

Management of Phytophthora root rot in radiata pine seedlings

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EXECUTIVE SUMMARY

Management of *Phytophthora* root rot in *radiata* pine seedlings

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BACKGROUND

Block 4 at Te Ngae nursery has recently suffered losses among *Pinus radiata* seedlings due to *Phytophthora* root rot. The purpose of this project was to investigate chemical and biological options under controlled environmental conditions for their ability to control root rot of *P. radiata* seedlings, caused by *Phytophthora cinnamomi*. This project complements FRST-funded studies conducted at Te Ngae nursery where various integrated programmes are being evaluated for their ability to manage root rot under field conditions.

SUMMARY

A series of four pot trials was conducted to evaluate selected chemical products and a biological agent, as potential alternatives to metalaxyl to control *Phytophthora* root rot caused by *P. cinnamomi* in *Pinus radiata* seedlings. Two soil treatments, Trichoderma and humate-lime, and one foliar treatment, Foli-R-Fos[®], were evaluated alone and in combination in order to identify potential additive benefits with regard to disease control. Treatments were applied to the soil and/or to seedlings before transplantation of seedlings into potting mix that was infested with *P. cinnamomi*. Seedlings were maintained in conditions that were highly favourable for the development of *Phytophthora* root rot for the duration of the experiment. Ridomil[®] Gold MZ (a.i. metalaxyl) completely suppressed root rot when applied to infected potting mix at a rate of 460 mg/L or higher. However, when applied at concentrations approximating the recommended field rate (33 mg/L), Ridomil[®] Gold MZ was not effective and disease incidence reached 65% after three weeks compared with 85% in the untreated control. Trichoderma and humate-lime, whether applied alone or in combination, did not control root rot. Foliar application of Foli-R-Fos alone reduced root rot incidence by up to 60%, but the efficacy of this treatment was not consistent among experiments. Combination treatments involving Foli-R-Fos with humate-lime or with Trichoderma generally resulted in lower disease incidence than the component treatments applied alone. Although the differences in disease incidence were not statistically significant, there is an apparent trend indicative of an additive benefit that merits further investigation.

The treatments under investigation in this study were also evaluated in FRST funded trials at Te Ngae nursery between 2006 and 2008. In each season, root rot symptoms developed following root pruning suggesting a link between this activity and root infection. Ridomil[®] Gold MZ provided moderate control (8% seedling mortality) when applied one week after root pruning, but was ineffective (21% mortality) when applied at seedling emergence. Poor control at emergence was attributed to dilution or degradation of metalaxyl during the period between application and root pruning. The most effective treatment was Foli-R-Fos, which reduced mortality from root rot to 0.14% when applied at fortnightly intervals commencing one month before root pruning (seven applications). Results of the field trial study have been prepared for publication and extracts from the manuscript can be found in Appendix 1.

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INTRODUCTION

Phytophthora spp. are destructive pathogens causing rots of roots, crowns, stems, leaves and fruits of a large range of economically important plants. *Phytophthora cinnamomi* Rands and *Phytophthora cactorum* (Lebert & Cohn) J. Schröt. are widely distributed in New Zealand and have been associated with root rot of trees, particularly on waterlogged soils (Newhook 1959; Gilmour 1966). *Phytophthora cinnamomi* is the most widely studied species in relation to the disease in *Pinus radiata* and the pathogen has been isolated from the roots, the collar, and the stems up to 2 cm above the soil in dead seedlings (Newhook 1959; Butcher et al. 1984).

Phenylamides such as metalaxyl (e.g. Ridomil[®] Gold, Apron[®] XL) have been used extensively for control of *Phytophthora* root rots of a wide range of plants including conifers (Humphrey 1980; Kenerley et al. 1984; Ray 1990). However, fungicide application against *P. cinnamomi* is sometimes uneconomic or impractical and so there is a need for alternative control strategies. In Australia, salts of phosphorous acid, also referred to as phosphonate or phosphite, have proven effective against *P. cinnamomi* in *P. radiata* seedlings (Ali et al. 1999) and in mature *Banksia* and *Eucalyptus marginata* trees (Shearer et al. 2006). These compounds exhibit direct antifungal activity and can activate host resistance against infection (Guest & Grant 1991; Hardy et al. 2001; Daniel et al. 2005). Phosphorous acid is the active ingredient in several registered products in New Zealand including Foli-R-Fos[®], Foschek[™] and Phosgard[™]. However, there are no published studies describing its use to control *Phytophthora* root rot in *P. radiata* in New Zealand forest nurseries.

Careful management of chemical control options is necessary to minimise the risk of resistance development among pathogen populations. Integrated management strategies promote the use of chemicals in a more sustainable manner by combining them with biological and cultural methods. Microbial antagonists such as *Trichoderma* spp. have demonstrated potential to control forestry pathogens (Reglinski & Dick 2005). Introduction of *T. harzianum* into growing medium resulted in suppression of damping-off caused by *P. cinnamomi* in *Pinus echinata* seedlings (Kelley 1976) and also reduced seedling mortality caused by *Fusarium oxysporum* in container-grown Douglas fir (Mousseaux et al. 1998). In New Zealand, the application of *Trichoderma* spp., both as an amendment to potting media or as a seed coating, promoted seed germination and enhanced the survival of container-grown *radiata* pine seedlings (Hill et al. 2007). There is evidence that amendment of the growing medium with organic compounds and/or minerals may also contribute to the suppression of root pathogens. For example, humate has been proposed to encourage the proliferation of beneficial microbes, including *Trichoderma* spp. (Vawdrey et al. 2002) whilst calcium, either as gypsum (calcium sulphate) or lime (calcium carbonate) has been used to suppress *Phytophthora* root rot in susceptible crops (Campanella et al. 2002).

In this study, Ridomil Gold MZ, Foli-R-Fos, *Trichoderma* spp. and humate-lime were evaluated alone and in combination, for their ability to control root rot caused by *P. cinnamomi* in *P. radiata* seedlings. Experiments were carried out in controlled environmental conditions and were designed to complement the FRST-funded study at Te Ngae nursery in which various management schedules were under investigation

MATERIAL AND METHODS

Four experiments were conducted to assess the effect of various fungicide and biological treatments on the incidence of root rot caused by *Phytophthora cinnamomi*. The experiments were conducted in a controlled environment room with a temperature of 20°C and a 16-h photoperiod.

