Symbiotic Systems NZ Ltd

Removing a significant constraint limiting the diversity of the forestry estate

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Ian R. Hall
and
Chris Perley

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P.O. Box 268
Dunedin
NEW ZEALAND

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Cover photo: Dennis Hocking's trials of novel plantation timber species, October 2005

Contact details for the authors

Dr Ian R. Hall
P.O. Box 268
Dunedin 9054
NEW ZEALAND
Telephone +64-3-454 3574
Mobile: +64-27-226 1844
email: truffle1@ihug.co.nz
web: www.trufflesandmushrooms.co.nz

Christopher Perley
P.O. Box 7116
Dunedin
NEW ZEALAND
Telephone +64-3-453 4948
Mobile: +64-274 880 977
Fax: +64-3-453 4945
email: chris@perleyandassoc.co.nz

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1 Summary

1.1 Background to the Project

Over the past 50 years the New Zealand forestry industry has become increasingly dependent on structural and industrial timber (lumber and pulp furnish) in general and radiata pine timber in particular, at a time when our competitive advantage in forest growing is reducing. A significant reason for this dominance by radiata pine is the poorer establishment success of other species. In the late 1950s Gilmore recognised that the poor growth of Douglas fir was due to a lack of mycorrhizal fungi (beneficial root inhabiting fungi). Many other alternative species, such as the stringybark eucalypts, also struggle in New Zealand when compared to their successful performance overseas and it is quite possible that this too is due to a lack of correct mycorrhizal fungi.

Spontaneous infections formed on roots formed by various fungi resident in a bare rooted nursery or by spores that might blow into a greenhouse through vents and doors cannot be relied upon to ensure adequate mycorrhizal formation. This is particularly important with plants raised in containers where soilless potting mixes are invariably devoid of mycorrhizal fungi.

In 2005 we received a 3 year Sustainable Farming Fund grant to demonstrate how the careful introduction and management of effective mycorrhizal fungi in nurseries could improve growth rates of forest species other than radiata pine. In this document we present our justification why New Zealand should not rely as heavily as it does on radiata pine and present the results of our project between August 2005 to June 2008.

1.2 General findings

During our work we found that although there is a general acknowledgement that mycorrhizas are important in forests:

- There was a general belief that all there is to know about mycorrhizas that is relevant is already known and that the practices used were sufficient to ensure adequate infection,
- Arbuscular mycorrhizal plants (e.g. cypresses, see page 16 for a definition) are never inoculated with mycorrhizal fungi,
- Arbuscular mycorrhizal plants grown in containers of soilless media are universally uninfected with mycorrhizal fungi,
- There is a general assumption that any infection on the roots of ectomycorrhizal plants (see page 14 for a definition) even by weed fungi, e.g., *Thelephora* and *Sphaerosporella* spp., which commonly inhabit nurseries, will be beneficial to the plant after outplanting when in fact there is no justification for this belief,
- Ectomycorrhizal plants are not universally inoculated with mycorrhizal fungi and if they are the appearance of any fungus on the root system is seen as a sign of success even if it is *Thelephora*,
- Where ectomycorrhizal plants are inoculated, the species of mycorrhizal fungi used may be incapable of forming effective mycorrhizas with the host plant,
- Applications of large amounts of fungicides and fertilisers are used by nurserymen to produce healthy looking plants and that these mask the lack of mycorrhizal fungi,

- Nurserymen argue that industry specifications emphasises quantitative parameters of seedling size rather than qualitative parameters such as appropriate mycorrhizal infections and when plants are too small to meet specifications they will add additional fertiliser to ensure they do so.

1.3 Choice of tree and mycorrhizal fungal species

The choice of trees used in our project was made after consultation with industry. While there was no consistency in the advice we received those species we eventually used presented a range of mycorrhizal challenges that once solved would be directly applicable to most other trees that might be grown in the future in New Zealand and elsewhere. The trees used were the arbuscular mycorrhizal species *Sequoia sempervirens* (coastal redwood) and *Chamaecyparis lawsoniana* (Port Orford cedar) and the ectomycorrhizal species *Nothofagus menziesii* and *Nothofagus fusca* (silver and red beech – the only sustainably grown native species), *Corymbia maculata* (one of the fast growing blood woods) and *Pseudotsuga menziesii* (Douglas fir).

1.4 Our findings

We have developed the necessary skills and techniques to establish mycorrhizas in greenhouse based nurseries. What is now needed are demonstration field trials to test mycorrhizal and non-mycorrhizal plants after outplanting particularly onto difficult sites – something we were unable to do in the current study. This would be most effectively achieved by again working with Oregon Nurseries and ArborGen but this time producing commercial numbers of novel plantation timber species.

1.5 Extension

The project required that we convey the results of our work to industry and this report is the last of these. Nine other publications and extension works were carried over the past three years but we expect to continue with these in the future as and when appropriate.

2 The New Zealand forestry estate

2.1 The New Zealand forestry estate – our view

If you visit a New Zealand accountant and tell them you are going to plant a forest it is very likely an internal rate of return (IRR) will be calculated using today's costs of establishment and maintenance, and today's returns from any harvest. The accountant would then tell you to plant radiata pine based on its productivity and short rotation. There are at least two traps to this simplistic approach: what looks best today may not look great tomorrow (and vice versa), and there are many values and qualities a financier will not appreciate if growth rate is the primary determinant of investment choice. As an example, how many people nowadays would take a mortgage out on their house and invest in blackcurrants, which was all the rage in the 1970s, or, more recently ostriches. A few, admittedly, but almost surely only after very careful consideration.

The future market for forest products will be different from today and positioning ourselves relative to the probable future whilst retaining options is likely to be a far more important consideration than growth rate alone. This is the classic distinction between the commodity, productionist approach and the differentiated marketing approach to land use.

Figure 1. Corymbia maculata (trees with reddish foliage at centre right), one of the spotted gums and blood woods, in Nelson's old Wakapuaka Cemetery. In the right location it will grow at 2.5 to 4 m per year, retails for A$1300/m^3 (tongue and groove) and has a dark coloured, durable and high density timber.

Species such as those used several generations ago to beautify Nelson's old Wakapuaka Cemetery (Figures 1 and 3) and Eastwood Hills might be considered. But there are more sound reasons beyond aesthetics why alternative species might be planted. Concentrating on just one species, i.e., *Pinus radiata*, no matter how good it may appear, makes the forest estate vulnerable to the competitive ups and downs of that one product. Diversity is a fundamental principle for any investment advisor. And if you pursue the cheapest commodity production, which for forest growing means faster growing trees, without considering market desires and future trends, you are more vulnerable to those commodity producers with greater

scale, cheaper labour, and lower social and environmental standards. That is an ever-accelerating wheel with an unenviable end. To quote C.J. Sansom (Dissolution, 2003, Viking), "These men of accounts believe that what is cheapest is best, and prink and save till all falls about them."

We are not disputing that radiata pine has some excellent properties and is relatively cheap - 100 x 40 H3 treated radiata decking retails on special for $1000/m^3 (Placemakers mailer for 4 June 2007), which is about half the price of hardwood decking in Australia (Nash Timbers 2005). However, a cost focus masks:

1) The possibility that in the future buyers may become less inclined to buy a product that must be treated with preservatives such as chromium, arsenic and copper to make it useful in many situations; cannot be burnt at the end of its useful life; may be rejected by landfills; and the possibility of previously good quality farm land becoming podsolized through the continuous cultivation of pines (Pajuste & Frey 2003).
2) The very real biological risks from pests and diseases entering the country, such as pitch pine canker,
3) The increased market risk in concentrating on just a few species that reduces future market and economic flexibility, especially related to high value products that are more economically transportable as energy costs rise,
4) The reduction of regional development and sustainable land management options,
5) The increased social risks associated with the public perception of planted forests as largely unattractive producers of 'industrial' products with no other values.
6) The market opportunities associated with the reduction in supply of high value timber currently sourced from unsustainable harvesting and conversion of tropical and boreal forests, particularly associated with the Asia-Pacific region.
7) The perceived need to plant species with long rotations that sequester carbon for 50 years or more such as redwood, Douglas fir, some eucalypts, totara and matai.

Figure 2. Seventeen year old Corymbia maculata on Dave Satchell's property near Kerikeri, Northland.

New Zealand's production of rough sawn timber of "minor species" (24,466 m^3) and eucalypts (3432 m^3) for the year ending 2005 accounting for only 0.55% and 0.078% of total production respectively (Table 1) shows an arguably misplaced emphasis on pines. For the same period New Zealand imported 56,000 m^3 of high quality woods to compensate, with some probably coming from non-sustainable logging of hardwood forests in developing countries (Table 2). When those supplies cease, is it likely that everyone would be happy with substitute furniture made from chipboard or mahogany-stained radiata? Ernslaw One's extensive plantings of Douglas fir in Otago and Southland and Soper Wheeler's plantings of redwood both reflect a belief that future markets will want the icon timber species, and never mind what the accountant thinks. One large forest company has even ceased planting radiata in the South Island. All this is a good start, but New Zealand also needs to look at trees with aromatic woods such as the cypresses and cedars, particularly for the east Asian market, and coloured, high density hardwoods for premium furniture and specialist applications (Kings Fourth Generation Woodworking Co. 2008, Appendix 1; Trend Timbers 2008; RIC good wood guide 2008).

To some, such talk of growing cultural icon species with high reputations is tantamount to heresy and that no country would dare go down that route. But they would be wrong. For centuries oak has been the ultimate timber in the UK while throughout Europe a wide range of trees are planted to suit the microclimate on each particular site. The nine native (only *Nothofagus menziesii* and *N. fusca* are grown sustainably) and eight exotic plantation species grown in New Zealand pales when compared with the routine range of species and volumes available in Australia (Table 3; Kings Fourth Generation Woodworking Co. 2008; Trend Timbers 2008; RIC good wood guide 2008). On the Ensis NZ web site "A selection of 2005 scientific publications" (Ensis 2007), where more than 100 publications are listed, there was an unmistakable bias towards radiata and industrial chipping/pulping timbers with only one reference to alternative forest species (Hay et al. 2005). This may well be what the Foundation for Research, Science and Technology and the industry partners and stakeholders wanted a few years ago and when funds were allocated but it is debatable whether this will be supported by future market and political trends.

In contrast, research overseas on alternative species is well established. For example, *Corymbia maculata* (Figures 1 and 2) is now widely planted in Australia (Macgregor-Skinner 2000) and a breeding programme for this species is well underway there (Dickinson et al. 2007). Similarly, there is an extensive research programme on alternative species in China that is being encouraged by scientists and funding from Australia (e.g. Harwood 2005, Appendix 2; Wei & Xu 2003). Some research is being carried out in New Zealand with the main impetus behind this is led by the New Zealand Farm Forestry Association and Ian Nicholas of SCION (e.g. Eucalypt action group 2008).

Figure 3. Our impatience to have "instant" mature trees for the landscape often leads New Zealanders to plant fast growing species like birch, eucalypts and pine rather than species that might take 50 to 100 years to reach maturity. As a consequence many attractive but relatively slow growing trees like these red gums are often ignored.

Table 1. New Zealand production (m^3) of rough sawn timber by major species, 1993-2005 (from: MAF 2005). Note the low volumes of minor species and eucalypts that have been produced over the period.

Year ending 31 March	Indigenous species								Planted production species							
	Rimu and miro	Matai	Totara	Kahikatea	Kauri	Tawa	Beech	Minor species	Radiata pine	Other pines	Douglas fir	Eucalyptus	Minor species	All natural species	All planted species	Total
2005	4 999	197	-	155	587	-	6 755	525	4 192 886	5 781	167 274	3 432	24 466	13 218	4 393 839	4 407 057
2004	5 351	596	361	264	749	216	8 286	22	3 979 540	7 621	178 425	3 785	24 269	15 845	4 193 640	4 209 485
2003	4 936	1 545	685	706	856	255	9 588	250	4 214 114	8 744	163 570	3 307	27 511	18 821	4 417 246	4 436 067
2002	13 204	451	573	272	759	311	12 523	80	3 677 743	4 594	124 359	2 803	26 607	28 173	3 836 106	3 864 279
2001	17 390	535	87	179	670	761	8 216	37	3 624 859	31 886	135 687	3 466	24 127	27 875	3 820 025	3 847 900
2000	21 701	140	298	596	806	1 197	5 613	82	3 583 420	27 948	134 316	3 983	26 270	30 433	3 775 937	3 806 370
1999	30 407	1 135	281	319	733	1 038	3 724	410	2 995 781	27 138	143 294	2 748	19 412	38 047	3 188 373	3 226 420
1998	28 473	993	573	278	1 722	719	5 024	37	2 994 547	18 686	105 084	2 262	36 817	37 819	3 157 396	3 195 215
1997	44 284	934	182	518	1 979	1 310	6 881	173	2 761 011	52 928	122 163	2 757	28 079	56 261	2 966 938	3 023 199
1996	44 230	1 760	194	630	1 010	3 288	3 770	152	2 631 088	63 089	104 305	5 017	45 579	55 034	2 849 168	2 904 202
1995	70 377	1 217	298	2 535	1 201	1 958	7 428	326	2 591 003	100 570	127 835	5 492	45 178	85 340	2 870 078	2 955 418
1994	66 635	847	924	3 107	1 401	3 379	4 427	370	2 497 059	72 350	122 756	4 436	39 352	81 090	2 735 953	2 817 043
1993	54 848	378	284	3 174	2 056	2 147	3 770	278	2 281 427	99 043	159 897	2 128	24 100	66 935	2 566 595	2 633 530

Table 2. New Zealand's production, imports (predominantly high quality hardwoods) and exports of sawn timber (000m^3) 1971-2005 (from NZ MAF 2005).

Year ending 31.3.05	Production	Imports	Exports
2005	4407	56	1837
2004	4209	43	1689
2003	4436	37	1809
2002	3864	34	1724
2001	3848	33	1492
2000	3806	35	1482
1999	3226	29	1298
1998	3195	32	1152
1997	3023	32	1082
1996	2904	38	948
1995	2955	34	1065
1994	2817	32	921
1993	2634	25	969
1992	2301	27	836
1991	2283	40	681
1990	2121	45	549
1989	1876	32	514
1988	1821	36	416
1987	2079	55	354
1986	2396	54	406
1985	2306	38	500
1984	2097	33	445
1983	2136	28	440
1982	2270	30	495
1981	2182	26	596
1980	2000	26	553
1979	1865	20	429
1978	1961	23	333
1977	2212	36	268
1976	2003	25	200
1975	2086	55	170
1974	2054	64	246
1973	1787	40	250
1972	1745	32	266
1971	1849	39	282

Table 3. Sawn Australian grown timber production (000m^3) (from Australian Bureau of Statistics 2005). Compare with Table 1.

