

# Biocontrol of forest nursery pathogens

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## Abstract

Forest nurseries in New Zealand produce over 50 million radiata pine plants annually. These comprise seedlings, rooted cuttings and micro-propagated plantlets. Regular chemical control measures are generally required in order to manage several of the fungal diseases affecting these plants. Global trends towards reduced fungicide inputs are putting pressure on growers to find alternative disease management strategies. There is therefore increasing interest in biological control methods to suppress the growth of plant pathogens and to stimulate natural plant disease resistance. In this article we discuss the potential for implementing biocontrol methods to suppress diseases of pine in forest nurseries.

## Introduction

*Pinus radiata* comprises approximately 90% of the exotic plantation forest area in New Zealand, six per cent is planted in Douglas fir (*Pseudotsuga menziesii*), and the remainder is a mix of hardwoods and other coniferous species. Current demand is for sufficient plants to establish 40-55,000 ha of forest each year, a mix of re-establishment and new areas. With the average initial stocking of the pine plantations at around 800 stems per hectare, this means that every year the market requires up to 44 million radiata pine seedlings, cuttings or plantlets that are suitable for planting. Inevitably some of the stock produced will be culled during the growing period, or rejected prior to planting, so forest nurseries will have to produce around 50 million plants annually in order to meet the demand. Although most of the plants are produced in bare-rooted nursery beds, the percentage of containerised stock has been slowly increasing in recent years. Currently approximately half of the ex-nursery stock for plantation establishment is produced as cuttings and half as seedlings.

Most forest nurseries in New Zealand operate with a considerable level of chemical intervention. In bare-root nurseries, weeds are controlled by pre-emergent and post-emergent applications of herbicides; fertility is largely maintained by the use of artificial fertilisers. Applications of fungicides for the management of disease are routine and regular for both bare-rooted and containerised plants. Most stem and foliage diseases are readily controlled, provided chemical applications begin as soon as environmental conditions become conducive to disease development. It can be more difficult to control disease in stool beds because of the problem of achieving good fungicide penetration into the thick mass of shoots and foliage. Wounds created during the process of taking cuttings may also be open to infection by secondary parasites or wound invaders.

Apart from the mechanical difficulty of ensuring good coverage by non-systemic chemicals, there are other issues around the requirement for sustained applications of fungicides. Primarily these are: the development of resistance by the target pathogen to a particular product, and concerns about the adverse effects of pesticides on human health and the environment.

Some chemicals (e.g. copper fungicides, mancozeb, captan) act at several sites in the biochemical pathways of fungi and such fungicides maintain their activity even with frequent use over long periods of time. Others act at one

specific site and development of resistance may occur as the result of a mutation at that site, which enables individuals to tolerate the effects of the chemical (Gullino 2000). The continued use of that chemical favours an increase in the population of the fungicide-resistant strains and results in a greater risk of disease epidemics. Many single-site fungicides act at the same biochemical site and are known as DMI (di-methylation inhibitor) type fungicides. Sportak®, used in many nurseries to control terminal crook disease is a DMI fungicide. The benzimidazoles, for example Benlate® and Bavistin®, form another group of site-specific fungicides and resistance to these has been recorded more often than in any other group. Metalaxyl (eg Ridomil®), which was once used extensively for control of *Phytophthora* root rots before resistance was recorded, belongs to the phenyl amide group of fungicides that are also site specific.

Concerns about the adverse effects of pesticides on human health and the environment are greater than ever. These include the direct effect of some chemicals on humans (e.g. the ban on mercury compounds), the promotion of multi-chemical resistance of some common pathogens through over-use of single-site fungicides, and the long-term impact on antibiotics indiscriminately sprayed into the environment to provide some control over bacterial diseases of plants. Residues (e.g. copper) in the soil are also a possible side effect of persistent chemical treatment of nursery diseases. Consequently, there is increasing scrutiny of pesticides and many chemicals previously thought of as "safe" are being voluntarily or forcibly withdrawn from the market. Biological control agents (BCAs) and elicitors of host defence have been proposed as alternatives to synthetic chemicals for disease control in crop production systems.