PLANT MATERIAL

Pinus radiata seedlings (GF Plus™; Olsen Seeds, PF Olsen and Company Ltd) were grown in 0.45-L pots (surface area = 59 cm²) in bark-based potting mix (Daltons) containing slow release fertiliser, but with no fungicide. The seedlings were approximately 12 weeks old and 8 – 10 cm tall when the experiments began.

PREPARATION OF INFESTED POTTING MIX

Phytophthora cinnamomi was cultured on oatmeal agar for one week and then sub-cultured onto sterilised oat grains and grown for a further three weeks. Potting mix was inoculated with 10 g/L of the oat-grain *P. cinnamomi* prior to transplantation of *P. radiata* seedlings. Once the seedlings showed severe wilting, they were removed to confirm that roots were symptomatic of root rot (dark brown water-soaked appearance) and the infested potting mix was retained and used for pot trial experiments.

TREATMENT APPLICATION

Each treatment was applied to 20 seedlings, with one seedling per pot.

Ridomil Gold MZ, hereafter referred to as Ridomil, and humate-lime, were applied to the infested potting mix one day before seedlings were transplanted. In experiments 1 and 2, Ridomil was applied at high concentrations, 1850 mg/L and 460 mg/L, respectively, to ensure positive control. In experiments 3 and 4, the Ridomil concentration was reduced to 230 mg/L and 33 mg/L, respectively, in order to establish a rate at which disease control was lost. Humate and lime were applied at rates of 1.25 and 0.6 g/L, respectively. The Trichoderma treatments (Arbor-Guard™ in experiments 1, 2 and 3 and Unite® in experiment 4) were each applied as a spore suspension at the recommended label rates (2.5×10^7 spores/L). The Trichoderma products were applied to the infested potting mix twice; one week and one day before transplanting in all cases except experiment 1 in which a single application was made one day before transplanting. Foli-R-Fos (5.3 ml/L) was applied as a foliar spray to run-off, one week and one day before transplanting. After transplanting into the infested mix, the treated seedlings were set out in randomised blocks on a bench. In experiment 1 only, an uninfected and untreated treatment was included as an extra control. In order to encourage root rot and prevent cross-contamination among pots, each pot was placed in a shallow saucer that was kept filled with water by hand irrigation every 2 – 3 days.

Disease assessments were carried out at intervals for 6 – 11 weeks, until the untreated control plants were mostly (>80%) infected. Plants were assessed as either healthy or infected, and typically showed symptoms of dry needles, followed by wilting and needle chlorosis (Figure 1). Disease incidence data were analysed using ANOVA in GenStat v9.



Figure 1. **Top.** *Pinus radiata* seedlings growing in potting mix infested with *Phytophthora cinnamomi*. The seedling on the left has healthy green needles whereas those in the centre and on the right are showing progressive development of needle chlorosis and wilt. **Bottom left.** Healthy seedling with new roots (white), **Bottom right.** Seedling with root rot.

RESULTS

EXPERIMENT 1

Ridomil completely suppressed root rot development for the duration of the experiment (41 days) when applied at the rate of 1850 mg/L to infested potting mix one day before inoculation (Figure 2). Foliar application of Foli-R-Fos, applied one week and again one day before inoculation, delayed the onset of root rot with 20% of treated seedlings exhibiting root rot symptoms after 21 days compared with an incidence of 45% in untreated controls. A similar result was obtained when Foli-R-Fos was applied in combination with the Trichoderma potting mix treatment. Trichoderma was not effective when applied alone. Uninfected untreated controls remained healthy throughout the experiment.