Year ending 31 March	Coniferous	Broadleaved	Total
2003	2986	1063	4049
2002	3011	1108	4119
2001	2351	1174	3525
2000	2637	1346	3983
1999	2338	1267	3606

3 Mycorrhizas

Mycorrhizas[1] (literally fungus-root) are intimate associations between plant roots and specially adapted mycorrhizal fungi. These were first described by Gibelli in 1883 when he was working on chestnut ink disease. However, it was Frank's discovery that the Périgord black truffle was one of the fungal partners (Frank 1877, 1888; Trappe 1985) that led to an understanding of the importance of these associations to plants and, incidentally, was later to provide the hint as to how truffles and other edible ectomycorrhizal mushrooms might be cultivated.

With a few notable exceptions like the brassicas (Brassicaceae), nettles (Urticaceae) and convolvulus family (Polygonaceae), the majority of higher plants form mycorrhizas. Almost all trees form mycorrhizas and from past research it is assumed that these are all completely dependent on mycorrhizal fungi for their mineral nutrition, in particular phosphorus, nitrogen and trace elements, although they also benefit plant growth in other ways too such as the control of plant disease and improve the stability of soils (Bucher 2007; Hamel 1996; Lekberg & Koide 2005; Ryan & Angus 2003; Smith & Read 2008; Wright & Upadhyaya 1998; c.f. Gehring & Connell 2006). While mycorrhizal fungi actually infect the roots of their host plants the relationship is generally beneficial because the cost of the carbohydrate they receive is generally more than made up for by the advantages the plant gains. The ways that the fungus produce their beneficial effects is by sending out a network of fine threads (hyphae) that penetrate areas of soil that the plant is not able to exploit with its roots and root hairs and creating a physical and probably a biochemical barrier to other soil organisms (Figures 4, 7, 8, 9) (Davis 2008; Smith & Read 2008; Sylvia 2008).

3.1 Types of mycorrhizas

There are a number of types of mycorrhizas and, unfortunately, all have rather cumbersome names such as ectomycorrhiza (often shortened to EM), arbuscular mycorrhiza (AM or VAM for vesicular-arbuscular mycorrhiza) and ericaceous mycorrhiza (Brundrett 2000, 2004; Smith & Read 2008). Generally plants within a plant family tend to form the same kind of mycorrhizas. For example, ectomycorrhizas are formed by most of the trees that dominate the forests of the Northern Hemisphere including birches (Betulaceae), oaks and beeches (Fagaceae), European limes (Tiliaceae) and many softwoods (Pinaceae) as well as the tropical dipterocarps (Dipterocarpaceae) and Australian eucalypts (Myrtaceae). In contrast, arbuscular mycorrhizas are formed by the vast majority of cultivated crops, flowering herbs, shrubs and trees, ferns, cycads, some gymnosperms such as North American redwood and cypresses and their ancestors, and almost all New Zealand natives excepting *Nothofagus*, *Leptospermum* and *Kunzea* (Cantrill & Douglas 1988; Díaz & Honrubia 1993; Muthukumar & Udaiyan 2002; Ouahmane et al. 2006; Stockey et al. 2001; Strullu-Derrien & Strullu 2007; Truffles & Mushrooms 2006). There are a few exceptions such as the Myrtales that contain both ectomycorrhizal and arbuscular mycorrhizal species. Some other tree species, like the poplars and willows (Salicaceae), some eucalypts and *Leptospermum* (Leptospermoideae, Myrtales), have the best of both worlds as they have the capacity to form both ectomycorrhizas and arbuscular mycorrhizas (Molina & Trappe 1984; Smith & Read 2008; Wang & Qiu 2006).

Fungi that form one kind of mycorrhiza are very different from those that form another and so ectomycorrhizal fungi cannot produce an arbuscular type of mycorrhiza and vice versa. Tables of some arbuscular and ectomycorrhizal plant species are listed in Appendix 3.

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[1] Part of this section has been adapted from the book "Taming the truffle" (2007) by Ian Hall, Gordon Brown and Alessandra Zambonelli.

3.2 Ectomycorrhizas

In an ectomycorrhiza the fungus wraps itself all around the outside of the host plant's fine roots just like the fingers of a glove (hence the name ecto- (outside) mycor- (fungus) rhiza (root); Figures 3 and 4). It has been estimated that there are somewhere between 5000 and 6000 species of ectomycorrhizal fungi with about 20% of these producing edible or medicinal mushrooms or truffles (Hall 2008; Hall et al. 2003; 2007).

The ectomycorrhizal association has probably been around for a mere 100 million years and so are considerably younger than the arbuscular type (Le Page et al. 1996; Trappe 1987). Ectomycorrhizas have a layer of fungal tissue on the surface of the fine roots called the mantle (Figures 3 and 4). From this tongues of tissue run in between the outer layers of the root to produce a three dimensional structure called the Hartig net. This can be visualised by imagining that the outer layers of cells of the root are like the bricks in a brick chimney and the fungus is the mortar between them. On the outside of the mantle hyphae run out into the soil (Figure 4). Truffle mycorrhizas (*Tuber* species, Figures 3 - 6) look like small sausages hanging from the lateral roots. However, positive identification of ectomycorrhizas requires the aid of a powerful microscope and considerable experience or molecular techniques (Hall et al. 2003, 2007).

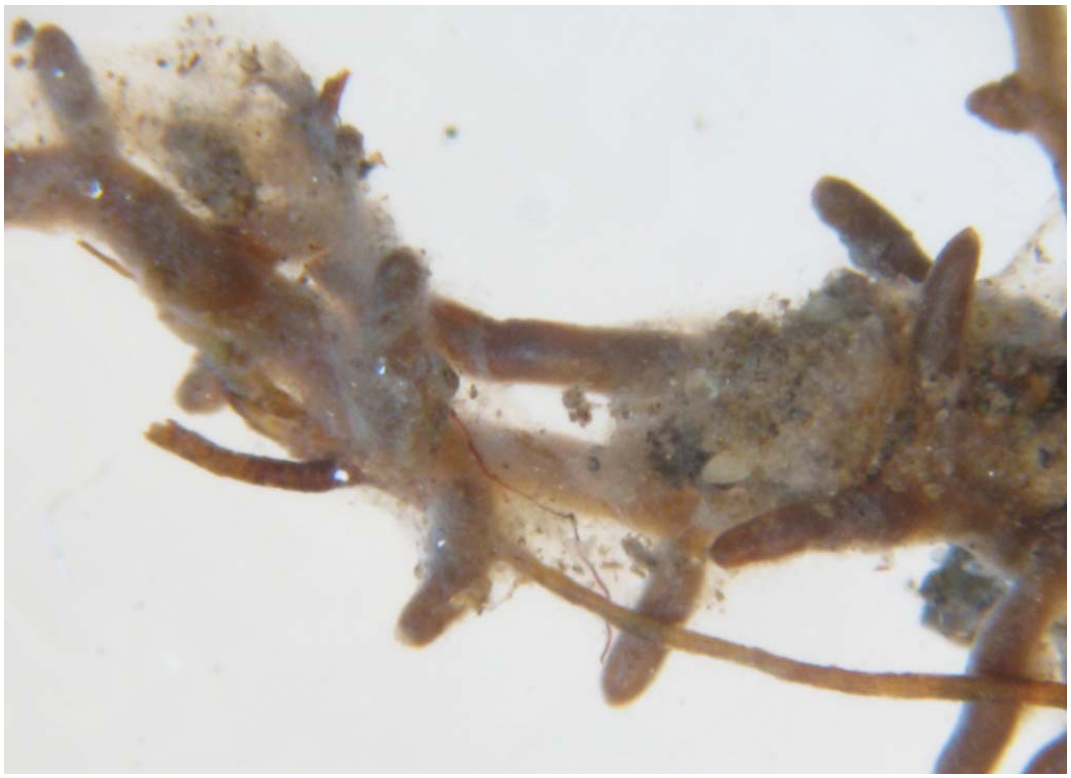


Figure 4. Mycorrhizas of the bianchetto truffle (the small sausage-shaped lateral roots (see below) being invaded by a competing mycorrhizal fungus probably the poison pie mushroom (Hebeloma crustuliniforme).

Figures 5 and 6. Most ectomycorrhizal fungi are dispersed through small spores formed on gills, spines or folds or in tubes on the undersides of mushrooms whereas the truffles and false truffles form them in enclosed structures below or just above the soil surface. Above is the poisonous brown roll rim (Paxillus involutus) and below one of the poisonous earth balls (Scleroderma) both of which are common mycorrhizal mushrooms on plantation trees in New Zealand.

Figure 7. Details of the surface appearance of a mycorrhiza and the fine hyphae emanating from it (cystidia) are diagnostic features. Rarely can a mycorrhiza be identified only with a binocular microscope let alone the naked eye. This is a highly magnified root tip infected with the bianchetto truffle showing fine, white, needle-like projections on the surface which are characteristic of the species.

Ectomycorrhizas have a beneficial effect on plant growth through the increased absorptive area of the root system leading to an improved nutrient status or by suppression of root diseases (Davis 2008; Rousseau et al. 1994; Smith & Read 2008). However, under some circumstances the drain the fungus has on the carbohydrate status of young plants can produce a growth depression at least until the plant reaches a point of equilibrium where the benefits of the association counteracts the disadvantages (Conjeaud et al. 1996). Similarly, water-stressed seedlings have been shown to exhibit no growth benefit from infection and seedlings with heavy mycorrhizal infections recovered more slowly from water stress than control seedlings (Parlade et al. 2001).

Burning, clear felling, drought, preparation of the ground, the application of dolomite, age of a stand, all have an impact on the composition of ectomycorrhizal communities, ability of some mycorrhizal fungi to establish on root systems and/or the size of any growth responses they might produce (e.g. Horton et al. 2005; Kennedy & Peay 2007; Jones et al. 2003; Jonsson et al. 1999; Mah et al. 2001; Nara et al. 2003; Shi et al. 2002; Smith et al.; Tedersoo et al. 2006; Trudell 2002; Trudell & Edmonds 2004; Xu et al. 2001). Clearly the choice of mycorrhizal fungus used by a nurseryman is an important decision.

3.3 Arbuscular mycorrhizas

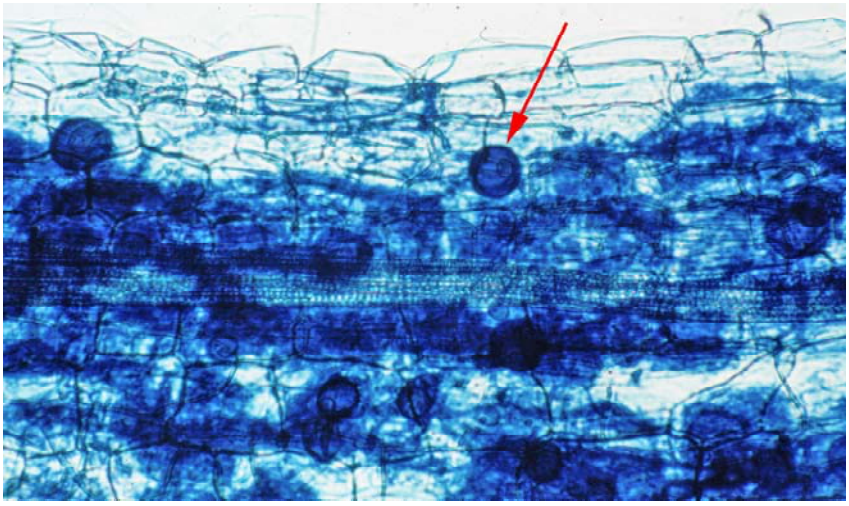
In arbuscular and ericaceous mycorrhizas the fungus actually gets right inside the cells of the outer layers of the roots producing structures called vesicles (Figure 7) and arbuscules (Figure 8). Despite the enormous ecological and economic importance of these fungi generally they go unnoticed because their fruiting bodies are usually microscopic and only provide lunch for very small animals like beetles, fly larvae and nematodes (Bratek et al 2001; Hall 1984; 1987; Smith & Read 1997).

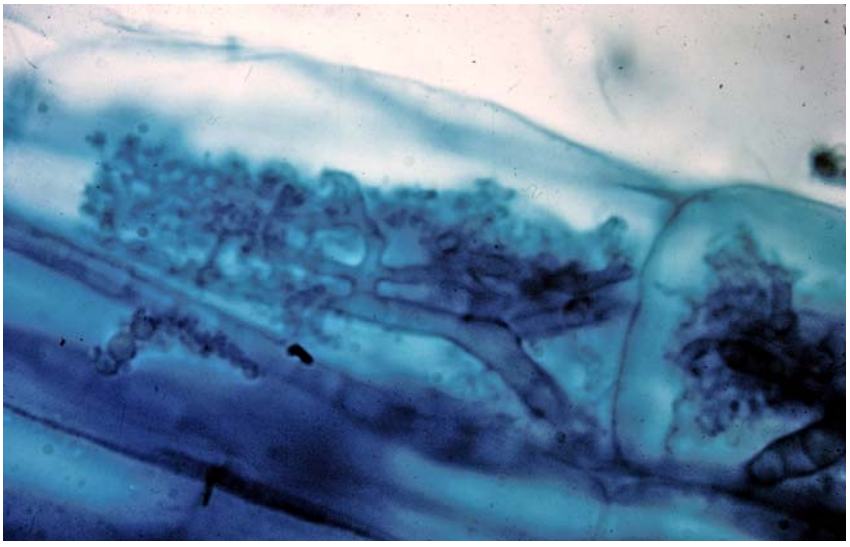
Arbuscular mycorrhizal fungi have been around since the Ordovician, about 460 million years (Redecker et al. 2000 a, b), so it is hardly surprising that most are now so specialised they cannot survive unless in contact with their host plants. Many plants have also become equally dependent on mycorrhizal fungi and without them become stunted and yellow often due to a lack of phosphorus (Al-Karaki et al. 2004; Amijee et al. 1992; Cavagnaro et al. 2005; Jacobsen et al. 2005; Landis & Fraser 2007; Li et al. 2006; Poulsen et al. 2005; Smith et al. 2000, 2003).