## Using Beneficial Microbes to Suppress Disease

Most fungi and bacteria in the nursery are either saprophytic on soil organic matter or beneficial rather than harmful. Some fix nitrogen, some are mycorrhizal, some are antagonistic to, or compete with, soil-borne pathogenic fungi. Many non-pathogenic saprophytes suppress the growth of plant pathogens through competition for nutrients, the production of inhibitory metabolites, and/or parasitism thereby naturally limiting the spread of plant disease in the environment. While diverse microbes may contribute in this way to the biological control of plant pathogens, most research and development efforts have focused on isolates of three genera, *Trichoderma*, *Bacillus* and *Pseudomonas*. Examples of commercially available products containing these organisms are listed in Table 1

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Table 1. Microbial-based products for promoting plant health.

Product	Microorganism	Manufacturer
Trichodex	<i>Trichoderma harzianum</i> T-39	Makhteshim-Agan, Israel
Rootshield G ®	<i>T. harzianum</i> T-22	BioWorks Inc, USA.
Plantshield HC®	<i>T. harzianum</i> T-22	BioWorks Inc, USA
BinabT®	<i>T. harzianum</i> & <i>T. polysporum</i>	Binab, Sweden
Bio-Fungus®	<i>Trichoderma</i> spp.	BioPlant, Denmark
Trichopel R®	<i>T. harzianum</i> & <i>T. viride</i>	Agrimm Technologies, NZ
Sentinel®	<i>Trichoderma</i> LC52	Agrimm Technologies, NZ
ArborGuard™	<i>T. harzianum</i> & <i>T. atroviride</i>	Gro-Chem NZ Ltd
Kodiak®	<i>Bacillus subtilis</i>	Gustafson, Inc. USA
Serenade™	<i>B. subtilis</i>	AgraQuest, USA.
BioYield™	<i>B. subtilis</i> GB03 & <i>B. amy-loliquefaciens</i> IN937a	Gustafson, Inc. USA
YieldShield ®	<i>B. pumilus</i>	Gustafson, Inc. USA
Bio-Save ® 10LP, 110	<i>Pseudomonas syringae</i>	EcoScience
Blight Ban® A506	<i>Ps. fluorescens</i>	Nu-Farm Inc.
AtEze™	<i>Ps. chloroaphis</i>	EcoSoil Systems, USA
Equity™	>40 microbial strains	Naturize Inc., Jacksonville, USA

## *Trichoderma* spp.

No other single fungal genus has received as much attention as *Trichoderma* spp. for biocontrol of plant pathogens. *Trichoderma* spp. are common components of the rhizosphere that grow rapidly and can tolerate a range of environmental conditions making them good candidates as biocontrol agents (Howell 2003). There are numerous studies describing plant disease control using *Trichoderma* spp., and in most cases the primary mode of action is attributed to direct antagonism towards the pathogen. However, there is increasing evidence that some *Trichoderma* isolates produce metabolites that enhance plant disease resistance via activation of the host defence response (Hanson & Howell 2004).

Most studies describing the use of *Trichoderma* spp. to suppress conifer pathogens have focussed on the potential of using the biocontrol agent as a soil amendment to suppress soil borne diseases. In moist soils during wet periods, germinating seedlings and young plants are more susceptible to infection by damping-off fungi. The most important of the damping-off fungi are species of *Fusarium*, *Cylindrocladium*, *Rhizoctonia*, *Phytophthora* and *Pythium* (Dick & Vanner 1986; Gilmour 1966). Kelley (1976) reported that damping-off in shortleaf pine seedlings (*Pinus echinata*) was suppressed if *Trichoderma harzianum* was

introduced to the growing medium at the same time as the pathogen *Phytophthora cinnamomi*. However, damping-off was not suppressed when soil moisture was maintained near saturation level, indicating the inability of *T. harzianum* to compete in extreme conditions. Soil freshly amended with *T. harzianum* was not inhibitory to colonisation of slash pine stem segments by the pathogen *Rhizoctonia solani* until seven days after amendment (Huang & Kuhlman 1991). The suppressive activity of the amended soil correlated with *T. harzianum* population level. Indeed, soils became immediately suppressive if *T. harzianum* population levels were increased to equate to those observed after seven days incubation. Furthermore, after seven days incubation, amended soils produced diffusates that were directly inhibitory to the growth of *Rhizoctonia solani* and *Pythium aphanidermatum* on a synthetic medium. The production of antimicrobial secondary metabolites by *Trichoderma* spp. has been shown to contribute to disease suppression in many studies (Howell 2003).