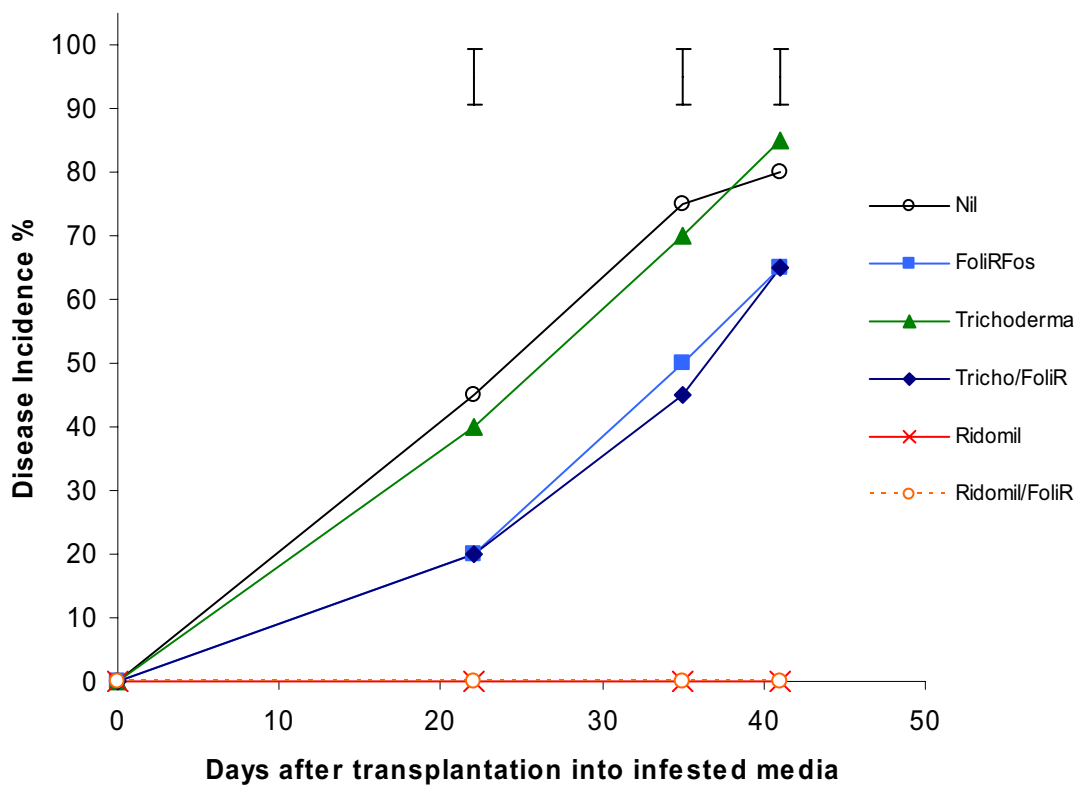


Figure 2. Effect of different treatments on the development of root rot in *P. radiata* seedlings after transplantation into potting mix infested with *P. cinnamomi*. Foli-R-Fos was applied to seedlings as a foliar spray, 7 days and 1 day before transplantation. Ridomil and Trichoderma were applied to the infested potting mix 1 day before transplantation of the seedlings. SEDs are presented for each timepoint. Treatment concentrations were; Foli-R-Fos (5.3 ml/L), Trichoderma (2.5×10^7 spores/L), Ridomil (1850 mg/L).

EXPERIMENT 2

Ridomil applied to potting mix at the rate of 460 mg/L completely suppressed root rot (Figure 3). The other potting mix treatments, humate-lime and Trichoderma, were ineffective when applied alone. Combinations of Trichoderma/Foli-R-Fos and humate-lime/Foli-R-Fos significantly delayed the onset of root rot. However, there was no treatment in which Foli-R-Fos was applied alone and therefore is not possible to confirm whether there was truly any additive effect of these combinations.

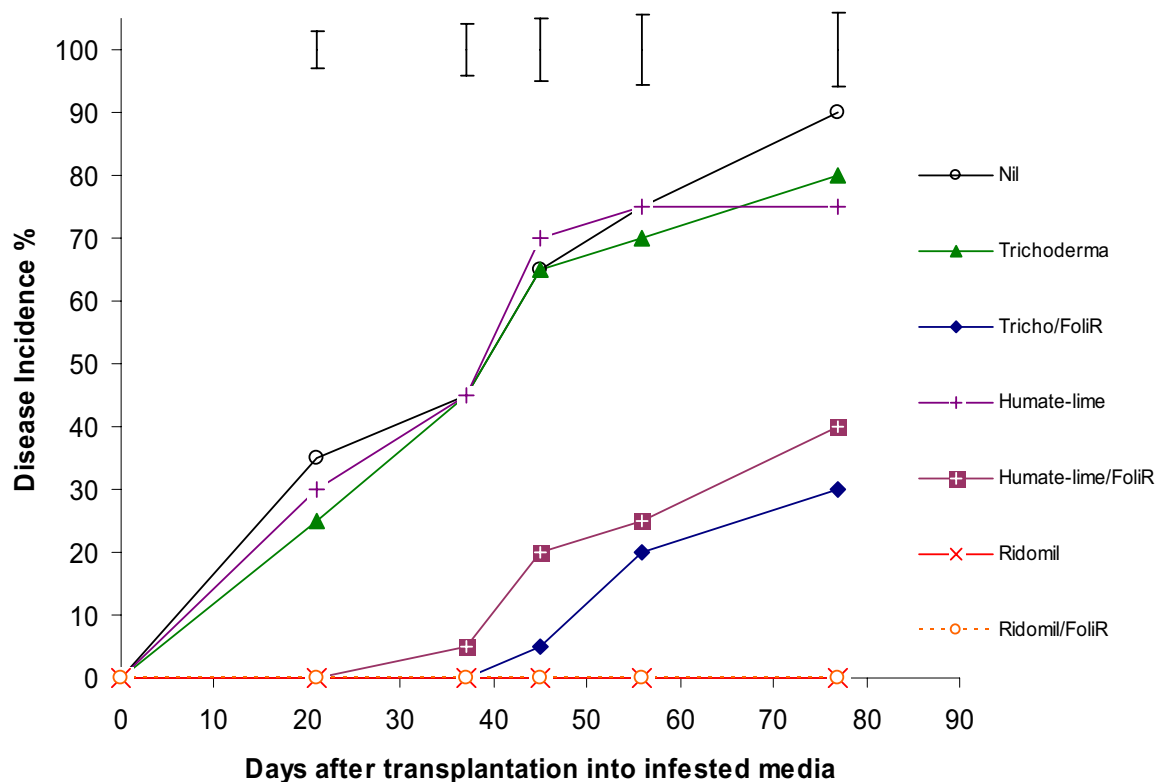


Figure 3. Effect of different treatments on the development of root rot in *P. radiata* seedlings after transplantation into potting mix infested with *P. cinnamomi*. Foli-R-Fos was applied to seedlings as a foliar spray, 7 days and 1 day before transplantation. Trichoderma was applied to potting mix 7 days and 1 day before transplantation. Ridomil and humate-lime were applied to the potting mix 1 day before transplantation. SEDs are presented for each timepoint. Treatment concentrations were; Foli-R-Fos (5.3 ml/L), Trichoderma (2.5×10^7 spores/L), Ridomil (460 mg/L), humate (1.25 g/L), lime (0.6 g/L).

EXPERIMENT 3

Ridomil did not completely suppress infection when applied at 230 mg/L but did delay the onset of infection until at least 35 days after transplanting (Figure 4). After 41 days there was only 5% root rot incidence among Ridomil-treated seedlings compared with 85% in the untreated controls. Root rot incidence among Foli-R-Fos-treated seedlings reached 35% after 26 days and did not increase above this level for the remainder of the experiment. The Trichoderma/Foli-R-Fos and the humate-lime/Foli-R-Fos combinations exhibited similar levels of disease incidence to Foli-R-Fos alone during the first month after inoculation. By day 41, however, the combination treatments had significantly higher disease incidence than Foli-R-Fos alone. The combination of humate-lime/Trichoderma was not effective and appeared to increase seedling susceptibility to root rot.

