herbicide applied (Simazine)
09.06.04	Spear emergence commenced
21.06.04	Approx 75 % spear emergence. Slug damage observed
23.06.04	Plant counts recorded
13.07.04	Metaldehyde applied
15.07.04	Irrigation stopped
29.07.04	Establishment and vigour assessment
04.08.04	Metaldehyde applied
31.08.04	Establishment assessment
20.09.04	Metaldehyde applied
22.10.04	Fern assessment
09.11.04	Soil samples taken for phytophthora testing. Ferns beginning to senesce. Trial area waterlogged
Dec 04	Removal of senesced fern
14.03.05	Application of Glyphosate to trial (as Sting-ECO)
11.04.05	Application of nitrogen
25.04.05	Application of Simazine to trial (alpha-Simazine). 1st spears emerging
26.04.05	Application of slug pellets (metaldehyde)
17.05.05	Plant counts recorded
13.07.05	Plant counts and vigour assessments
20.09.05	Foliar disease assessment
20-27.09.05	Biomass assessment (fern)

Effects of metalaxyl-M (SL567A) and potassium phosphite (DP98) on asparagus phytophthora

Date	Activity
19.04.05	Plots marked out in the field.
21.04.05	Pre-harvest sprays applied
27.04.05	Spear emergence occurring in most plots
29.04.05	1st harvest – dry weather. No phytophthora
03.05.05	2nd harvest – dry weather. No phytophthora
06.05.05	3rd harvest – dry weather. Phytophthora confirmed
11.05.05	4th harvest – dry weather. No phytophthora
16.05.05	5th harvest – dry weather. Phytophthora confirmed
20.05.05	6th harvest – rainy weather. No phytophthora
25.05.05	7th harvest – rainy weather. No phytophthora
27.05.05	Disease assessments but no harvest. Phytophthora confirmed
31.05.05	8th harvest – dry. No phytophthora T4 spray applied
03.06.06	9th harvest – previously rainy. Phytophthora confirmed
07.06.05	10th harvest – dry. No phytophthora
14.06.05	11th harvest – dry. Phytophthora confirmed
17.06.05	12th harvest – dry. Phytophthora confirmed
21.06.05	13th harvest – dry. No phytophthora. Grower ceased harvesting
05.08.05	Phytophthora confirmed on emerging ferns and at base of mature fern

Effect of fungicides on phytophthora rot of asparagus

Date	Activity
25.01.06	Bags of vermiculite with V8 juice solution prepared and autoclaved
26.01.06	Vermiculite inoculated with *Phytophthora* sp. *ex* asparagus
17.02.06	Vermiculite from infested bags plated onto selective agar
20.02.06	Consistent growth of *Phytophthora* sp. from vermiculite on agar. No contaminants
24.02.06	Vermiculite inoculum mixed with F1 compost in trays
01.03.06	Fungicide applications to compost
02.03.06	Treatments watered in
06.03.06	Asparagus seeds sown in treated compost
18.03.06	Trays moved into controlled environment room
23.03.06	First emergence
24.03.06	Assessment 1
28.03.06	Assessment 2
30.03.06	Assessment 3
04.04.06	Assessment 4
10.04.06	Assessment 5