*Trichoderma harzianum* did not suppress damping-off in container-grown Douglas fir if added to the growth medium at the same time as the pathogen *Fusarium oxysporum* (Mousseaux *et al.* 1998). However, mortality was reduced by 50% if seedling roots first grew through *T. harzianum*-supplemented medium before being exposed

to the pathogen. This may indicate that early colonisation of the plant roots by the biocontrol agent is a prerequisite for effective disease suppression.

The importance of establishment of *Trichoderma* populations before pathogen inoculation was further demonstrated in recent glasshouse studies using *T. harzianum* and *T. reesei* to control damping-off (*Sclerotium rolfsii*) in tropical pine (*P. merkusii*) seedlings (Widyastuti *et al.* 2003). Suppression of damping-off was most effective when the *Trichoderma* was added to the growth medium four days before pathogen inoculation and became ineffective if added 4 days after inoculation. In glasshouse studies, we observed that root immersion of bare-root *P. radiata* seedlings into a *Trichoderma* spore suspension, immediately before planting in potting mix containing *P. cinnamomi*, reduced seedling mortality by 50-66% (Taylor & Reglinski, unpublished data). *Phytophthora cinnamomi* is a commonly isolated root rot pathogen from conifers in New Zealand and causes considerable losses in some areas (Ray 1990). This method may have potential to offer protection to bare rooted plants before establishment in plantations.

In studies in forest nurseries in the USA, *T. harzianum* was evaluated for its potential to suppress increases in *Fusarium* spp. populations that occur following the incorporation of organic matter into soil (James *et al.* 2004a, b). The addition of *T. harzianum* after the incorporation of green manure did not affect either pathogen populations or Douglas fir production. The authors propose that further experiments should be carried out to investigate whether the biocontrol agent would prove more beneficial if applied next to sown seed.

Application of *T. harzianum* at the time of planting improved the post-planting (180 days) survival rate of *P. patula* seedlings at field sites in South Africa (Mitchell *et al.* 2004). In New Zealand, one nursery application of ArborGuard™ significantly improved the size and health of container-reared *P. radiata*. In addition, mortality from *Armillaria* disease in forestry plantation sites was reduced by ca. 34% by ArborGuard™ treatment two years after planting out (Hill 2005). This is an ongoing trial and treated plants will be regularly monitored in the field.

*Trichoderma* spp. are commonly isolated from wounds and have shown potential to control disease in aerial plant tissues. In recent studies Binab T, which contains *T. harzianum* and *T. polysporum*, was evaluated alongside two other biocontrol products GlioMix (*Gliocladium* sp.) and Mycostop (*Streptomyces griseoviridis*), as potential control agents for grey mould (*Botrytis cinerea*) in Scots pine (*P. sylvestris*) seedlings (Capieau *et al.* 2004). Seedlings were co-inoculated with suspensions containing the BCAs and pathogen inoculum and then incubated at high humidity for 2 weeks. Grey mould was reduced by 51-94% in controlled climatic conditions and by 16-57% in a forest nursery. Binab and GlioMix were more consistent than Mycostop and were able to suppress disease as effectively as the fungicide dichlofluanid (e.g. Euparen). The authors suggested that biocontrol of *B. cinerea* in conifer seedlings is likely to be a result of the displacement of *B. cinerea* from

dead and senescing needles in the lowermost parts of the seedlings. This would prevent the spread of developing mycelium of *B. cinerea* into adhering non-infected tissues and the build-up of spore inoculum that may cause secondary spread of the disease.

Although *P. radiata* seedlings are in general not particularly susceptible to infection by *Botrytis*, tender tissues on young plants may become infected under conditions of high humidity. Recently established shoot cuttings are more prone to infection than bare-rooted seedlings. Container-reared plants are often more closely spaced than those in nursery beds, with consequent higher humidity, and the difference is particularly marked in the weeks following germination when plants are most susceptible. Containerised systems therefore tend to be more prone to *Botrytis* problems than open-grown plants and require more rigorous chemical control regimes.