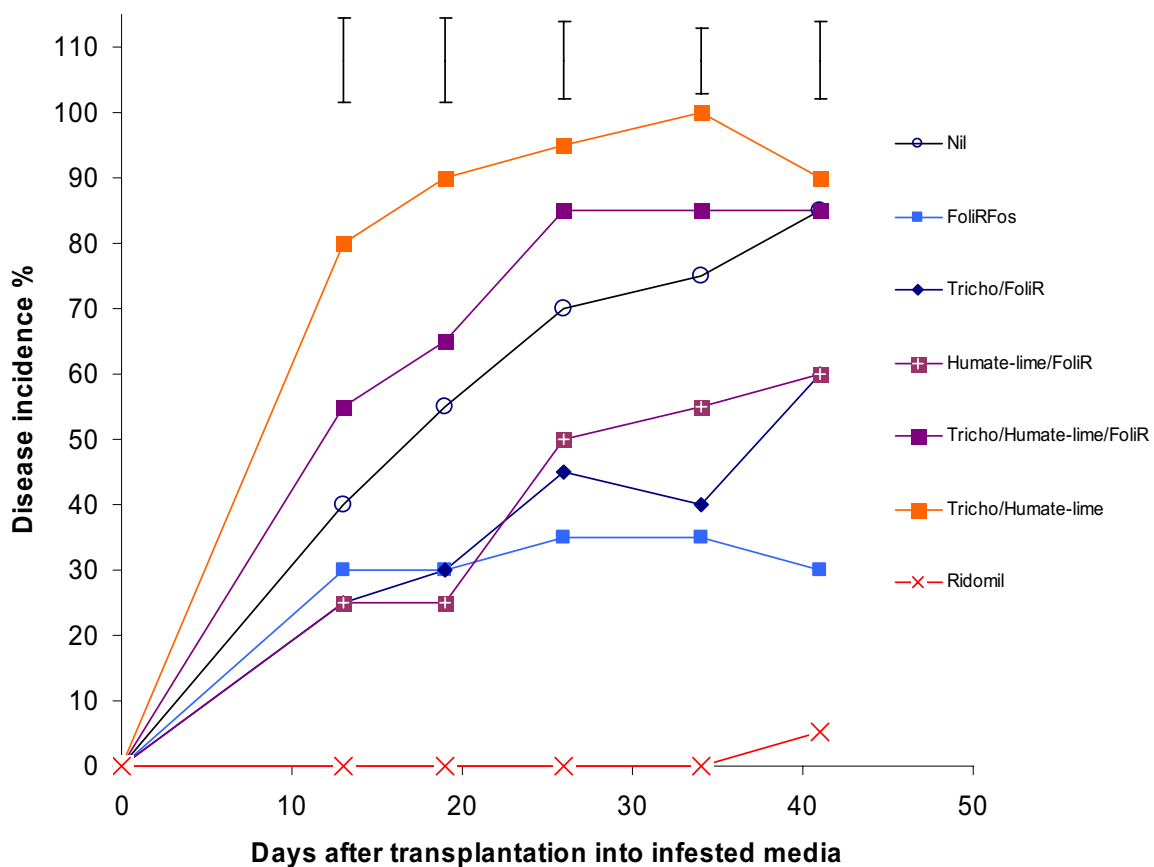


Figure 4. Effect of different treatments on the development of root rot in *P. radiata* seedlings after transplantation into potting mix infested with *P. cinnamomi*. Foli-R-Fos was applied to seedlings as a foliar spray, 7 days and 1 day before transplantation. Trichoderma was applied to potting mix 7 days and 1 day before transplantation. Ridomil and humate-lime were applied to the potting mix 1 day before transplantation. SEDs are presented for each timepoint. Treatment concentrations were; Foli-R-Fos (5.3 ml/L), Trichoderma (2.5×10^7 spores/L), Ridomil (230 mg/L), humate (1.25 g/L), lime (0.6 g/L)

EXPERIMENT 4

Ridomil did not prevent root rot development when applied at concentrations approximating to field application rates (33 mg/L), with disease incidence rising to 65% after 21 days compared with 85% in untreated controls (Figure 5). The most effective treatment was the Trichoderma/Foli-R-Fos combination, with 45% disease incidence after 21 days. These two components provided significantly greater disease control when used in combination than when used alone. Humate-lime and Trichoderma/humate-lime were not effective.

