loss declines after 10 years. From then on losses result from physical damage through fallen tree branches, especially if the forest is undergoing a general decline at the time. The seedlings on the wet sites face intense competition from other rimu and silver pine seedlings.

Planted rimu seedlings have a marked advantage in that they are initially equivalent in height to 10-year-old natural seedlings and then gain a respite from neighbouring root competition through the act of planting. These advantages allow a high proportion of seedlings to outgrow the competing vegetation and consequently survival rates are quite high at 85% after 17 years.

This soil cultivation during planting is probably the reason why no response could be attributed to soil disturbance from logging in the Saltwater trial. Even seedlings placed into undisturbed forest gain the effect of disturbance as a 20 x 20 x 20 cm sod of soil is inverted and mixed during planting.

The light response at Saltwater needs to be put into perspective. The shade categories used related only to competing ground vegetation, and seedlings classed as unshaded seedlings had an estimated 30% overhead shade because of the high forest alongside the haul lanes. Many of the planted seedlings at Ianthe and Wanganui are out in the open, as the original forest was clearcut. This may account for their slightly better growth performance than the Saltwater seedlings.

This data provides useful information needed for improved yield prediction models. The recorded growth estimate over 25 years of 4 cm/year and a survival of 22% provides a "rule of thumb" for natural rimu seedlings in lowland forest conditions. This suggests that it will take around 35 years for a rimu seedling to grow into sapling size (above 1.4 m height). By that time only 15% of seedlings will survive if the present trend continues. One can therefore forecast that there should be a minimum of 233 seedlings/ha present in the forest continuously to ensure that at least one seedling/ha/year becomes a sapling.

By contrast, planted rimu seedlings show considerably better growth and survival over the first 35 years. The Ianthe and Wanganui plantings are three times the height and many times the diameter of natural seedlings. Only 20 planted seedlings are needed to be present in the forest continuously to ensure one seedling/ha/year becomes a sapling.

Nonetheless, planting is used sparingly in Saltwater and Okarito Forests because the goals of sustainable management are not to alter the status or natural ecological processes of rimu in these lowland forests. No planting is done where natural seedlings are present. Elsewhere, three to five seedlings are placed in suitable sites in the vicinity of felled trees. No fertiliser is applied. The results observed at Ianthe support practical experience that chemical fertiliser application might be harmful to rimu seedlings in a natural forest environment.

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References

Foweraker , C.E. and F.E. Hutchinson. 1934: Report on investigations, Westland Forests 1928-1934. Unpublished report to New Zealand Forest Service.

Howard, A.F. and J. Valerio. 1992. A diameter class growth model for assessing sustainability of silvicultural prescriptions in natural tropical forests. Commonwealth Forestry Review Vol. 71 (3/4) No. 227: 171-177.

James, I.L. and D.A.Franklin. 1978. Recruitment, growth, and survival of rimu seedlings in selectively-logged terrace rimu forest. New Zealand Journal of Forestry Science Vol. 8(2): 207-212.

James, I.L. 1984. Supplementary Plantings in South Westland. New Zealand Forest Research Institute, "What's New" No.123.

James, I. L. 1992: Prescriptions for the Sustainable Management of Saltwater and Okarito Forests. Unpublished report for Timberlands West Coast Limited.

June, S.R. 1982: Ecological studies in the indigenous forests of North Westland, New Zealand. Unpublished Ph.D. thesis, University of Canterbury, Christchurch.

Wardle, P. 1963: The regeneration gap of New Zealand gymnosperms. New Zealand Journal of Botany 1:301 - 315.

Pine pitch canker – the threat to New Zealand

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Abstract

Pine pitch canker caused by the fungus Fusarium subglutinans f. sp. pini is a serious disease of many species of pine and has severely affected Pinus radiata in California since its discovery in 1986. The fungus, together with its bark beetle vectors, causes dieback, reduced growth, reduced timber quality due to stem deformation, reduced seed crops and tree mortality. A number of potential pathways for the entry of the pitch canker fungus into New Zealand are recognised. These are live plant material, Pinus seed, plant debris associated with used logging machinery and vehicles, timber used as wood packaging and insects known to transmit the disease in North America. There would be no climatic barriers to the fungus or to introduced vectors if they escaped the quarantine net. If the fungus were to become established in New Zealand its spread would probably be limited by the paucity of suitable resident insect vectors. Hylastes ater, Hylurgus ligniperda and Pineus laevis would be the most likely vectors of the disease. Airborne inoculum appears to play no part in disease spread in California but it is a major source of infection of Pinus species in the south-eastern United States. Its potential importance in New Zealand cannot be predicted.