### **Rhizobacteria - *Bacillus* and *Pseudomonas* spp.**

Microbial activity in the rhizosphere is particularly intense because of the accumulation of nutrient-rich exudates around plant roots. Some soil bacteria, particularly *Bacillus* spp., and *Pseudomonas* spp., are referred to as plant-growth promoting rhizobacteria (PGPR) because of their intimate association with improved plant growth and health (Kloepper 1993). Growth promotion results primarily from an antagonistic effect on soil-borne pathogens through competition for nutrients. PGPR have been shown to enhance the rate and amount of seedling emergence and also to stimulate seedling growth in conifers (Chanway 1997; Enebak *et al.* 1998). This could be of interest for container-grown forest nurseries where uneven emergence of seedlings necessitates oversowing to meet production targets.

Growth conditions have an important influence on PGPR and their effects on plants. The effect of PGPR on seedling growth was compared at different "quality" field sites as defined by the ability of that site to support the growth of untreated seedlings. PGPR treatment significantly increased biomass of hybrid spruce (Chanway & Holl 1993) and *P. taeda* (Chanway & Holl 1994) seedlings, compared with control seedlings at "poor quality" growth sites. However, the growth of untreated pine seedlings actually exceeded that of PGPR treated seedlings at a "high quality" planting site. A more recent study confirmed the site-specific nature of PGPR on growth promotion of spruce seedlings and demonstrated that in some cases beneficial effects can extend into a second year after outplanting (Chanway *et al.* 2000). The authors suggest that it may be necessary to match PGPR with specific outplanting sites in order to use this approach effectively in an operational basis. However, it is questionable whether or not this would be economically practical.

PGPR also have potential as biocontrol agents and have been shown to suppress plant disease by competing with pathogen populations for nutrients and space, and by inducing plant resistance to pathogen infection (Kloepper 1993; Zehnder *et al.* 2001). Treatment with *Pseudomonas* spp. suppressed infection of Douglas fir seedlings by

*Fusarium oxysporum* in growth chambers and reduced incidence of *F. oxysporum* and *Pythium ultimum* in white spruce in a forest nursery (Reddy *et al.* 1994). In subsequent studies two bacterial strains (*Burkholderia cepacia* RAL3 & *Pseudomonas fluorescens* 64-3) were identified that reduced disease of white spruce seedlings caused by *Fusarium* spp., and *Pythium* spp. in a commercial nursery and increased the survival of out-planted bare root white spruce in a re-forestation site (Reddy *et al.* 1997). The treatments were applied by soaking either seeds or the seedling roots in bacterial suspension before planting.

In glasshouse studies, seed treatment with *Bacillus pumilus* significantly enhanced the resistance of *P. taeda* to inoculation with *Cronartium quercuum* f. sp. *fusiforme* (the causal agent of fusiform rust) one month later (Enebak & Carey 2000). Rust infection in treated seedlings 6 months after sowing was reduced on average by 18% compared with untreated controls. More recently, Enebak & Carey (2004) reported on the effects of seed treatment with *B. pumilus* strains on seedling growth and on fusiform rust infection in bare root nurseries in Alabama and in Georgia, USA. In the Georgia nursery, seed treatment with *B. pumilus* strains T4 and SE34 promoted seedling growth. In addition,

treatment with T4 significantly reduced infection by the rust fungus and resulted in the development of fewer galls. However, in Alabama there was no treatment effect. Such site specificity mirrors the findings reported above for effects of PGPR on growth promotion and highlights the importance of understanding the impact of biotic and abiotic soil factors on PGPR.