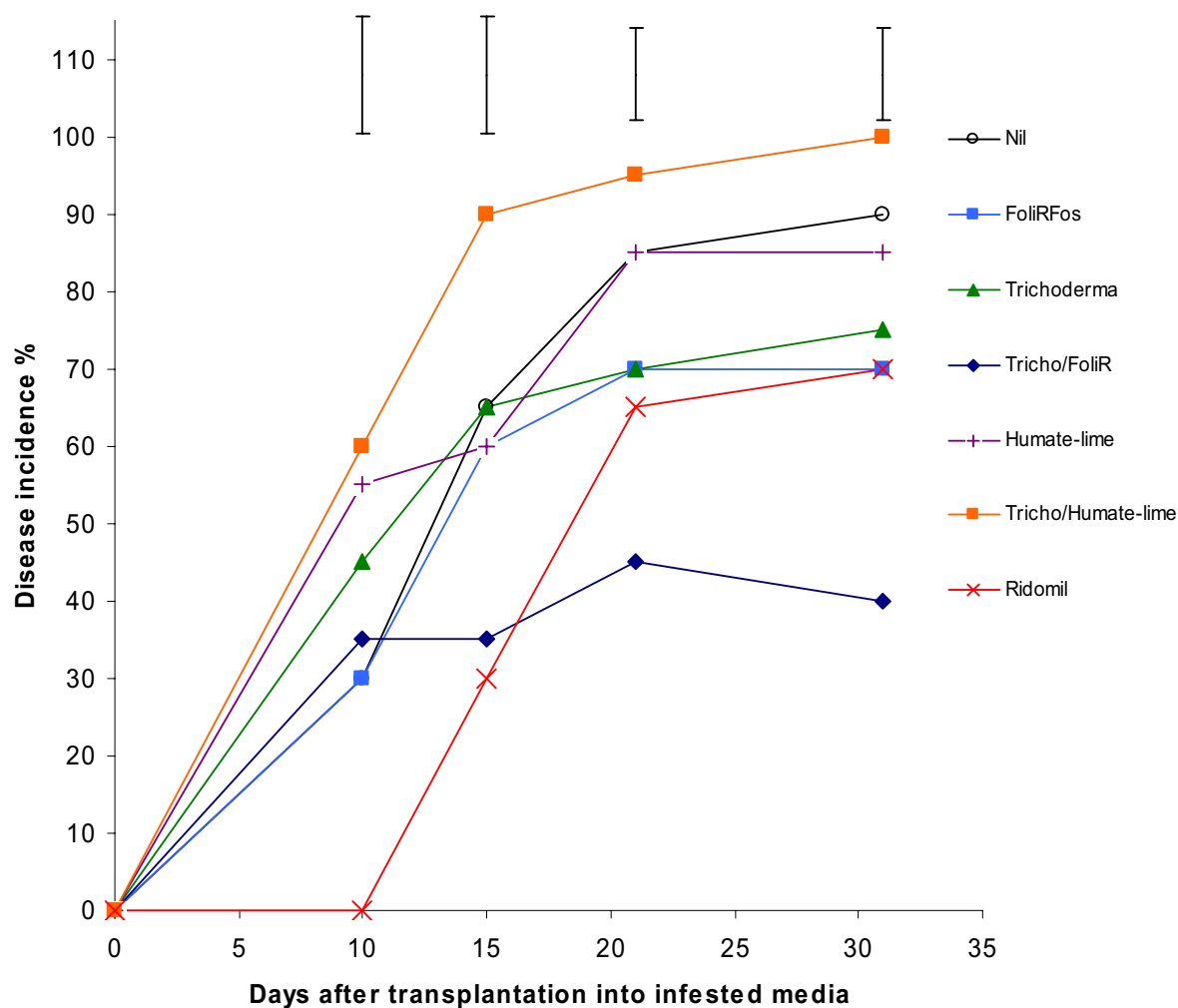


Figure 5. Effect of different treatments on the development of root rot in *P. radiata* seedlings after transplantation into potting mix infested with *P. cinnamomi*. Foli-R-Fos was applied to seedlings as a foliar spray, 7 days and 1 day before transplantation. Trichoderma was applied to potting mix 7 days and 1 day before transplantation. Ridomil and humate-lime were applied to the potting mix 1 day before transplantation. SEDs are presented for each timepoint. Treatment concentrations were; Foli-R-Fos (5.3 ml/L), Trichoderma (2.5×10^7 spores/L), Ridomil (33 mg/L), humate (1.25 g/L), lime (0.6 g/L)

It is difficult to compare treatments across experiments because of likely differences in inoculum loading in the batches of *P. cinnamomi* infested potting mix used for each trial. This variability is illustrated, in part, by the pattern of disease development in untreated seedlings in each experiment. For example, in experiment 1 disease incidence among untreated seedlings reached ~70% after 35 days whilst in experiments 2, 3 and 4 this level of

infection was observed after 56, 26 and 15 days, respectively. Therefore, in order to compare the relative performance of Foli-R-Fos, Trichoderma and Trichoderma/Foli-R-Fos, disease incidence was averaged across the four experiments and normalised by selecting data from the time points at which disease incidence was ~70% in untreated controls (Figure 6). Results confirm that Trichoderma alone is ineffective but indicate that the Trichoderma/Foli-R-Fos combination provides slightly greater disease suppression than Foli-R-Fos alone.

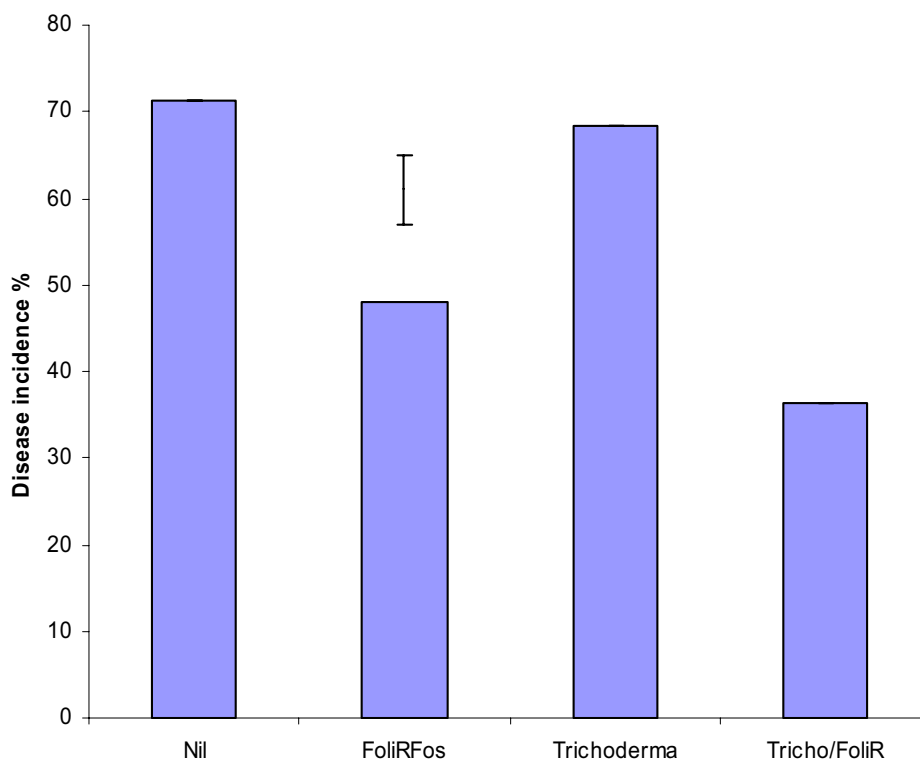


Figure 6. Average disease incidence, from four experiments, in *P. radiata* seedlings after transplantation into potting mix infested with *P. cinnamomi*. Foli-R-Fos was applied to seedlings as a foliar spray, 7 days and 1 day before transplantation. Trichoderma was applied to potting mix 7 days and 1 day before transplantation. SED is presented as a bar. Treatment concentrations were: Foli-R-Fos (5.3 ml/L), Trichoderma (2.5×10^7 spores/L)

DISCUSSION

Chemical and biological treatments were evaluated for their potential to control *P. cinnamomi* root rot in *P. radiata* seedlings. A series of four pot trials was conducted in controlled environmental conditions that were highly favourable for pathogenic infection.