The greatest growth responses to arbuscular mycorrhizal fungi are shown by plants with coarse roots and no root hairs (Baylis 1975; Javot et al. 2007; St John 1980). Interestingly, coastal redwood has no root hairs and coarse roots (Miller 2005) and so might be expected to be dependent on arbuscular mycorrhizas and respond strongly to inoculation with arbuscular mycorrhizal fungi in the nursery.

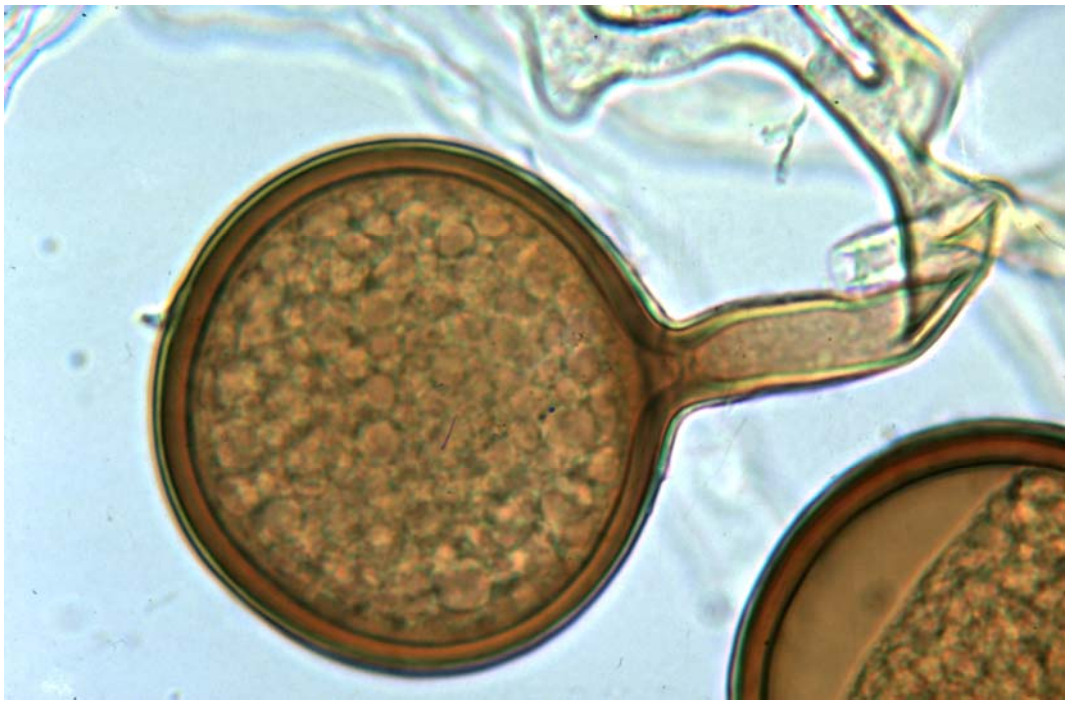
Some arbuscular mycorrhizal fungi have been demonstrated to stimulate the growth of a host plant more than another so there is the possibility of not only producing responses in soils where arbuscular mycorrhizal fungi are absent but also in soils where there are inefficient or ineffective arbuscular mycorrhizal fungi (Gazey et al. 2004; Jansa et al. 2007; Klironomos 2003; Schweiger et al. 2007; Smith et al. 2004; Thomson et al. 1991).

Arbuscular mycorrhizas can have other beneficial effects, for example, they can suppress pests and diseases and may improve soil structure (Akköprü & Demir 2005; Azcón-Aguilar & Barea 1996; Gosling et al. 2006; Newsham et al. 1995; Petit & Gubler 2006; Sharma et al. 2007; Smith & Read 2008; Rillig 2004; Rillig & Mummey 2006; Whipps 2004).





Figures 8 and 9. An arbuscular mycorrhizal infection inside a fine root. The round vesicles (red arrow) and tiny tree-like arbuscules (below) are small enough to fit inside a cell in the outer layer of the root cortex. The fungal hyphae are about 1 μm wide ($^{1}/_{1000}$ mm). (Figure 9 courtesy of Jim Gerdemann)



Figures 10. Spores of arbuscular mycorrhizal fungi are very large compared with ectomycorrhizal fungi. This one of the fungus Glomus invermaium are close to 0.1 mm across and are formed in the soil close to infected roots.

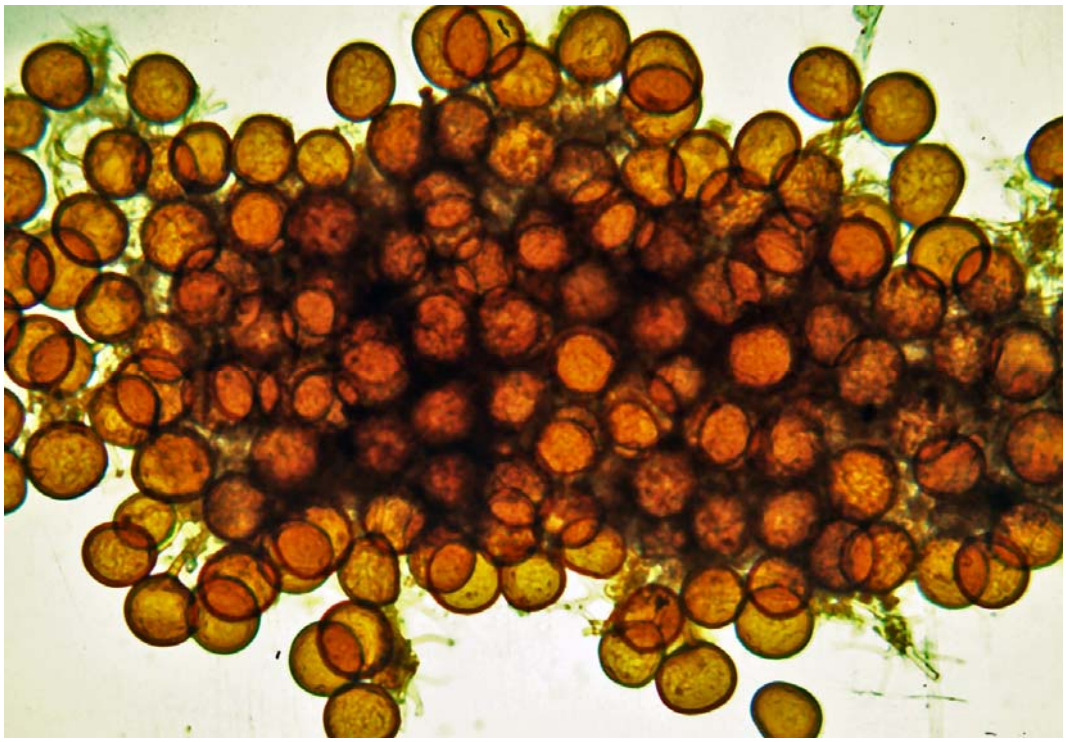


Figure 11. A few species of arbuscular mycorrhizal fungi form their spores in clusters (sporocarps) in the soil. This one is a small sporocarp of Glomus fasciculatum which is visible with the naked eye and too large to become airborne and be blown into a greenhouse.

3.4 Expected response to arbuscular mycorrhizal inoculum

While mycorrhizal fungi are generally expected to stimulate plant growth under some circumstances the carbon drain placed on the plant by the fungus can also lead to growth depressions. Both growth depression and stimulation in Schweiger et al. (2007) experiment (Figure 12) where the two inoculant fungi have dissimilar effects on plant growth and a small, but relatively large growth depression when based on size, at a very low soil phosphorus concentration. Similarly, at very high levels of applied phosphorus growth depressions have frequently been detected (also see Hall 1988, Appendix 5).

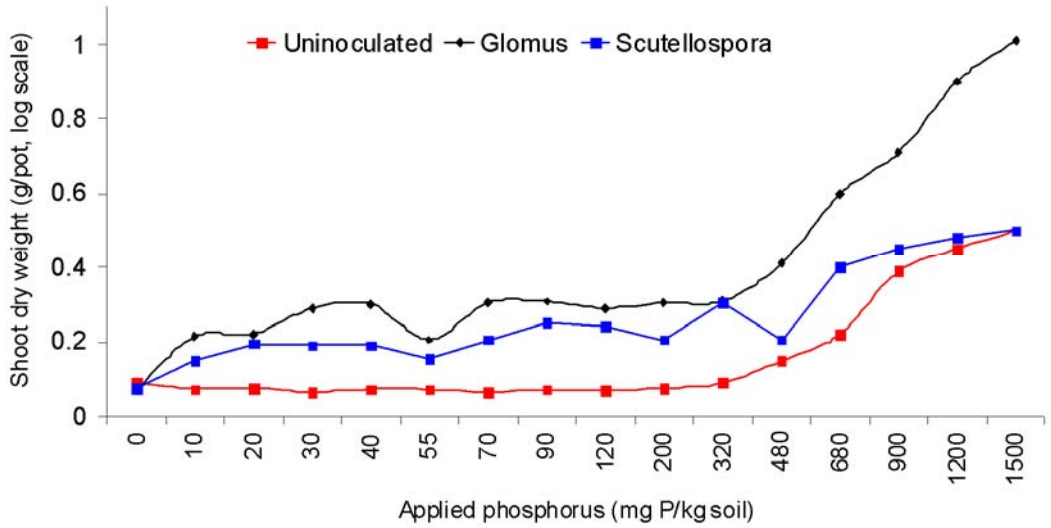


Figure 12. Effect of two arbuscular mycorrhizal inocula, Glomus and Scutellospora, on subterranean clover shoot dry weights in a phosphorus fixing soil with increasing applications of applied phosphorus (redrawn from Schweiger et al. 2007).

4 Mycorrhizal fungi and the nursery

4.1 Mobility of mycorrhizal fungal propagules

Many ectomycorrhizal fungi spread via the production of vast numbers of air borne spores generally only a few microns (µm = 0.001mm) in diameter in various kinds of mushrooms (Figures 8 and 9; Hall et al. 2003). Others produce spores in truffles and false truffles where the dispersal agent is either the wind (Figure 9) or mycophagous animals such as squirrels and pigs. In contrast, most of the arbuscular mycorrhizal fungi produce relatively large spores ranging in diameter from 60 µm up to 1.5 mm which can be spread by water, by movement of soil and possibly animals (Figures 10 and 11). The exception is a group of fungi that have very thin hyphae which produce very small spores. Called the fine endophytes or *Glomus tenue* these fungi are found everywhere but seem to be particularly common in hostile environments such as inside the arctic circle, New Zealand's tussock grasslands, and on the roots of tree dwelling bromeliads (Crush 173; Olsson et al. 2004; Rabatin et al. 1993) and particularly on grasses (Crush 1973; McGonigle & Fitter 1990). Through these dispersal mechanisms mycorrhizal fungi have become almost ubiquitous.

4.2 Specificity of plant for fungus and fungus for plant, and mycorrhizal efficiency

It is known that there is considerable specificity between plantation forest trees and mycorrhizal fungi, i.e., some ectomycorrhizal fungi will stimulate growth of a tree species whilst others will either be less effective or have little or no effect (e.g. Newton & Haigh 1998; Rousseau et al. 1994). For example, fungi in the Gomphidiaceae and species in the section of the Russulaceae that contains the saffron milk cap (*Lactarius deliciosus*) only form ectomycorrhizas with Pinaceae (Miller 2003). Similarly, a radiata pine mycorrhizal fungus like *Rhizopogon rubescens* is not a good symbiont for Douglas fir whereas *Rhizopogon parksii* does, and *Rhizopogon roseolus* on *Pinus pinea* is superior to *Melanogaster ambiguus*, *Pisolithus tinctorius*, *Rhizopogon luteolus* or *Scleroderma verrucosum* (Rincón et al. 2005).

Specificity in arbuscular mycorrhizal fungi is not well understood but some species are better symbionts than others and can affect the ability of plants to compete in ecosystems (Graham & Abbott 2000; Oliveira et al. 2006; Scheublin et al. 2007; Stampe & Daehler 2003; Sylvia et al. 2003). Avio et al. (2006) state:

> These differences are attributable to two main parameters: colonization ability and efficiency. The rate of colonization is influenced by the ability of AM fungi (AMF) to spread rapidly and extensively in plant roots, and is affected by factors linked to spore germination, presymbiotic mycelial growth and appressorium formation (Giovannetti, 2000). Efficiency is correlated with the ability of different isolates to promote plant growth by improving mineral nutrition and increasing tolerance to biotic and abiotic stresses (Giovannetti & Avio, 2002; Jakobsen et al., 2002).

Figure 13. Non-mycorrhizal stunted and chlorotic Douglas firs with deep-green mycorrhizal ones of the same age at the rear.

Figure 14. The effects of soil fumigation on mycorrhizas of onions. The fumigated non-mycorrhizal onions are on the right.

4.3 Mycorrhizas and the nursery

While mycorrhizal fungi are almost ubiquitous there are some notable exceptions where mycorrhizal fungi are absent or poorly represented. The first five of the following bullet points are of particular concern to the forest nursery and forester alike:

- Soilless media (e.g. Graham & Timmer 1984),
- Soils where either ectomycorrhizal or arbuscular mycorrhizal fungi are sparse because of deforestation or ectomycorrhizal or arbuscular plants have never grown in the soil or not for many years (Figure 13; Dickie et al. 2007; Haskins & Gehring 2005; Janos 1996; Onguene & Kuyper 2002; Outerbridge & Trofymow 2004; Simard & Durall 2004; Weber et al. 2005; c.f. Hagerman et al. 2001),
- Sterilised, fumigated or steamed soils (Figure 14; Hall 1988; Miyasaka et al. 2003; Trevors 1996; Wang et al. 2008),
- Where the application of large amounts of phosphorus containing fertilizers have suppressed arbuscular mycorrhiza formation (Daft & Nicolson 1969; Javot et al 2007; Thomson et al. 1991),
- Ectomycorrhizal plants have grown on a site prior to planting a new species that requires different ectomycorrhizal fungi (see section 4.4),
- Eroded or disturbed soils and mine spoils (Hall 1980; Fagbola et al. 2004; Reeves et al. 1979),
- Solarised soils (Wininger et al. 2003),
- Flooded soils (Ipsilantis & Sylvia 2007).