## Induction of resistance using microorganisms

Induced resistance is a natural phenomenon in plants in which localised inoculation, with a pathogen or non-pathogen, results in enhanced resistance to subsequent pathogenic challenge (Tuzun & Kloepper 1995). Only relatively recently have we begun to understand some of the processes underlying the phenomenon and considered the potential of implementing 'induced resistance' as a method of disease control. Hubbes & Jeng (1981) published one of the earliest studies on induced resistance in tree species in which they reported that 4-year-old elm seedlings (*Ulmus americana*) acquired resistance against aggressive strains of *Ophiostoma novo-ulmi*, the causal agent of Dutch elm disease (DED), after pre-inoculation with the less aggressive *O. ulmi*. Over the last two decades Professor Hubbes and co-

Table 2 –Commercially available products that enhance plant resistance.

Inducer	Active ingredient	Manufacturer
ActiGard®/Blockade®/Bion®	acibenzolar-s-methyl	Syngenta Crop Protection, USA
Aliette® WG	fosetyl-Al (aluminium tris-o-ethyl-phosphonate)	Bayer CropScience, Germany
Ellexa	chitosan and other carbohydrates	SafeScience, USA
Foli-R-Fos® 400	phosphorous acid	UIM Agrochemicals, Australia
Goemar H11	laminarin	Laboratoires Goemar, France
KeyPlex	alpha-keto-acids	Morse Enterprises, USA
Messenger®	harpin	Eden Bioscience, USA
Milsana®	extract from Reynoutria sachalinensis	KHH BioScience Inc USA
NutriPhite® P	phosphorus acid	Biagro Western Sales Inc. USA
Oxycom	hydrogen peroxide	Redox Chemicals Inc. USA
Potassium dihydrogen Phosphate (eKsPunge®)	potassium dihydrogen phosphate	Lido Chemical, USA
PhytoGard®	potassium phosphonate	Intrachem Bio, France
ProPhyt®	potassium phosphite	Helena Chemical Company, USA
ReZist™	Copper, Manganese, Zinc	Stoller Enterprises Inc. USA
Synermix™	Seaweed extract (hexahydratedaluminium chloride)	Laboratoires Goemar, France
VacciPlant (Physpe)	β-1,3 glucan	Laboratoires Goemar, France (Agrimar)

workers at the University of Toronto, Canada have carried out extensive investigations into the potential of induced resistance for the control of DED (Hubbes 2004).

In conifers, localised induced resistance to a blue stain fungus (*Ceratocystis polonica*) was observed in Norway spruce after prior inoculation with the same fungus (Christiansen *et al.* 1999; Krokene *et al.* 1999). Resistance to *C. polonica* was also induced by the root pathogen, *Heterobasidium annosum* indicating the non-specific nature of the induced response. A subsequent study by the same group reported induction of resistance to *Leptographium wingfieldii* following inoculation with the same pathogen or with *Ophiostoma canum* (Krokene *et al.* 2000). Induction of systemic resistance to the pitch canker fungus *Fusarium circinatum* has been reported in *P. radiata* (Bonello *et al.* 2001) and in *P. muricata* (Schmale & Gordon 2003) following repeated inoculations with the same fungus. The induced resistance was expressed as a progressive reduction in lesion length with each subsequent inoculation but there was considerable clonal variability with respect to the induced resistance response.

#### Induction of resistance using chemicals

Pathogen-mediated induced resistance is unlikely to provide a practical method of disease control in forest nurseries. However, the induction of resistance using chemical 'elicitors' may be more practical (Oostendorp *et al.* 2001). Elicitor-active compounds involved in pathogen detection (carbohydrates, peptides, glycoproteins) and in signalling process (salicylic acid and jasmonic acid) leading to defence gene expression have been identified (Lyon *et al.* 1995; Ebel 1998). Application of elicitors has been shown to stimulate plant defences and to enhance resistance to subsequent pathogenic infection in various crops (Tuzun & Kloepper 1995). Increasing interest in chemical induction of resistance has led to the commercial development of several products that operate by activating plant resistance (Table 2).