Ridomil was included as a positive control since this chemical has been used for Phytophthora control at Te Ngae nursery and has proven effective for *P. cinnamomi* control in agricultural and horticultural crops. When applied at 460 mg/L or higher, Ridomil was extremely effective and completely suppressed root rot for the duration of the experiment. The fungicide was not effective, however, when applied at 33 mg/L. This loss of control at 33 mg/L is of interest since the recommended application rate for Ridomil in tree nurseries is 12.5-50 kg/ha and this would equate to 12.5-50 mg/L, assuming an even distribution of chemical to a depth of 10cm (e.g. 50 kg/ha = 50 kg/10,000 m² = 5 g/m²; since 1 m² area x 10 cm depth = 100 L volume then 5 g/100L = 50 mg/L). This suggests that field application rates are too low to ensure disease control when conditions are highly conducive for infection. Indeed, this may be an overestimate of soil concentration, since the chemical will not necessarily be restricted to the top 10 cm of soil and the seedling roots will extend below this depth. The actual concentrations and persistence of this fungicide in the field will vary according to various biotic and abiotic factors (Monkiedje et al. 2007).

Trichoderma species are common soil fungi and can tolerate a range of environmental conditions making them good candidates for the suppression of root pathogens. There is increasing interest in the use of Trichoderma as a seed coating in forest nurseries in New Zealand. Hill and colleagues (2007) reported enhanced germination and survival of Trichoderma-treated radiata pine in the nursery and a reduction in seedling mortality from *Armillaria* disease in the forest after planting out. In this study, Trichoderma was incorporated into potting mix with and without humate/lime since humate is reported to encourage the proliferation of beneficial microbes, including Trichoderma (Vawdrey et al. 2002) whilst lime (calcium carbonate) has been used to suppress Phytophthora root rot in susceptible crops (Campanella et al. 2002). Neither Trichoderma nor humate/lime reduced the incidence of root rot in *P. radiata* seedlings when applied individually and appeared to increase disease incidence when used in combination. It is possible that the prevailing environmental conditions (saturated potting mix), whilst favouring pathogen development, were unsuitable for proliferation of Trichoderma. This concurs with a report by Kelley (1976) who found that Trichoderma was unable to suppress damping-off in *P. echinata* seedlings, caused by *P. cinnamomi*, when soil moisture was maintained near saturation level. These results stress the importance of understanding the biology of alternative management methods in order to appreciate their likely limitations.

Foliar application of Foli-R-Fos reduced root rot incidence by up to 60% but was not consistent among experiments when used alone. Interestingly, in some instances combinations of Foli-R-Fos with humate/lime or with Trichoderma exhibited lower disease incidence than the individual treatments when applied alone. Although these differences were generally not statistically significant, this trend that merits further investigation. Improvements in suppression of root diseases have been reported in other pathosystems when biological control agents have been used in combination with different chemicals (Vogt & Buchenauer, 1997; Benhamou et al. 1998).

These methods were also evaluated at Te Ngae nursery between 2006 and 2008 in a parallel study that was funded in part by FRST with significant in kind support from the nursery.

Root rot symptoms in the nursery commonly developed following root pruning, suggesting a link between this activity and root infection. Roots were not trimmed in the laboratory study but would have suffered damage during transplantation into infested potting mix. The results from the laboratory study and the field study show strong similarities, with Foli-R-Fos emerging as the most likely candidate to provide an alternative to Ridomil. Ridomil provided moderate control (8% root rot) when applied one week after root pruning but was ineffective (21% root rot) when applied at seedling emergence, possibly due to degradation of metalaxyl during the period between application and root pruning. Foli-R-Fos reduced root rot incidence to 0.14% when applied at fortnightly intervals commencing one month before root pruning (seven applications). The field trial study has been prepared for publication and excerpts from the submitted manuscript are presented in Appendix 1.

CONCLUSIONS

Ridomil completely suppressed *P. cinnamomi* root rot when applied at 460 mg/L or higher but was less effective when applied at concentrations (33 mg/L) that equate to the recommended rate for use in tree nurseries. Overall, this fungicide demonstrates good activity against *P. cinnamomi* and can contribute to disease management if targeted at periods of high risk. Foliar application of Foli-R-Fos alone reduced root rot incidence by up to 60% but this level of control was not consistent among experiments. Given that Foli-R-Fos is less expensive than Ridomil, there may be merit in developing a management schedule involving both of these chemicals. Furthermore, although Trichoderma and humate/lime were not effective against root rot when used alone, there were some underlying trends in the data to suggest a benefit in combining these treatments with Foli-R-Fos. The management of intractable diseases such Phytophthora root rot require an integrated approach that includes chemical, cultural and biological control measures.

RECOMMENDATIONS

The following recommendations for the management of Phytophthora are based on the findings of this report and of the FRST funded field studies summarised in the appendix.