4.4 Mycorrhizas and the New Zealand forest estate

A significant reason for the dominance by radiata pine in New Zealand is the poorer establishment success of other species. In the late 1950s Gilmore (1958) recognised that the poor growth of Douglas fir was due to a lack of mycorrhizal fungi. Many other speciality timber species, such as the stringybark eucalypts, also struggle in New Zealand when compared to their successful performance overseas and it is quite possible that this too is due to a lack of correct mycorrhizal fungi. As a consequence, eucalypts generally are being planted on more fertile soils normally reserved for farming, whereas they ought to be able to perform on soils more akin to those in their home environment.

Spontaneous mycorrhizal infections that are formed by mycorrhizal fungi resident in a bare root nursery or spores that might blow into a greenhouse through vents and doors cannot be relied upon to ensure the correct mycorrhizal fungus establishes on plants. This is particularly important with plants raised in containers where the soilless potting mixes used are invariably devoid of mycorrhizal fungi. A quote from a New Zealand nurseryman illustrates this false, yet commonly held assumption:

> *"…..currently our nurseries have good mycorrhizal populations, including our containers, which* we feel *is a result of the proximity of the outside conditioning area to open ground beds, allowing for mycorrhizal infection.*"

Such a lack of understanding and a failure to ensure adequate mycorrhizal formation of Douglas fir in a bare rooted nursery, coupled with poor planting practices, resulted in the failure of a 60,000 tree plantation in Southland in 2005. Litigation was only avoided when the nurseryman agreed to pay all the costs of replanting plus reparations. In our experience this is not an isolated occurrence with species other than radiata pine. Some nurserymen compensate for a lack of mycorrhizal fungi on their plants, make them look healthy and ensure

that they meet industry standards simply by applying large amounts of nutrients and fungicides but eventually the lack of mycorrhizas may surface after outplanting.

We believe that the opportunities for improving New Zealand's competitive advantage provided by diversifying the forest estate could be unlocked by the careful management of mycorrhizas in nurseries. As a result we anticipate reduced biological and market risks, improved regional and industry development options, increased value-added opportunities in primary and secondary processing industries, improved growth rates, cheaper establishment costs, greater returns on investment and a reduction in root diseases.

5 Brief summary of our research

Our research was divided into sections with each dependent on the findings of those that preceded it.

1. Sample root systems of containerised or bare rooted seedling stock from nurseries, confidentially document management practices, and assess the incidence and level of mycorrhizal infection on plants.
2. We consulted with free thinking people in the forestry industry (and the literature e.g. Libby 1996) and asked for a list of trees which they considered do well in New Zealand and have a potential economic future here but have establishment problems. The accumulated list was wide and varied and from this we selected half a dozen species that while probably not suiting anyone did encompass both ectomycorrhizal and arbuscular mycorrhizal species and together presented a range of mycorrhizal problems that when solved would be applicable to many other forest species. Those that we finally used in our experiments are listed in Table 4.
3. After identifying healthy, rapidly growing, single plants or trial plantings of our chosen species we collected mycorrhizas from them and used these either to raise larger quantities of inoculum on suitable directly or produced inoculum from them by inoculating suitable host plants grown in containers. The mycorrhizal fungi that were used as inocula were chosen on the basis of convenience and suitability for the host plant rather than any pre-judged effectiveness.
4. Once we had our inocula we established experiments in commercial greenhouses or bare root nurseries where the treatments were with or without inoculation with mycorrhizal fungi, and with varying levels of applied nutrient so that we could obtain growth response curves.
5. Plants from our experiments were then used to establish field experiments or were sold by our nursery partners to those who wanted to establish trial plantations.
6. From the experiments described above we devised methods that might be used by commercial nurseries.
7. Rather than writing up our work for scientific journals, which would have been in a format and a style unsuited to many potential users, we distributed our findings in popular articles, seminars, workshops and field days and easy to read reports some of which are lodged on the Sustainable Farming Fund's and Truffles & Mushrooms web sites. This document is the most recent of these.

Table 4. Plantation trees used in our research.

Common name	*Botanical name*	Mycorrhizal status
Coastal redwood	*Sequoia sempervirens*	Arbuscular mycorrhizal
Port Orford cedar	*Chamaecyparis lawsoniana*	Arbuscular mycorrhizal
Silver beech	*Nothofagus menziesii*	Ectomycorrhizal
Red beech	*Nothofagus fusca*	Ectomycorrhizal
Spotted gum	*Corymbia maculata*	Ectomycorrhizal
Douglas fir	*Pseudotsuga menziesii*	Ectomycorrhizal

6 First findings

There has been a great deal of research over the past 75 years that has demonstrated the importance of ectomycorrhizal fungi including Gilmore's ground breaking work on Douglas fir in New Zealand in the 1950s (Gilmore 1958; Appendix 4). However, despite Hall & Garden's demonstration in the 1980s that a lack of mycorrhizas continued to be the cause of poor growth of newly planted Douglas fir, nurserymen now are still doing little or nothing to ensure their plants are infected with appropriate mycorrhizal fungi.

Figures 15 and 16. Rhizopogon rubescens ectomycorrhizas on Pinus radiata.

Several of the nurserymen we visited were happy with heavy *Thelephora* mycorrhizal infections that formed spontaneously in their greenhouses on radiata pine (Figure 17) but could not distinguish them from mycorrhizas formed by *Rhizopogon rubescens* (Figures 15 - 16). Some also confused *Trichoderma* (a free living fungus that can suppress pathogenic fungi) and mycorrhizas and made the assumption that the two names were synonymous.

While nursery personnel appreciated the importance of mycorrhizas and may sometimes inoculate ectomycorrhizal species there is a general lack of background information in the industry. For example, some nurserymen had no idea that some mycorrhizas were specific to certain trees and, for example, that *Rhizopogon rubescens* forms a good association with radiata pine but not on Douglas fir. Another section of the industry believed that research done in New Zealand in the 1970s provided all the information that was needed to understand and facilitate the use of mycorrhizas in the industry.

Despite a naïve approach to mycorrhizas nurserymen and their customers were fixated on minimum plant specifications, particularly collar diameter and height although the scientific basis for these specifications that have been set by industry may have little justification. When batches of trees did not meet these standards the nurseryman would apply copious amounts of fertilisers to stimulate growth and viewed as an economic necessity but one likely to ensure arbuscular mycorrhizal plants remain non-mycorrhizal (section 4.2).

Arbuscular mycorrhizal plants grown in soilless media were never inoculated which accounted for the complete absence of mycorrhizas on them. The subsequent application of very high rates of nutrients ensured that even rare spontaneous infections from wind blown spores had no chance of forming mycorrhizas. Plants for challenging sites such as mine reclamation sites, where there would have been low mycorrhizal populations, were supplied uninoculated.

Because of the above problems we felt committed to educating some sections of the forest industry so that our work could be fully comprehended.

Figure 17. Spontaneous Thelephora infections on the bottom of cells in Lannen trays. There is a general assumption that infections produced by this weed fungus will be beneficial to the plant whereas there is little justification for this belief.

7 Arbuscular mycorrhizal cultures

Traditional, non-high-tech techniques were used to establish arbuscular mycorrhizas on white clover in a greenhouse at Oregon Nursery (e.g. Brundrett et al. 1996; Corkidi et al. 2004; Hagerman & Durall 2004; Hall 1976; Kitt 1992; Miyasaka et al. 2003). The standard limed Oregon Nursery mix but without added nutrients was used to fill 36 trays 0.4m x 0.3m x 0.15m. Basal dressings applied to the trays were:

> 1.4 mg of Na_2MoO_4 per tray applied prior to sowing in 10 mL of solution spread evenly over the surface of each tray.
>
> 50 mg phosphorus applied as 1.135 g of Pete Lite Special (4.4% P) per tray in 10 mL of solution spread evenly over the surface of each tray. This was reapplied when the clover appeared to need rejuvenating.

The trays were then inoculated with one of three arbuscular mycorrhizal inocula derived from vigorous stands of *S. sempervirens* and *C. lawsoniana* or white clover collected adjacent to a main road.

The cultures were allowed to grow for 12 months before they were used in experiments. Using clover as the host plant for the arbuscular mycorrhizal fungi ensured that the final inoculum was free of any significant *S. sempervirens* and *C. lawsoniana* pathogens.

8 Sequoia experiment at ArborGen Nursery

8.1 Experimental design

Sequoia sempervirens apical cuttings about 12.5 cm high were taken by ArborGen (previously Horizon 2) on 11 April 2007 and raised under a plastic tent with 8 weeks bottom heat and misting every second day. As a precautionary measure they were sprayed with a fungicide after 3 weeks. The tent was removed after 6 weeks when 25% of the cuttings were showing callusing.

The experiment was established on 8 October 2007 when half of the cuttings were inoculated with a *Sequoia* arbuscular mycorrhizal inoculum raised on white clover. There were four rates of nutrients where the highest rate was that normally used by in ArborGen's nursery and there were two inoculation treatments:

1. Nutrients:
    - 0.125 Standard ArborGen's fertiliser
    - 0.25 Standard fertiliser
    - 0.5 Standard fertiliser
    - 1 x Standard fertiliser
2. Inocula:
    - No inoculum - control
    - *Sequoia sempervirens* inoculum raised on clover
4. Replications 5

8.2 Results

Large growth responses to both the inoculum and nutrients were evident by the end of 2007. The photographs below were taken in mid February 2008 about 10 months after the cuttings were made.

In each photo the uninoculated tray is on the left and the inoculated one on the right. Shoot heights were used as an estimate of plant growth[2] (Figure 21) but as can be seen from the photographs below these underestimated differences in shoot bulk (Figure 20).

Although there was no replication the plant analysis data suggests that shoot phosphorus concentrations (Figure 22, Table 5) increased with inoculation and with increasing level of applied nutrient and more or less mirrored shoot height (Figure 21). Inoculation also appeared to have stimulated shoot nitrogen, potassium, manganese, zinc, copper and iron concentrations. All nutrient concentrations were within the ranges published by Rose & Ketchum (2002) and Zinke et al. (1996).

[2] Because of the wide range of people who will read this report and difficulties that some might have understanding statistical analyses we decided not to include the methods that were used to analyse the data, probabilities and the like. However, this statistical information is available from the authors.

Figure 18. Representative trays of Sequoia sempervirens cuttings with the lowest rate of fertilizer (⅛ the normal rate applied by the nursery). The inoculated tray is on the right. Note the yellow foliage in the uninoculated tray which was probably due to phosphorus deficiency.

Figure 19. Representative trays of Sequoia sempervirens cuttings with ¼ the normal rate of fertiliser applied by the nursery. Like the ⅛ fertiliser treatment the foliage of the uninoculated plants was yellow.

Figure 20. Representative trays of Sequoia sempervirens cuttings with the full rate of fertiliser normally applied by the nursery. Although the heights of the cuttings are similar (see the graph below) the inoculated ones were considerably larger and the uninoculated plants were still somewhat yellow at the tips.

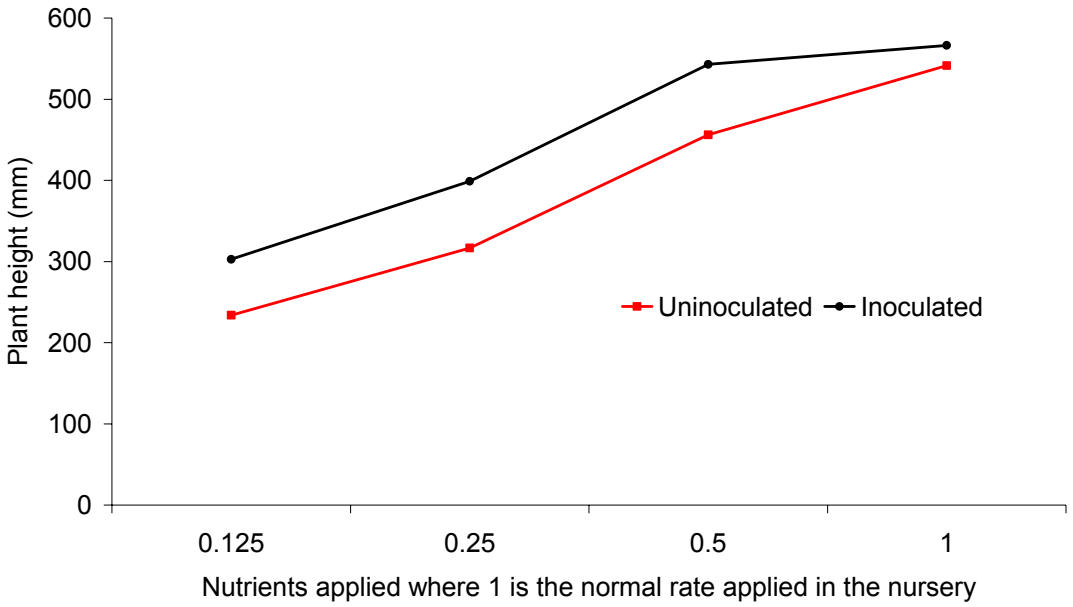


Figure 21. Heights of 10 month old Sequoia sempervirens cuttings with the application at 6 months of four rates of fertilisers (where the highest was the normal rate in ArborGen's nursery) and with and without arbuscular mycorrhizal inoculum.