#### Elicitor studies in conifers

##### Carbohydrate Elicitors

Carbohydrate components in fungal cell walls such as glucan, chitin, and chitosan are among the best-characterised elicitors (Ebel 1998). Cell wall fragments that are released during the infection process are detected by highly sensitive receptors in the host plant. These operate like an early warning system and trigger the activation of plant defences. Chitosan is a structural component of fungal cell walls and has been reported to activate phenylpropanoid and lignin biosynthesis in *Pinus elliotii* (Lesney 1989; Mason & Davis 1997) and stimulated monoterpene synthesis at wound sites in *P. contorta* (Miller *et al.* 1986; Lieutier & Berryman 1988). These are important defensive responses in conifers that are involved with countering pathogen attack and sealing wounds. In addition, chitosan has also been shown to be directly inhibitory to the growth of forestry root rot pathogens, including *F. oxysporum* and *F.*

*acuminatum* (Laflamme *et al.* 1999). In recent studies on *P. radiata* seedlings, foliar application of chitosan resulted in induction of resistance to wound-inoculation with *F. circinatum* (Reglinski *et al.* 2004). Induced resistance was expressed as the suppression of symptom development on treated seedlings compared with the untreated controls. In the same study chitosan application activated systemic resistance against *S. sapinea* on four-year old *P. radiata* trees. There was an 86% reduction in average lesion length on inoculated branches on the treated trees. There are several commercially available chitosan products and the implementation of chitosan into nursery disease management in rotation with fungicides may be a viable means for reducing fungicide inputs and reducing the risk of fungicide resistance development.

##### Salicylic acid

Salicylic acid (SA) plays a regulatory role in the establishment of induced resistance in plants and has been one of the most intensively studied inducers over the last 20 years. Foliar application of SA and 5-chlorosalicylic acid (5CSA) on glasshouse *P. radiata* seedlings induced a transient increase in the activity of the defence-related enzyme phenylalanine ammonia-lyase activity (PAL) (Reglinski *et al.* 1998). Furthermore, seedlings treated with SA and 5CSA exhibited greater resistance to infection by *S. sapinea* than untreated controls. 5CSA was a more potent elicitor than SA. Seedlings treated with 1mM 5CSA remained resistant to fresh inoculation challenge for up to 32 days after application. At higher concentrations (2mM) 5CSA exhibited direct antimicrobial activity against *S. sapinea* but also caused burning of needles on treated seedlings. Diplodia dieback, caused by *S. sapinea*, is widespread in New Zealand and occurs in a range of *Pinus* spp. over a wide range of age groups. Stool beds may suffer severe dieback, and sometimes mortality, as a result of infection through the wounds inflicted when the shoots are removed for provision of cuttings. The demonstration of chemical-induced resistance to this fungus offers potential means of mitigating these losses.

Nine monthly-applications of SA (1M) significantly increased the biomass of *Pinus patula* seedlings in glasshouse experiments (San-Miguel *et al.* 2003). Stem diameter, height and root growth were increased by approximately 30% indicating that regular SA applications may assist establishment of young seedlings in plantation sites. Benzoic acid (BZA) is structurally related to SA and has recently been reported to induce resistance to stem inoculation with *P. cinnamomi* in *Banksia attenuata* seedlings when applied by foliar spray or soil drench one week before inoculation (Williams *et al.* 2003). The most effective treatment, soil drench with 0.5mM BZA, reduced lesion length by over 90% compared with untreated controls.

A commercially available functional analogue of SA (Bion® or Actigard®) was developed by Novartis Crop Protection AG (now Syngenta) and represented the first of a new generation of crop protectants specifically selected to activate plant resistance. Bion®, applied as a foliar



spray, reduced the incidence of root rot infection caused by *P. cinnamomi* in *P. radiata*, *Banksia integrifolia* and *Isopogon cuneatus* (Ali *et al.* 2000). Most effective suppression was obtained when Bion® (2.5ug/L) was sprayed in combination with potassium phosphonate (1g/L). All untreated seedlings died within 14 week of inoculation with *P. cinnamomi* whereas all treated plants remained alive. Earlier studies by the same authors demonstrated that either foliar spray or root drench with potassium phosphonate (Foli-R-Fos 200, UIM Agrochemicals) reduced the incidence of *Phytophthora* root rot in *P. radiata* (Ali *et al.* 1999). Phosphonates are proposed to have direct fungicidal activity and also to activate plant defences (Hardy *et al.* 2001). Fosetyl-Al (Aliette WG®), a commonly used fungicide against root pathogens, releases phosphonate as a breakdown product and has also been proposed to operate through the activation of host disease resistance.