- Foli-R-Fos[®] should be applied every two to four weeks during periods of high risk
- Ridomil[®] Gold should be used at the highest recommended label rate.
- Further research is recommended to:
 - Investigate the combined use of Foli-R-Fos[®] and Ridomil[®] Gold in the forest nursery.
 - Determine persistence of metalaxyl (a.i. in Ridomil[®] Gold) in soil and potting mix.
 - Investigate effects of soil water content on ability of Trichoderma and other biocontrol agents to suppress Phytophthora.
 - Investigate the use of biological seed treatments

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APPENDIX

Summary of Te Ngae field trials

Trials were conducted over two seasons in Block 4 at Te Ngae nursery. In each season, symptoms of *Phytophthora* root rot developed during April, one month after root pruning, when seedlings were approximately six months old. In trial one, by mid July 2007 root rot incidence was 9.1% in untreated plots and 8.4% in the plots that had been treated with Ridomil[®] Gold MZ (14 kg/ha) at seedling emergence. Disease incidence was lowest (2.1%) in plots that received seven monthly applications of Foli-R-Fos (6.5 L/ha). Other treatments, including seed coating with thiram or *Trichoderma* spp., and foliar applications of methyl jasmonate did not affect disease incidence. In trial two, effects of treatment timing relative to root pruning were investigated. By late June 2008, three months after root pruning, root rot incidence was 22.2% in the untreated plots. Foli-R-Fos was the most effective treatment and almost completely suppressed disease (0.1% incidence) when applied fortnightly from February until May (seven applications). Ridomil[®] Gold MZ (15 kg/ha) was not effective (21.4% incidence) when applied five months before root pruning. Disease incidence was reduced, however, when the chemical was applied one week after root pruning (14.9% incidence) and greater control was achieved (8.2% incidence) when the application rate was increased to 50 kg/ha.

Materials and methods

Radiata pine seed (*Pinus radiata* D. Don), supplied by PF Olsen Ltd, New Zealand, was a control pollinated mix of 15 parents with a GF24 ranking (seed lot 05/203) in trial one and was an open pollinated mix with a GF19 ranking (seed lot 05/611) in trial two. Before sowing, seed was stratified by soaking for 48 h and then storing for 14 days at 4°C in moist conditions.

Details of the treatments for each trial and of the routine management activities are listed in Tables 1 and 2. In trial one, seed was treated before being sown on 28 September 2006. In addition to the trial treatments, all seed was treated with methiocarb to mitigate against losses to birds. Soil treatments were applied on 18 October 2006; Ridomil[®] Gold MZ was applied as a soil drench (550 L/ha) whilst humate plus lime was broadcast over the soil. Foli-R-Fos and methyl jasmonate were applied monthly using a backpack pressure sprayer on 21 November, 18 December 2006, 19 January, 12 February, 6 March, 19 April and 22 May 2007. Root pruning was carried out on 16 March.

In trial two, all seed was treated with *Trichoderma* spp. and methiocarb and sown on 16 October 2007. The early soil treatments were applied on 1 November 2007; Ridomil[®] Gold MZ was applied as a soil drench (550 L/ha) whilst humate plus lime was broadcast over the soil. Late soil treatments were applied on 26 March 2008, one week after root pruning on 19 March. Foli-R-Fos was applied on 13 December 2007, 17 January, 13 February, 27 February, 13 March, 26 March, 10 April, 24 April and 7 May 2008, according to treatment.

Table 1. Treatment details

Trial 1 (2006/07)	
Main plot seed treatments	
Untreated	
Thiram	
<i>Trichoderma</i> spp.	
Sub-Plot treatments	
Soil	Foliar spray
Untreated	Untreated
Untreated	Foli-R-Fos monthly from Nov 06
Ridomil [®] Gold MZ (14 kg/ha) at emergence	Untreated
Ridomil [®] Gold MZ (14 kg/ha) at emergence	Methyl jasmonate monthly from Nov 06
Ridomil [®] Gold MZ (14 kg/ha) at emergence	Foli-R-Fos monthly from Nov 06
Humate-lime at emergence	Methyl jasmonate monthly from Nov 06
Humate-lime at emergence	Foli-R-Fos monthly from Nov 06
Trial 2 (2007/08)	
Treatments	
Soil	Foliar spray
Untreated	Untreated
Ridomil [®] Gold MZ (15 kg/ha) at emergence	Untreated
Ridomil [®] Gold MZ (15 kg/ha) at root pruning	Untreated
Ridomil [®] Gold MZ (50 kg/ha) at root pruning	Untreated
Untreated	Foli-R-Fos monthly from Dec 07
Humate-lime at emergence	Foli-R-Fos monthly from Dec 07
Untreated	Foli-R-Fos monthly from Feb 08
Untreated	Foli-R-Fos two-weekly from Feb 08

Table 2. Schedule of other fungicides and routine management activities on the trial site

Trial 1		Trial 2	
Date	Product / Activity	Date	Product / Activity
28 Nov 06	Prochloraz	20 Nov 07	Fluazinam
22 Dec 06	Prochloraz	4 Dec 07	Prochloraz
2 Jan 07	Prochloraz	14 Dec 07	Fluazinam
11 Jan 07	Captan	27 Dec 07	Prochloraz
16 Jan 07	Fluazinam	9 Jan 08	Prochloraz
24 Jan 07	Fluazinam	18 Jan 08	Fluazinam
30 Jan 07	Fluazinam	4 Feb 08	Prochloraz
9 Feb 07	Prochloraz	26 Feb 08	Prochloraz
9 Feb 07	Copper	17 Mar 08	Copper
16 Feb 07	Prochloraz		
16 Mar 07	Root prune	19 Mar 08	Root prune
16 Apr 07	Lateral prune	16 Apr 08	Lateral prune
27 May 07	Top to 40 cm height		

Results

Trial 1, 2006/07.