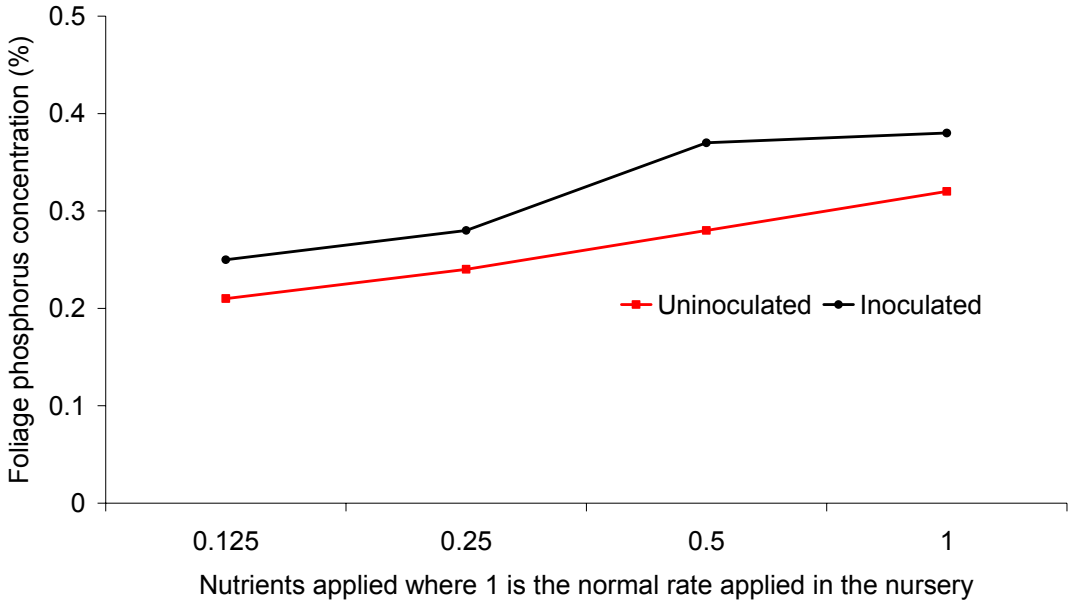


Figure 22. Needle phosphorus concentrations in 10 month old Sequoia sempervirens cuttings with the application at 6 months of four rates of fertilisers (where the highest was the normal rate in ArborGen's nursery) and with and without arbuscular mycorrhizal inoculum.

Table 5. Concentrations of elements in Sequoia sempervirens at ArborGen (previously Horizon 2) with and without arbuscular mycorrhizal inoculum and with four rates of complete nutrients where 1.0 was the normal rate applied by the nursery. Each analysis was carried out on pooled leaves taken from every plant within a treatment. "Standard" needle nutrient concentrations at Arcata, California, and in a nursery from Rose & Ketchum 2002 and from Zinke et al. 1996. Nutrients in blue text appeared to increase with inoculation.

Nutrient level	Mycorrhiza	Nitrogen %	Phosphorus %	Sulphur %	Magnesium %	Calcium %	Sodium %	Potassium %	Manganese ppm	Zinc ppm	Copper ppm	Iron ppm	Molybdenum ppm	Boron ppm
ArborGen experiment														
0.125	-	1.12	0.21	0.11	0.45	0.73	0.06	0.95	96	30	2.8	130	4.62	25
0.125	+	1.40	0.25	0.13	0.53	0.90	0.07	0.99	130	39	4.9	192	7.58	30
0.25	-	1.37	0.24	0.12	0.41	0.66	0.06	1.07	87	31	3.2	127	4.44	23
0.25	+	1.64	0.28	0.14	0.41	0.62	0.06	1.14	106	36	3.8	114	3.04	25
0.5	-	1.84	0.28	0.14	0.39	0.59	0.06	1.03	128	34	4.2	122	2.36	25
0.5	+	2.20	0.37	0.16	0.50	0.79	0.08	1.16	158	46	6.9	141	4.27	30
1.0	-	2.33	0.32	0.17	0.40	0.58	0.05	1.20	168	36	5.4	128	1.21	26
1.0	+	2.43	0.38	0.17	0.41	0.60	0.05	1.41	225	49	9.6	179	1.38	27
Rose & Ketchum 2002														
Arcata	-	1.0	0.17	-	0.22	0.70	-	0.46	-	-	-	-	-	5.5
Nursery	-	1.91	0.30	-	0.21	0.78	-	0.85	-	-	-	-	-	7.8
Zinke et al. 1996														
- second year foliage	-	1.07	0.11	-	0.19	0.79	0.07	0.57	250	29	-	209	-	-
50 to 99% quantile	-	1.01 - 1.95	0.13 - 0.48	-	0.17 - 0.42	0.82 - 2..14	0.03 - 0.39	0.59 - 1.89	208 - 1038	33 - 111	-	178 - 1111	-	-

9 Experiments on arbuscular mycorrhizal plants at Oregon Nursery

9.1 Plants used in the experiments

Redwood cuttings taken earlier in 2006 in Horizon 2's nursery at Te Teko were slow to root and seemed unlikely to be available for experimentation. In anticipation that the cuttings would not have been available cloned redwood plantlets and *C. lawsoniana* seedlings were raised at Oregon Nurseries using standard nursery practices. Roots from a sample of these were stained for mycorrhizal fungi using a modification of Phillips & Hayman's technique (1970). This involved washing out the roots of each seedling, heating the roots in 10% KOH (potassium hydroxide) for several hours at 85°C in a domestic oven on fan bake, washing the roots in running water to remove excess KOH, rinsing three times with tap water, neutralising the KOH with a dilute solution of HCl (hydrochloric acid), decolourising the roots in a dilute solution of 10% H_2O_2 (hydrogen peroxide) for 5-10 minutes at room temperature and then staining in lactic trypan blue for 7 days at room temperature.

There was no sign of arbuscular mycorrhizal fungi in the roots even though the phosphorus concentration was only 0.26% in the foliage, a level where mycorrhizas would probably have benefited growth (Figure 18).

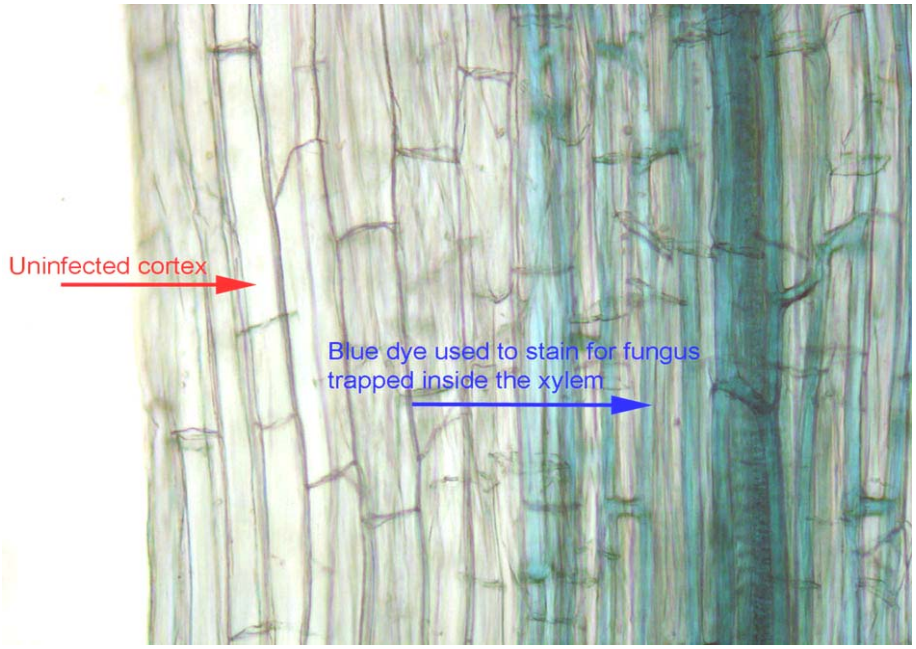
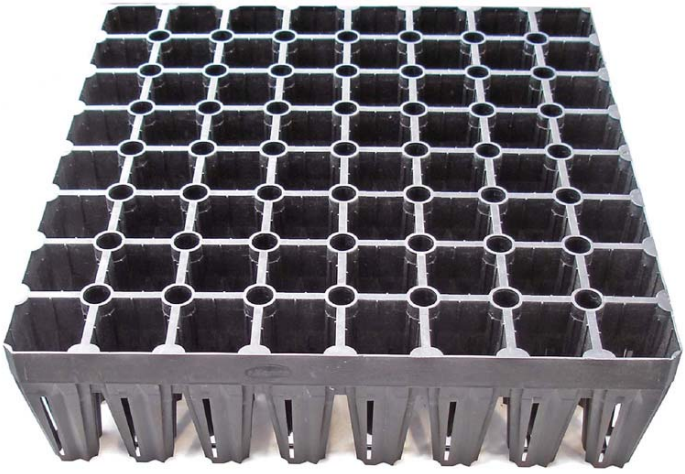
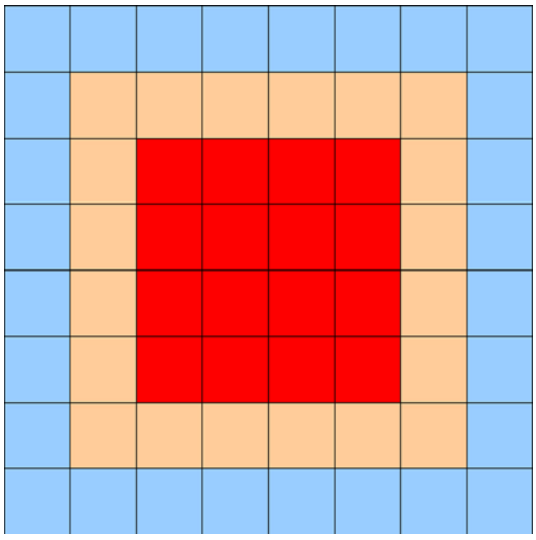


Figure 23. Sequoia sempervirens seedlings raised in Oregon Nurseries had no sign of endomycorrhizal infections in the root cortex.

The experimental unit was the Lannen 64 tray (Figure 24). The treatments were applied to all the cells but only the centre 16 plants were considered part of the main body of the experiment. The outer row was a guard row while those between were used for sampling and following infection as the experiment progressed. The basal treatments were herbicides and pesticides (but not fungicides) as recommended by nursery personnel.





Figures 24 and 25. The Lannen 64 tray used in the Nothofagus experiment and the layout of the cells with the outer guard row, innermost experimental plants with the plants that were used to check for progress during the experiment in-between.

9.2 Chamaecyparis lawsoniana experiment

As with the later ectomycorrhizal experiments the experimental treatments were with and without inoculum and rates of applied nutrients and except for using arbuscular mycorrhizal inocula were essentially similar to the *Corymbia maculata* and *Nothofagus fusca* experiments. The highest rate of fertiliser applied was 0.8 times the normal rate applied in Oregon's Nursery and the 12 experimental treatments were:

1. Nutrients:
    - 0.1 Slow release fertiliser
    - 0.2 Slow release fertiliser
    - 0.4 Slow release fertiliser
    - 0.8 Slow release fertiliser
2. Inocula.
    - No inoculum - control
    - Inoculum 1 Clover roots infected with *Chamaecyparis* inoculum on clover
    - Inoculum 2 Clover roots infected with white clover inoculum on clover
3. Replications 3

9.2.1 Results

The white clover inoculum derived from white clover stimulated growth at all levels of nutrients except the highest. In contrast, the *C. lawsoniana* inoculum failed to stimulate growth at all levels of applied nutrient. Both inocula depressed growth at the highest rate of applied nutrient.

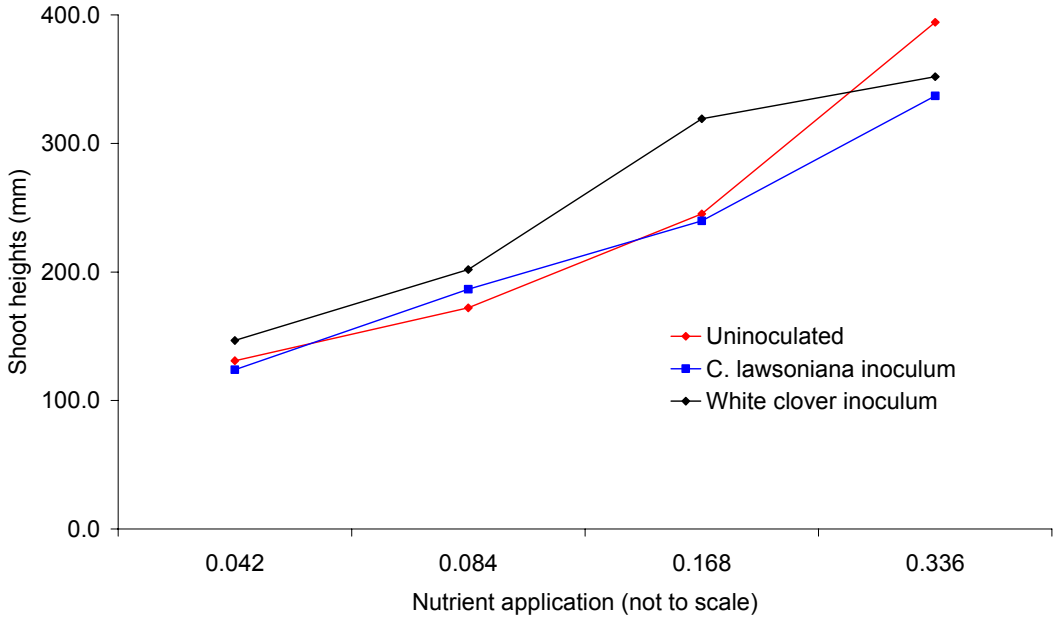


Figure 26. Effect of two arbuscular mycorrhizal inocula on Chamaecyparis lawsoniana.

9.3 Sequoia sempervirens experiment at Oregon Nursery

The *S. sempervirens* experiment at Oregon Nursery was a repeat of the *C. lawsoniana* one above except that two inocula were used. The treatments were:

1. Nutrients:
   - 0.1 Slow release fertiliser
   - 0.2 Slow release fertiliser
   - 0.4 Slow release fertiliser
   - 0.8 Slow release fertiliser
2. Inocula
   - No inoculum - control
   - Inoculum 1 Clover roots infected with *Sequoia sempervirens* inoculum
3. Host plants
   - Clone 1
   - Clone 2

4. Replications 3

5. Three additional trays of seedlings were inoculated with clover roots infected with clover inoculum (inoculum 2) at the second level of applied nutrients and there were three control trays.

9.3.1 Results

Inoculation had no effect on *Sequoia sempervirens* Clone 1 but increased growth of Clone 2 at low levels of applied nutrient and depressed it at the higher levels.