## Jasmonates

Jasmonates are endogenous plant hormones and have been shown to play a central signalling role in plant defence responses against insect attack and some necrotrophic pathogens. Application of methyl jasmonate (MeJA) to the bark of four species in the Pinaceae has been shown to induce anatomical and chemical changes generally associated with defence (Franceschi *et al.* 2002; Martin *et al.* 2002; Hudgins *et al.* 2003). In 30-year-old Norway spruce these responses were accompanied by enhanced resin flow and induced resistance to inoculation with the blue stain fungus *Ceratocystis polonica* (Franceschi *et al.* 2002). Induced resistance was expressed as a 50% reduction in lesion length in treated trees. MeJA readily volatilises and has been reported to function as an airborne chemical signal among plants (Kessler & Baldwin 2001). Young Norway spruce seedlings were more resistant to infection by *P. ultimum* after exposure to gaseous MeJA (Kozłowski *et al.* 1999). Mortality was reduced from 80% to 40% in seedlings that were exposed to 26ppb MeJA for 3 days. Curiously seedlings exposed to 108ppb MeJA became more susceptible to *Pythium* infection. Possible reasons for this increase in susceptibility are not discussed.

## Summary

Disease management in forest nurseries at present is predominantly reliant upon regular fungicide application. However, concerns over the development of fungicide resistance by pathogens and about potential adverse effects of pesticides on human health and the environment have seen the deregistration of a number of effective chemicals. Hence the addition of environmentally friendly tools to the armoury available for the management of nursery health is not only desirable but may become essential. The introduction of ecologically sound biocontrol methods would reduce the dependence on high-risk chemicals for disease management. In this review we present evidence that biocontrol methods, BCAs and PGPR in particular, have potential to improve seedling quality and health in container and bareroot nurseries.

Soil amendments with *Trichoderma*-based products or

seed treatment with PGPR can promote seed emergence and growth as well as provide a useful level of disease suppression, particularly for the management of soil-borne plant pathogens. Furthermore, such treatments also show potential to enhance seedling health and survival in reforestation sites. Of particular interest are the findings that PGPR can enhance the survival of out-planted seedlings in poor quality planting sites. BCAs or PGPR are essentially prophylactic treatments and best results have been obtained when treatments were applied before pathogen challenge. In operational terms this would involve application as seed treatments in nurseries or as root dips before outplanting. Studies on induced resistance to forest nursery pathogens are providing encouraging results but this technology is at an earlier stage of development and requires field validation. In addition, effects of environmental (temperature, moisture, light), agronomic (soil nutrients, pH), and microbiological (mycorrhizae) factors on BCA and PGPR performance require further study. A better understanding of these complex issues will allow smarter use of biocontrol technologies in the field.

The introduction of biological control methods into forest production is likely to occur slowly. Any new method of disease control takes time to gain acceptance and credibility. The way forward may involve gradual integration of biocontrol methods with more traditional disease control methods. However, this should be approached with caution since compatibility of BCAs with fungicides may be problematic in some cases. The use of biocontrol methods fits perfectly within the philosophy of Integrated Disease Management (IDM), which aims to combine biological, cultural, physical, and chemical tactics in a sustainable manner that strives to minimize economic, health, and environmental risks. IDM has potential to lead to less expensive production systems that involves minimal pesticide use and has a lower impact on the environment.

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## letter

### Seeking information on indigenous forestry research data

Sir,

Tane's Tree Trust has been granted funding from the Sustainable Farming Fund to create a database which will hold references to all research involving the growing of indigenous species. The Trust will be searching archival records held by Archives New Zealand, Forest Research, the Macmillan Brown Library and other institutions which may hold data.

We have anecdotal evidence which suggests that, at the dissolution of the Forest Service, many staff saved material

which would otherwise have been lost and may still hold this. Alternatively, retired officers may still hold material that they were working on.

The Trust would like to hear from anyone who holds indigenous research data, or knows of others who do. We are interested in recording this information and discussing its future care and storage.

Please contact me at <ibtrees@wc.net.nz>; telephone 09 239 2049 or write to PO Box 1169, Pukekohe 1800.

Ian Barton