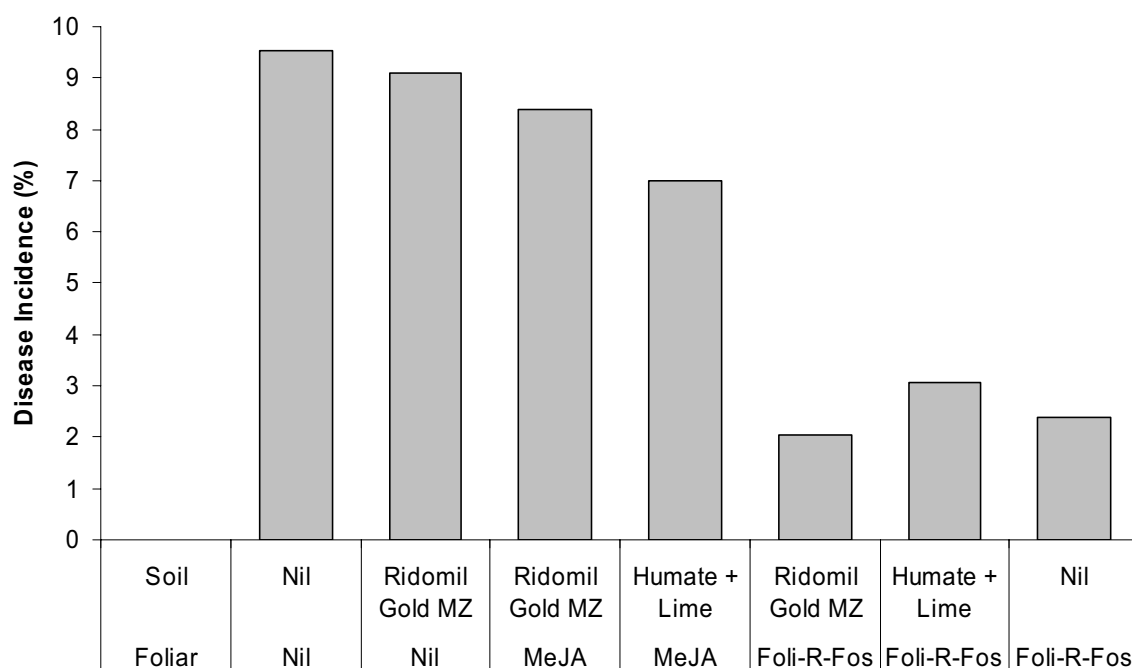


Figure 1. Incidence of root rot in pine seedlings in trial 1 at Te Ngae nursery assessed on July 18, 2007. Note that the final foliar applications were applied on May 22, 2007. S.E.D. = 1.42

The standard nursery management treatment (Ridomil[®] Gold MZ at seedling emergence) did not reduce disease incidence compared to the untreated control (Figure 1). Foli-R-Fos, whether used alone or in combination with soil treatments, was the only treatment that significantly ($p < 0.001$) reduced disease incidence (Table 4). On 18 July 2007, lowest disease incidence (2.1%) was recorded in plots treated with Foli-R-Fos, a reduction of 75% compared to the Ridomil[®] treatment. However, this was not significantly different to plots treated with Foli-R-Fos in combination with Ridomil[®] (3.1%) or humate-lime (2.4%). Humate-lime reduced the incidence of root rot slightly when contrasted with Ridomil[®] ($p = 0.009$ and 0.062 at 17 May and 18 July, respectively). Methyl jasmonate, used in combination with Ridomil[®] or humate-lime, did not affect root rot incidence compared with the untreated control, and performed significantly poorer ($p < 0.001$) than the equivalent Foli-R-Fos combinations.

Trial 2, 2007/08.

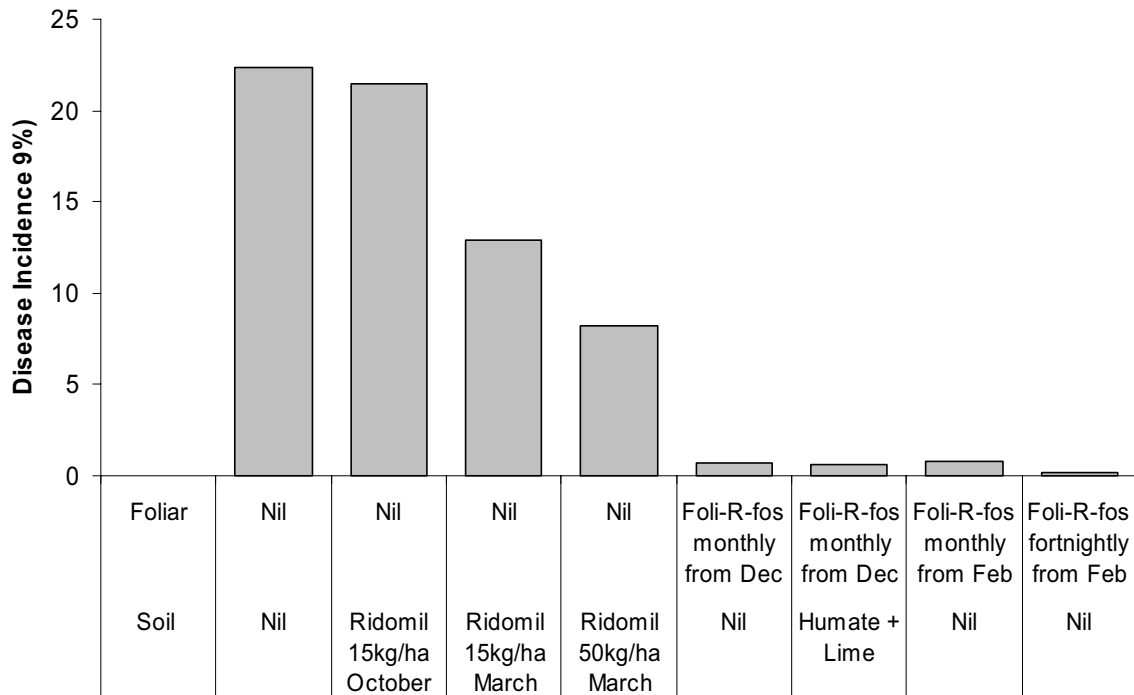


Figure 2. Incidence of root rot in pine seedlings in trial 2 at Te Ngae nursery assessed on June 30, 2008. Note that the final foliar applications were applied on May 7, 2008. S.E.D. = 1.93

In trial two, *Phytophthora cactorum* was isolated from soil and root tissue samples taken from plots exhibiting disease symptoms. By June 30, 2008 root rot incidence in untreated plots was 22.2% and 21.5% in plots that had been treated with Ridomil (15 kg/ha) at seedling emergence. However, Ridomil reduced root rot incidence to 14.9%, when applied one week after root pruning. Efficacy was further enhanced (8.2% incidence) when Ridomil was applied at 50 kg/ha. Foli-R-Fos was the most effective treatment and reduced disease incidence to 0.8% or below when applied monthly from December (six applications) or February (four applications), and almost completely suppressed disease (0.1% incidence) when applied fortnightly from February (seven applications).



Root rot symptoms in trial plots at Te Ngae nursery.

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