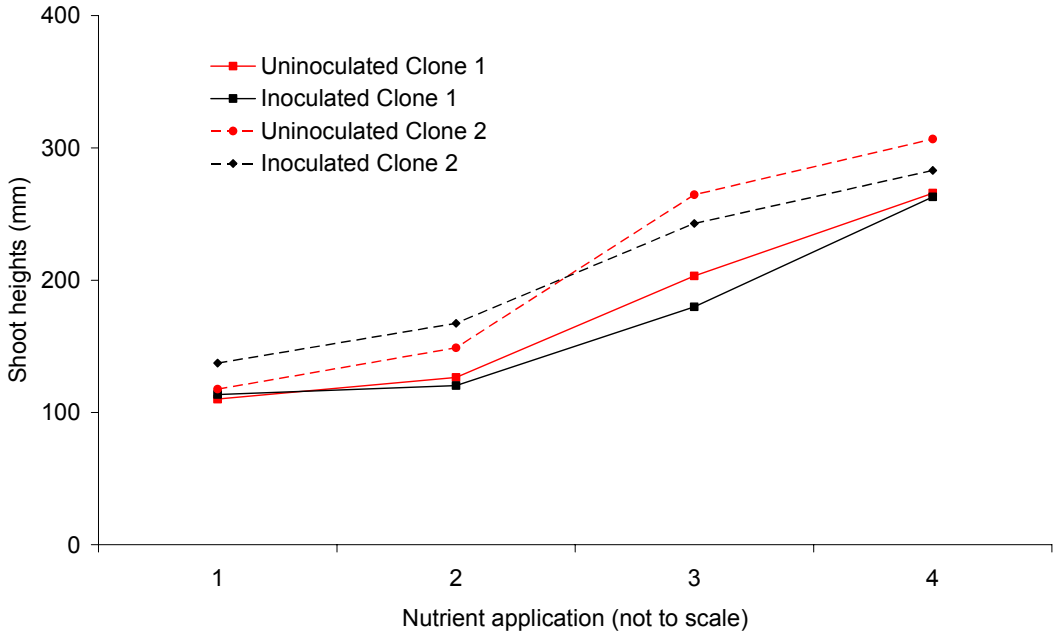


Figure 27. Inoculation had no effect on Sequoia sempervirens Clone 1 but increased growth of Clone 2 at low levels of applied nutrient and depressed it at the higher levels.

Inoculation appeared to have produced a small increase in the phosphorus concentration at the lower levels of applied nutrient and falls in the concentrations of calcium, manganese, zinc and boron (Table 6). However, the foliage concentrations of nitrogen, phosphorus and iron were all well below Rose & Ketchum (2002) and Zinke et al.'s (1996) standards at all levels of applied nutrient (Table 6) and just a fraction of those found in the experiment at ArborGen Nursery (Table 5) suggesting that our results would have been very different had the range of nutrient concentrations used extended much higher.

Table 6. Concentrations of elements in two clones of Sequoia sempervirens at Oregon Nursery, with and without arbuscular mycorrhizal inoculum, and with four rates of complete nutrients where 1.0 was the normal rate applied by the nursery. Each analysis was carried out on pooled leaves taken from every plant within a treatment. Numbers in blue and red are where inoculation appeared to have respectively increased or decreased the concentration of a nutrient.

Nutrient level	Mycorrhiza	Clone	Nitrogen %	Phosphorus %	Sulphur %	Magnesium %	Calcium %	Sodium %	Potassium %	Manganese ppm	Zinc ppm	Copper ppm	Iron ppm	Molybdenum ppm	Boron ppm
0.1	No inoculum	1	0.47	0.08	0.09	0.43	1.26	0.12	0.95	244	37	21	29	0.22	18.8
	Inoculated	1	0.55	0.10	0.10	0.41	1.23	0.09	0.93	197	32	28.4	33	0.13	14.1
0.2	No inoculum	1	0.52	0.09	0.11	0.46	1.45	0.11	0.91	211	46	23	31	0.22	22.1
	Inoculated	1	0.56	0.10	0.10	0.39	1.18	0.09	0.89	169	32	22.1	31	0.21	13.9
0.4	No inoculum	1	0.54	0.07	0.08	0.37	1.26	0.08	0.65	176	28	15.5	26	0.08	16.9
	Inoculated	1	0.54	0.11	0.10	0.39	1.30	0.09	0.85	194	28	20.2	26	0.2	14.8
0.8	No inoculum	1	0.59	0.07	0.08	0.41	1.54	0.09	0.54	150	31	18	30	0.19	18.2
	Inoculated	1	0.56	0.08	0.09	0.35	1.34	0.08	0.67	120	27	20.2	29	0.17	13.5
0.1	No inoculum	2	0.59	0.07	0.08	0.32	1.24	0.12	0.84	208	55	32	25	0.11	17.7
	Inoculated	2	0.52	0.09	0.07	0.29	1.04	0.08	0.84	246	41	23.6	26	0.08	12.9
0.2	No inoculum	2	0.55	0.07	0.07	0.31	1.28	0.11	0.79	188	48	25.1	26	0.05	15.9
	Inoculated	2	0.55	0.10	0.07	0.28	1.08	0.08	0.86	177	38	22.9	28	0.09	10.4
0.4	No inoculum	2	0.54	0.06	0.06	0.30	1.40	0.09	0.75	165	38	23.2	25	0.14	13.9
	Inoculated	2	0.59	0.08	0.06	0.28	1.27	0.07	0.86	135	34	25.7	23	0.11	10.4
0.8	No inoculum	2	0.59	0.07	0.07	0.26	1.27	0.10	0.88	146	42	19.7	41	0.17	15.6
	Inoculated	2	0.56	0.08	0.06	0.25	1.23	0.09	0.87	138	37	22.2	28	0.12	10.1
No inoculum mean			0.55	0.07	0.08	0.36	1.34	0.10	0.79	186.00	40.63	22.19	29.13	0.15	17.39
Inoculated mean			0.55	0.09	0.08	0.33	1.21	0.08	0.85	172.00	33.63	23.16	28.00	0.14	12.51
Rose & Ketchum 2002															
Arcata	-		1.0	0.17	-	0.22	0.70	-	0.46	-	-	-	-	-	5.5
Nursery	-		1.91	0.30	-	0.21	0.78	-	0.85	-	-	-	-	-	7.8
Zinke et al. 1996															
- second year foliage	-		1.07	0.11	-	0.19	0.79	0.07	0.57	250	29	-	209	-	-
50 to 99% quantile	-		1.01 - 1.95	0.13 - 0.48	-	0.17 - 0.42	0.82 - 2..14	0.03 - 0.39	0.59 - 1.89	208 - 1038	33 - 111	-	178 - 1111	-	-

10 Experiments on ectomycorrhizal plants at Oregon Nursery

10.1 New Zealand silver beech raised in soilless media in the greenhouse

The first genus we decided to work on was *Nothofagus* because there was considerable anecdotal information that it was difficult to infect and often failed when transplanted into pastures – a situation where it would have been unlikely for ectomycorrhizal fungi to be present.

10.1.1 Design

In this first experiment, carried out in Oregon Nurseries greenhouse near Oamaru, we used *Nothofagus menziesii* . There were 4 replicates and 12 treatments:

1. Pete Lite Special high N applied weekly beginning two weeks after establishing the experiment (1.0 would have been the normal dose was that applied by the nursery).
    - 0.042 normal dose 0.001 g per plant in 1 mL of solution per application
    - 0.084 normal dose 0.002 g/ "
    - 0.168 normal dose 0.004 g/ "
    - 0.336 normal dose 0.008 g/ "
2. Inocula
    - No inoculum - control
    - Inoculum collected from the hills to the east of Taieri Mouth, Otago
    - Inoculum collected from Waipori Gorge

10.1.2 Results

Within 3 months of inoculation most of the inoculated plants were showing early signs of mycorrhizal formation and by 6 months mycorrhizas were found on all of the inoculated plants (Figure 14) with some being particularly heavy. With one or two exceptions all uninoculated plants remained non-mycorrhizal.

Six months after the start of the experiment there were extensive mycorrhizas on the inoculated *Nothofagus menziesii* but not on the uninoculated plants. By mid winter 2006 the weed fungus *Thelephora* was found on plants in most of the cells in the Lannen trays but the often very heavy infections produced by the inoculant mycorrhizal fungi dominated and suppressed it. Mycorrhizas produced by the inoculant fungi were heaviest in the upper part of the cells where there were almost no uninfected tips. The only mycorrhizas on the uninoculated trees were formed by *Thelephora*.

By the end of the experiment all the inoculated *Nothofagus menziesii* plants had formed heavy mycorrhizal infections on the root systems – a very satisfactory result.

Figures 28 and 29. Pricking out and inoculating Nothofagus menziesii, Oregon Nursery, September 2005.

Figure 30. Applying measured quantities of nutrients to Nothofagus menziesii in each cell of Lannen trays, a method of applying nutrients that was abandoned in all other experiments in favour of mixing varying amounts of slow release fertilisers into the potting mix.

Figure 31. Part of the Nothofagus trial at Oregon Nurseries 3 months after establishment.

Figure 32. Mycorrhizal root tips (three arrowed) on Nothofagus menziesii 6 months after inoculation and a detail of the same.

The mycorrhizal fungi chosen for this trial proved to be very aggressive and spread from the inoculated trays into adjacent uninoculated trays where they formed mycorrhizas. We are sure this is how the uninoculated trays became infected because *Coenococcum*, one of the inoculant ectomycorrhizal fungi and one with a wide host range, does not produce spores and was not found on other ectomycorrhizal plants elsewhere in the greenhouse.

As a result of the relatively low rates of nutrient we used in the experiment our plants although all healthy and dark green (Figure 13) were somewhat smaller than the uninoculated and uninfected plants produced by the Oregon Nursery in adjacent trays.

The growth of *Nothofagus menziesii* was enhanced by inoculation throughout the experiment with the Taieri Mouth inoculum superior to the Waipori one (Figure 15). It is possible that the apparent growth depression at the highest level of applied nutrients was an aberration but this seems unlikely given the degree of replication in the experiment. A more likely explanation is that the highest rate of nutrients applied once every two weeks burnt the roots of control plants whereas the mycorrhizal plants were protected by the fungal tissue around the roots.

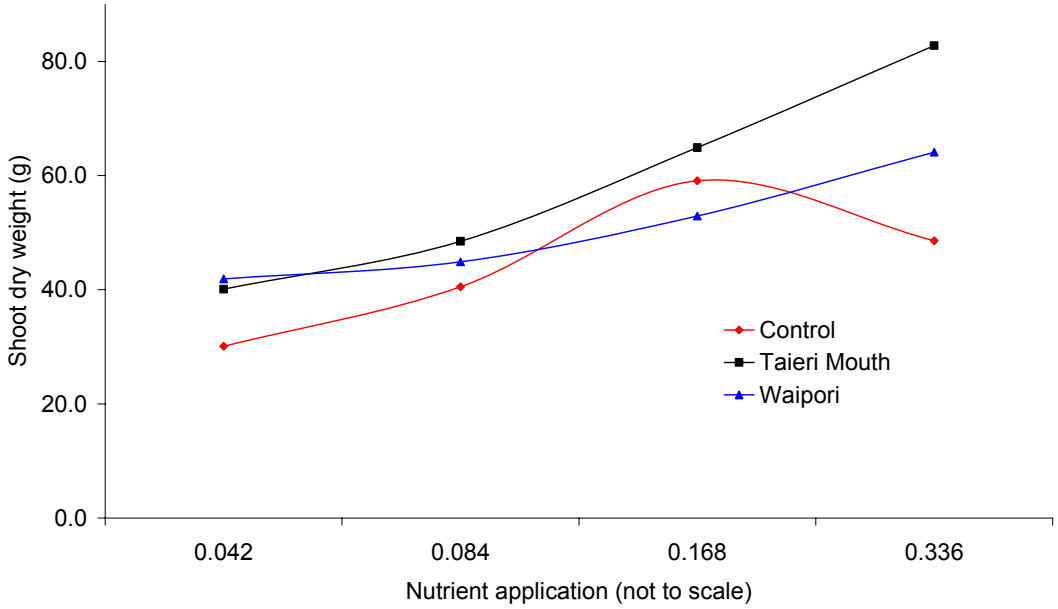


Figure 33. Mycorrhizal inoculation began to stimulate the growth of Nothofagus menziesii around 4 months after setting up the experiment. Apparent growth depressions in the control plants at the highest rate of applied nutrient seems likely to have been a toxic effect of the concentrated nutrients on the roots when they were applied to the soil surface - see Figure 30.

10.2 Corymbia maculata experiment

Because of the problems experienced with applying high rates of nutrients to *Nothofagus* (section 7.1) in the second greenhouse experiment on *C. maculata* we incorporated slow release fertiliser in the potting mix at four rates where unity was the rate normally applied by Oregon Nursery.

1. Nutrients:
    - 0.1 Slow release fertiliser
    - 0.2 Slow release fertiliser
    - 0.4 Slow release fertiliser
    - 0.8 Slow release fertiliser
2. Inocula
    - No inoculum - control
    - Inoculum derived from Nelson Cemetery.
3. Replications 4

The inoculum was derived from approximately 70 year old *C. maculata* trees in the Wakapuaka Cemetery 2 km to the northeast of Nelson. At the time of inoculation the *C. maculata* seedlings were only 5 weeks old but were already etiolated, chlorotic, and obviously phosphorus deficient – all signs of a lack of mycorrhizas (Figure 16). Because these seedlings may not have been sufficiently vigorous to form mycorrhizas an additional seed was sown into each cell. Because of the limited number of seedlings available to us we omitted the uninoculated treatments at the two highest levels of applied nutrient.

Figure 34. Chlorotic and etiolated C. maculata seedlings showing obvious signs of phosphorus deficiency and a lack of mycorrhizal fungi just a few weeks after sowing.

10.2.1 Results

All the plants in the inoculated treatments became mycorrhizal (Figure 35). However, the inoculum appeared to have transferred an agent which produced galls just below the soil surface (Figure 36).

Figure 35. Web of mycorrhizal fungi growing between the roots of Corymbia maculata on the surface of an inoculated plug from a Lannen 64.

Figure 36. Galls on Corymbia maculata formed just below the surface of the potting mix.

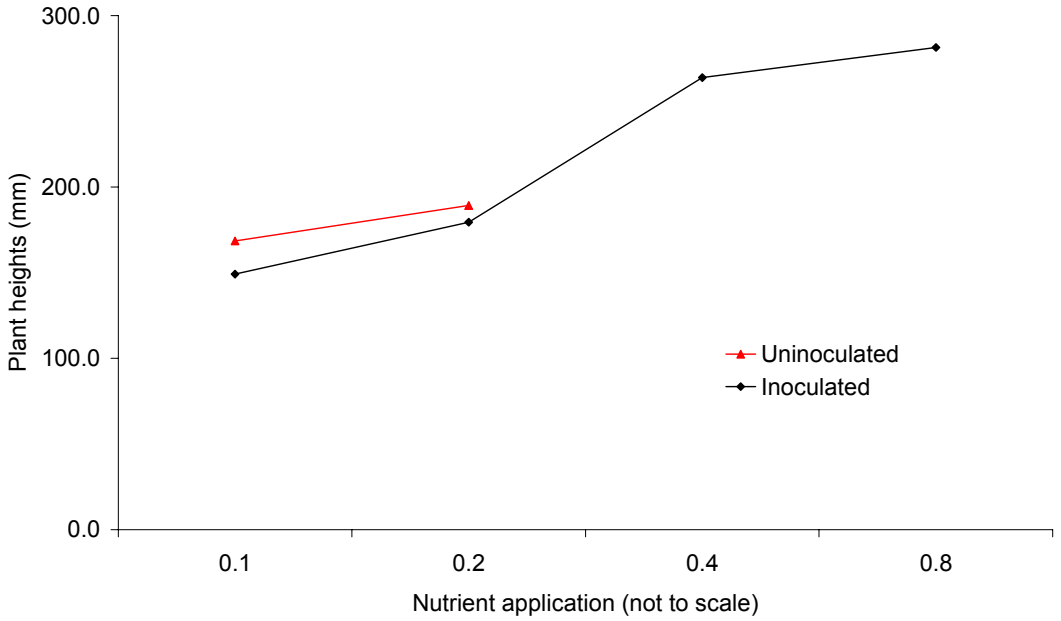


Figure 37. The growth of mycorrhizal Corymbia maculata approached the maximum with 0.8 times the fertiliser rate normally used in Oregon Nursery.

Because of the lack of treatments in the uninoculated control it was not possible to determine if there were any growth responses to inoculation although plant growth in the inoculated treatments did appear to approach the asymptote – maximum plant growth. This was despite Oregon Nursery's rate begin considerably lower than that normally recommended within the industry. Within 6 months of establishing the experiment the foliage of the inoculated plants had developed a better colour probably as the phosphorus concentrations in the plants recovered (Figures 25 and 29).

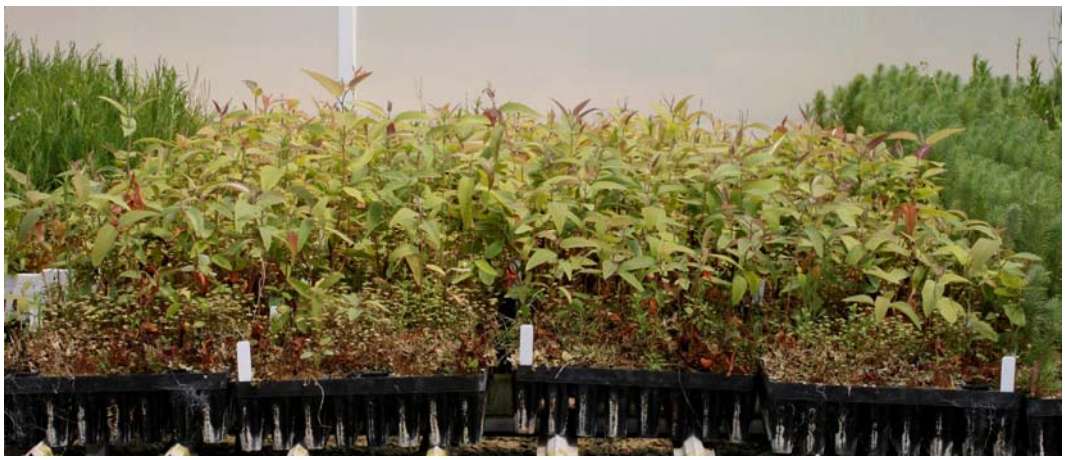


Figure 38. The colour of the Corymbia maculata improved considerably as the experiment progressed probably because of improved tissue phosphorus concentrations.

10.3 Nothofagus fusca experiment

An experiment conducted on *Nothofagus fusca* was essentially similar to others described above and below with four rates of applied nutrients and with and without inoculation with mycorrhizal fungi. The inoculum for this experiment was derived from under well established *N. fusca* at Waianakarua, North Otago.

1. Nutrients:
    - 0.1 Slow release fertiliser where 1.0 was the rate normally applied by Oregon Nursery
    - 0.2 Slow release fertiliser
    - 0.4 Slow release fertiliser
    - 0.8 Slow release fertiliser
2. Inocula
    - No inoculum - control
    - Inoculum derived from Waianakarua
3. Replications 4

10.3.1 Results

Four months after inoculation mycorrhizas had begun to form on the roots of the red beech (Figure 30).

Figure 39. Sausage-shaped mycorrhizas on the root tips of Nothofagus fusca had become well established by 4 months into the experiment.

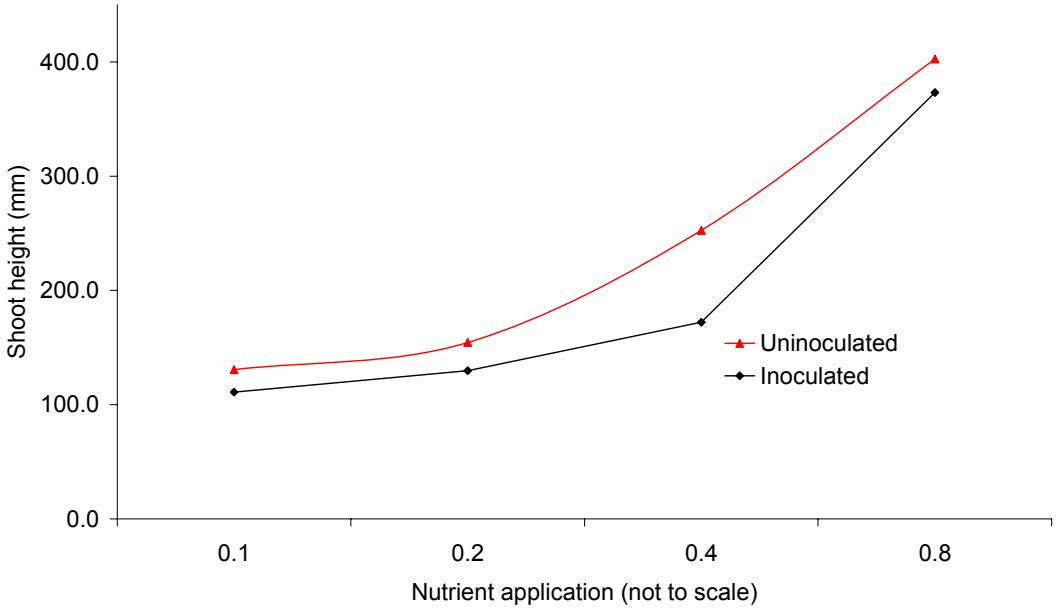


Figure 40. Nothofagus fusca shoot heights 12 months after inoculation with the uninoculated plants exceeding the height of the inoculated ones at all levels of applied nutrient.

In this experiment the inoculum depressed plant growth, a feature that is common to many ectomycorrhizal fungi in the initial stages of plant growth and is brought about by the drain the fungus places on the plant's carbohydrate supply. However, if the experiment had been allowed to proceed for longer or if higher nutrients had been used it would have been normal for the mycorrhizal plants to have exceeded the growth of the uninoculated ones.

10.4 Pinus pinea at Oregon Nursery

Pinus pinea (stone pine) were raised in mycorrhiza free potting mix in hygiene trays and topped prior to use. In April 2007 the seedlings were pricked out into Lannen 64 trays and inoculated with inoculum sourced from well established *P. pinea* growing in Mossburn, Southland. There were 4 treatments:

- Inoculum placed beneath the seedling,
- Inoculum pushed down the side of each plant in each cell (a treatment that disturbed the seedlings more than the other treatments),
- Inoculum ground up and scattered on the surface of the cells,
- Inoculum in the form of pebbles that were scattered on the surface of the cells.

There were not less than 9 trays in each treatment and the inoculated trays surrounded with 26 trays of uninoculated plants.

10.4.1 Results

Fifteen months after inoculation plants that had received the most disturbance were the smallest (Table 7). Despite all plants that had been inoculated had become well infected. These Mossburn mycorrhizal fungi had also migrated to trays of uninoculated plants (Figure

41). Those uninoculated plants that had not become contaminated with the Mossburn fungi had become contaminated with *Thelephora* (Figure 41).

Table 7. Heights of Pinus pinea 15 months after inoculation.

	Inoculum			
	Below seedling	Pushed down next to the roots	Ground up and on the cell surface	Pebbles on the cell surface
Mean plant height	17 - 30 cm	17 - 36 cm	26 - 49 cm	

Figure 41. Fifteen months after inoculating Pinus pinea with a Mossburn inoculum all plants had become infected (right) and this had spread to many of the surrounding trays of plants that had not been inoculated (left plant, left photograph). Plants that had not been inoculated and did not show signs of becoming infected with the Mossburn mycorrhizal fungi became contaminated with Thelephora (left photograph, right plant).

11 Douglas fir bare root nursery trial

In the mid 1990s Ian Hall was able to demonstrate that containerised Douglas fir grown in a soilless medium in a greenhouse could be infected with the mycorrhizal fungus *Rhizopogon parksii.* However, this did not provide any assistance to those raising Douglas fir in bare root nurseries some of whom as recently as 2004 were having problems producing plants with adequate mycorrhizal infections. In 2005 an experiment was established at Leithfield Nurseries near Wyndham, Southland, to investigate the effect of nutrients, fungicides and *R. parksii* inoculum on mycorrhizal formation by Douglas fir. This was in an area of the nursery that had been left fallowed for a few years (Figure 42) and where it was expected that mycorrhizal infection was likely to be poor in the first year (Figure 43).

Figure 42. The area set aside for the Douglas fir field trial at Leithfield Nursery was immediately to the right of the fence line.

Figure 43. Leithfield Nursery where Douglas fir germination, growth and mycorrhizal formation was generally poor in the first year after fallow.

11.1 Basal dressing

Potassium was the only element that was obviously too low from an analysis of the soils from the experimental plot (Table 8) which was corrected by the application of 100 kg/ha of potassium chloride (KCl) which was 10.8 g per 1.2 m x 0.9 m plot. The nursery's normal herbicide and pesticide regime was applied by nursery personnel.

Table 8. Soil analyses from Leithfield Nurseries, 19 August 2005. Potentially deficient elements are in red

pH	5.7
Available calcium *	5
Extractable phosphorus (µg/mL)	19
Extractable potassium *	1
Extractable magnesium *	12
Extractable sodium (µg/mL)	4
Extractable sulphur (µg/mL)	24
Extractable iron (µg/mL)	550
Extractable boron (µg/mL)	1.2
Extractable copper (µg/mL)	4.1
Extractable manganese (µg/mL)	92

* MAF units. To convert to µg/mL multiply calcium by 125, K by 20, and Mg by 5.

11.2 Treatments

1. Triple super applied prior to sowing in an inert carrier to ensure even spread within a plot.
   - No Triple super
   - 41/9 = 4.6 g triple super per 1.2 m x 0.9 m plot - equal to 0.1 x the rate applied by the nursery
   - 41/3 = 13.7 g triple super per 1.2 m x 0.9 m plot - equal to 0.33 x the rate applied by the nursery
   - 41 g triple super per 1.2 m x 0.9 m plot - equal to the full rate applied by the nursery.

2. Inoculum – 20 mL/plant of a slurry of *Rhizopogon parksii* spores containing not less than 10^7 /mL (about 40 times the required amount of inoculum) applied to the roots in January 2007 using a pressure sprayer when the seedlings were beginning to form second order laterals (Figure 51).
   - No inoculum - control
   - Spore inoculum from Ernslaw One.

3. Fungicides
   - No fungicides
   - Fungicides as recommended by nursery personnel

4. Replications 4 (i.e. a total of 64 plots, Figures 44 and 45).

The beds were prepared by Leithfield Nurseries and on 21 October 2005 the phosphorus treatments were applied and the seed sowed using the nursery's seeder (Figures 45 – 47). A 0.6 m guard strip between plots was designed to prevent the triple super being dragged from one plot into another. The position of the top left hand corner peg of Replicate 1 (viewed from the gate) was triangulated from a fence post with the top painted white. The bottom left hand corner peg of the last plot of each replicate were similarly positioned.

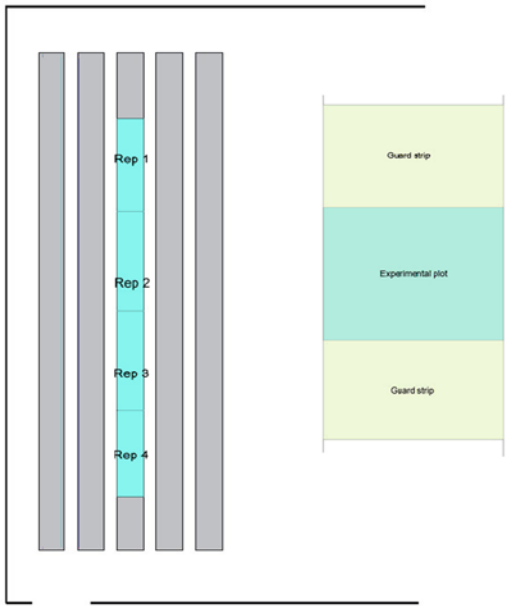


Figure 44. Location of the experiment (in turquoise) spread over a single planting row two rows in from the fence line. Inset: an experimental plot (pale blue) 0.9 m long separated from adjacent plots by 0.6 m guard strips. The guard strips received no nutrients or inocula.

Figure 45. Laying out the experiment at Leithfield Nursery after the planting beds had been prepared.

Figure 46. Applying the phosphorus treatments after mixing the small amounts of fertiliser with an inert carrier.

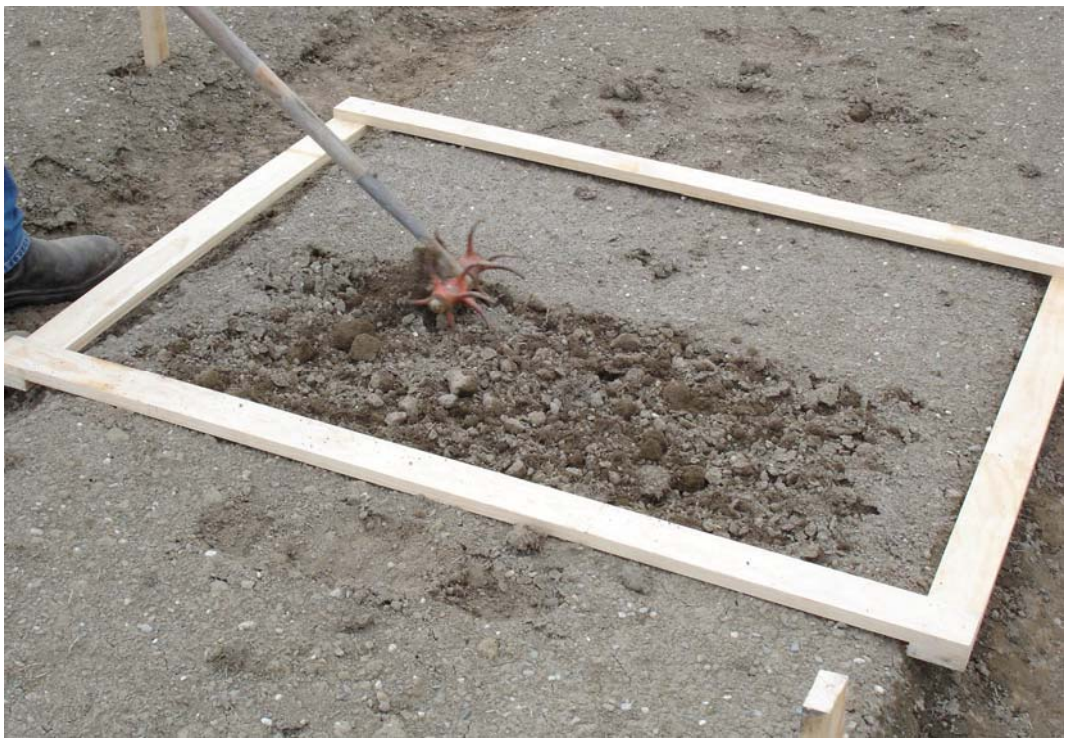


Figure 47. Mixing the phosphorus fertiliser treatment into the plot using a Spintiller.

Figure 48. Appearance of the beds after sowing to the right. The as yet unsown experimental plots are to the left of the pegs.

Figure 49. Covering the beds after sowing with a dressing of fine gravel (also see Figures 50 and 51).

As expected by the nurseryman only 50% of the seed germinated, a feature that he considers may be due to a lack of mycorrhizal fungi in the fallowed soil (Figure 50). The inoculum was applied in January when sufficient second order lateral roots had developed (Figure 51).

Figure 50. Poor germination at Leithfield Nursery, January 2006.

Figure 51. The jet of inoculum exiting from the pressure sprayer excavated a hole in the soil that allowed the inoculum to be placed next to the roots.

11.2.1 *Results*

By January 2006 there was no observable effect from the phosphorus fertiliser applied at the start of the experiment. In mid April a representative sample of seedlings were collected from the trial. These were completely free of mycorrhizas although we would have expected them to have become well established by this stage. At this point we were told that the whole experiment had been sprayed with fungicide every 10 days as a preventative measure. Clearly this was a likely reason for the lack of mycorrhizal formation in the first year. In the second year mycorrhizas were found throughout the trial area.

12 *Nothofagus field trial*

An 0.5 hectare field trial was established at Gowan Hills, Southland were transplanted into a site at Gowan Hills, Southland, on 13 December 2006 with *N. menziesii* taken from the first ectomycorrhizal greenhouse trial at Oregon Nurseries (section 9.1). The layout of the trial was as shown in Figure 52 with 25 trees per square (5 x 5) and with a 2.8 m x 2.8 m spacing giving a total of 500 trees spread over 0.4 ha.

The site was a runout pasture with no ectomycorrhizal plants nearby. Each seedling was planted into an area 1 m x 0.5 m of bare, predominantly clay, subsoil low in organic matter that had been produced by turning over a scoop of soil using a digger bucket (Figure 53). It was highly therefore unlikely that there would have been any ectomycorrhizal fungal propagules capable of forming mycorrhizas with *Nothofagus*.

The seedlings were between 150 mm and 300 mm tall at planting. Blue squares were planted with trees from guard trays placed around the experiment 9.1 growing in standard Oregon Nurseries potting mix; green squares are plants raised by Oregon Nurseries; yellow squares contain two year old plants from the nursery; red squares are infected with inoculum 1, black squares with inoculum 2 and white squares were planted with uninoculated control plants from the experiment. However, because mycorrhizas had spread into the control plants in the greenhouse all the plants were mycorrhizal.

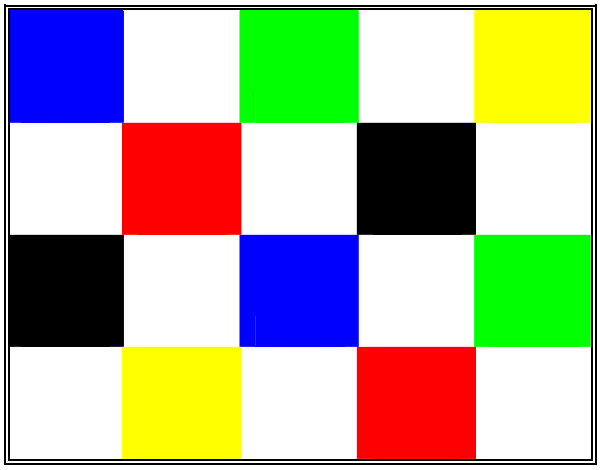


Figure 52. Layout of the Nothofagus field trial. Blue squares are uninoculated trees from guard trays; green squares are uninoculated trees raised by Oregon Nurseries; yellow squares two year old uninoculated trees from the nursery; red squares infected with inoculum 1; black squares inoculated with inoculum 2; white squares with uninoculated control plants from our experiment.

Figure 53. Each Nothofagus was planted into an area 1 m x 0.5 m of bare, predominantly clay, subsoil low in organic matter that had been produced by turning over a scoop of soil using a digger bucket.

12.1.1 Results

Herbicide was applied in spring 2007 in an attempt to suppress the flat weeds and grass close to the seedlings but this failed. On 30 January 2007 a small number of dead or poor plants were replaced. Despite a population of hares inside the experimental area (21 were killed in spring 2007) and winter deer depredation a very high percentage of the plants survived. However, because many had a poor growth form, the time it would have taken to correct plant shape and SFF management's disinterest in field trials we decided to abandon this trial.

Figure 54. Herbicides failed to control regrowth of the pasture.

13 Discussion and future prospects

Mycorrhizas were established on all of the species we worked with and in all of the experiments. This confirms that technology is available to ensure nurseries produce plants suited to difficult sites where suitable mycorrhizal fungi are either absent or poorly represented (section 4.3). In this respect this Sustainable Farming Fund sponsored work was an unqualified success.

We have developed the necessary skills and techniques to establish mycorrhizas in greenhouse based nurseries. What is now needed are demonstration field trials to test mycorrhizal and non-mycorrhizal plants after outplanting particularly onto difficult sites – something we were unable to do in the current study. This would be most effectively achieved by again working with Oregon Nurseries and ArborGen but this time producing commercial numbers of novel plantation timber species.

13.1 Use of fungicides and other nursery practices

In Finland, like other parts of the world, containerised plants have largely replaced bare rooted seedlings (Laatikainen 2004; Appendix 6). During their production, as in New Zealand, fungicides are applied routinely to control various fungal pests in particularly canker but at the cost of detrimental effects on mycorrhizal formation. Clearly, the control of serious diseases is essential but calendar spraying perhaps every 10 to 14 days because a problem *might* develop does not fit into the same category. Perhaps this should be discouraged for similar reasons that wholesale use of antibiotics for treating minor human ailments has been outlawed.

Other nursery practices such as the indiscriminate use of fertilisers to ensure plants reach, "questionable" minimum specifications set by industry within a timescale set by economic realities but resulting in poor mycorrhizal formation can also only be questioned. For *Pinus radiata*, which is almost promiscuous in the range of mycorrhizal fungi it can become involved with, a lack of adequate mycorrhizas seems not to be much of a problem and was certainly instrumental in its one time adoption as the only plantation timber species for New Zealand. However, for tree species that have much more specific mycorrhizal requirements a lack of mycorrhizas is likely to be much more important than arbitrary minimum plant size specifications perhaps adopted from those developed for radiata, i.e. arbitrary size requirements are being valued more than a known requirement for mycorrhizas.

The general lack of arbuscular mycorrhizal fungi on container-grown arbuscular mycorrhizal plants simply because it may be too difficult to achieve is not an excuse. How many people would be happy buying a new car without an engine and an instruction to pick one up down the road? This is in essence what mycorrhizas are for most plants. Legislation is probably not the answer but a realisation amongst nurseryman that mycorrhizas must be considered certainly is. Hopefully this report and other extension work we have carried out will help but we are sure that more is needed and recommend a series of workshops be held for the industry.

13.2 Dangers associated with the use of potentially contaminated inocula

The production of galls on *Corymbia* in our work perhaps caused by organisms introduced with the inoculum illustrates the potential downside of ensuring plants are mycorrhizal. Schwartz

and co-workers (2006) writing on the "promise and the potential consequences of the global transport of mycorrhizal fungal inoculum" made the following comments:

> "The intentional movement of mycorrhizal fungal species is growing, but the concomitant potential for negative ecological consequences of invasions by mycorrhizal fungi is poorly understood…. Invasive species problems are costly and often impossible to control by the time they are recognized. We recommend using local inoculum sources whenever possible. Non-sterile cultures of inoculum can result in the movement of saprobes and pathogens as well as mutualists.

However, a problem that was not stressed by Schwartz et al. relates to the potential movement of plant pathogens from a contaminated location *within* a country to another location that is not. For example, it would be very unwise to source mycorrhizal inocula from an area where a serious pathogen was present, for example, where *Phytophthora* is rife such as some of the kauri forests of Northland (e.g. Trounson Kauri Park; Beever, et al. 2007; Gill 2006; McKenzie et al. 2002). This is not a trite statement because in the past at least one mycorrhizal inoculum producer in the USA was forced out of business because the inoculum it produced was contaminated with *Phytophthora* that had probably entered the nursery through irrigation water. Similar concerns have been expressed regarding the global trade of edible mycorrhizal mushrooms and inocula (Hall & Zambonelli 2008).

We believe that the above problems could be solved easily and cheaply by using molecular testing for known pathogens in inocula.

13.3 Growth responses

In an artificial and very restricted environment like a Lannen cell, beneficial growth responses to mycorrhizas may or may not develop. This is well illustrated by our two redwood experiments. The one at ArborGen Nursery was the classic "big plant, little plant" experiment that have been published innumerable times in the past (Hall 1988; Appendix 5). In contrast, nutrients in the 3 month Osmocote, used in the potting mix in the Oregon Nursery experiment were quickly used up. Consequently, by the end of the 15 month experiment the most dominant factor was the lack of nutrients in the media rather than mycorrhizas - mycorrhizas cannot stimulate the uptake of nutrients and produce growth responses when nutrients are no longer in the substrate. Despite this after outplanting the hidden advantage of the mycorrhizal plant would again come into play.

14 Talks and publications to date

- 15 October 2005. Attend and answer questions at the alternative timber species field day on Dennis Hocking's property, (SFF grant 04/106 "Best practice with farm forestry timber species" www.maf.govt.nz/sff/about-projects/search/04-106/index.htm
- Article "Mycorrhizal inoculation in forest tree nurseries" for the New Zealand Tree Grower, November 2006 (Hall 2006).
- 13-15 April 2007. Talk on mycorrhizas in forestry plantations and edible fungi produced by some mycorrhizal fungi. NZ Tree Crops Association Conference, UNITEC, Auckland.
- 4 May 2007. Present an invited talk "Ectomycorrhizas, forestry practices and edible ectomycorrhizal mushrooms" at the annual conference of the Korean Society of Mycology (Hall & Perley 2007).
- 26 April 2007. Present talks at SFF project seminars, Balclutha.
- Article for the New Zealand Lifestyle Farmer magazine (Perley and Hall 2007).
- Korean interest in our programme led to a request that Ian Hall make 3 presentations on mycorrhizas in forestry: at the 2007 Annual Meeting of the Korean Society of Mycology (KSM), a special lecture at Chungnam National University hosted by Dr. Chang-Duck Koo, and an in-house lecture to the management of an R & D company on the Yonsei University campus in Seoul.
- Contribute to, supply photographs for and proof articles being prepared by Delwyn Dickey "Fabulous fungi and their tree companions" for the Rodney Times' Northern Focus and two articles written by Donna Russell.
- 19-22 July 2007, three talks combining the SFF work and Ian Hall's edible mycorrhizal mushroom projects were presented in Whangarei, Wellsford and Auckland. Press releases were made to the following papers: Rural Report, Northern Age, Bay Report, Bay Chronicle, Bream Bay News, The Whangarei Report, The Leader, Dargaville News, and Tangihua Times. These were funded by the Landcare Trust and written by Donna Russell. Delwyn Dickey is also writing three articles for the Rodney Times.[3]

[3] Farm Forestry initiated and supported the presentations, North Tech facilitated them by providing funding and the use of the Whangarei North Tec Lecture Theatre.

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16 Contact details of the participating companies

ArborGen Nursery, 1943 State Highway 30, Te Teko, RD2, Whakatane, Bay Of Plenty, New Zealand, 07-322 9030, 07-322 8451

Wade Cornell, Diversified Forests Ltd, 247 Forest Hill Road, Henderson, Auckland 1008, cornell@clear.net.nz

Ernslaw One, Tapanui, Cemetery Road, Tapanui, Southland, New Zealand, telephone 03-204 8061, fax 03-204 8067

Leithfield Nursery, R D 3, Wyndham, Southland, telephone, 03-206 6746, fax 03-

Malcolm Douglas and Associates, 37 Chain Hills Road, Dunedin, 03-489 3317

Oregon Nurseries Ltd, P.O. Box 384, Oamaru, Otago, New Zealand, telephone: 03-431 3627, Fax: 03-4313 657, 027-450 4605

Robin Hall Biostatistics, 233 Portobello Road, RD2, Dunedin, New Zealand, telephone 03-454 3574, 027-229 0283

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