Introduction

Pine pitch canker caused by the fungus *Fusarium subglutinans* f. sp. *pini* is a serious disease of many species of pine. It was first described (Hepting and Roth, 1946) on *Pinus virginiana, P. echinata* and *P. rigida* in North Carolina in the United States of America. In the following 15 years the known host range expanded as the disease was discovered in more of the south-eastern states of the USA, and considerable damage to pines was periodically reported, particularly in plantations and seed orchards of *P. elliottii* and *P. taeda* (Blakeslee and Oak, 1979; Kuhlman *et al.* 1982; Barrows-Broaddus and Dwinell, 1983). The disease was not seen on *Pinus radiata* until 1986 when the first record was noted in Santa Cruz County, California (McCain *et al.* 1987). Since then the disease has spread and become prevalent on *P. radiata* in most coastal counties of California (Correll *et al.* 1991; Storer *et al.* 1994; 1995).

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In addition to the USA, the pitch canker fungus has been recorded in Haiti (Berry and Hepting, 1959), Japan (Kobayashi and Murumoto, 1989), Mexico (Santos and Tovar, 1991), and South Africa (Viljoen *et al.* 1994). The source of these introductions is unknown but it is postulated that the fungus may have its origin in central America (A.J. Storer, pers. comm.).

The current list of susceptible species now includes 47 species of *Pinus*. Douglas-fir (*Pseudotsuga menziesii*) is the only recorded non-pine host (Storer *et al.* 1994), the only record being from a single site in California. Pitch canker has not been recorded elsewhere in Douglas-fir, although there are other locations where this species is growing in close proximity to badly diseased *P. radiata.*

All species of pines currently grown in plantations in New Zealand (*Pinus attenuata, P. contorta, P. elliottii, P. muricata, P. patula, P. ponderosa, P. radiata, P. radiata x attenuata, P. strobus* and *P. taeda*) have been found to be susceptible to pitch canker (Dwinell and Phelps, 1977; Storer *et al.* 1994; Viljoen *et al.* 1994). Current indications are that *P. radiata* could be the most susceptible of all pine species exposed to the pathogen to date.

The Disease

Symptoms

The fungus infects vegetative and reproductive plant parts of susceptible pine hosts of all ages. Shoots, branches, cones, seed, stems and exposed roots may all become infected. With the exception of seed, infected tissues become resin-soaked, developing a characteristic honey colour, and typically copious resin bleeding occurs at the point of initial infection (hence the common name of the disease, "resin", is referred to as "pitch" in North America). Stem infections often produce large quantities of resin which coats the bark and dribbles down the stem. First symptoms of infection are usually of needle discoloration, twig and branch flagging and dieback. Young trees (up to four years old) may, in addition to these characteristic symptoms, wilt and die following a single basal infection at soil level. Seedlings may develop root-rot and other symptoms indistinguishable from those caused by a range of common nursery soil pathogens.

To date infection of Douglas-fir has been characterised by twig dieback only, with swollen resinous tissue apparent at the infection point on the twigs (Storer *et al.* 1994).

Dispersal and spread

The fungus sporulates on some of the infected tissues, producing salmon-pink masses of asexual spores. In nature the sexual stage of the fungus has never been observed. Spores are dispersed by water splash and carried in air currents throughout the year in infected stands of trees (Blakeslee *et al.* 1978b; Correll *et al.* 1991; Kuhlman *et al.* 1982).

In the south-eastern states of the USA natural infection of wounds by air-borne spores was demonstrated by Kuhlman *et al.* (1982) in a study where 52% of wounded *P. elliottii* and *P. taeda* seedlings placed under infected trees in a seed orchard developed pitch canker. No infection was observed in the absence of wounds, whether experimentally-inflicted or of abiotic origin. Insects were also shown to play an important role in dissemination. Matthews (1962) recorded that cyclic outbreaks of the disease were associated with damage caused by tip moth (*Rhyacionia* spp.). The deodar weevil, *Pissodes nemorensis,* has frequently been found to be carrying the fungus in Florida and infection of pine seedlings has been clearly linked with the presence of artificially-contaminated weevils in laboratory studies (Blakeslee *et al.* 1978a).

By contrast, no association of the disease with either artificial wounding (Correll *et al.* 1991) or abiotic damage (Schultz and Gordon, unpublished data) has been observed in California, even in heavily infected *P. radiata* stands. In the south-west of the USA, insects are therefore considered to be the primary, if not the only, agents of transmission to *P. radiata.* Twig and cone beetles (four species of *Pityophthorus, Conophthorus radiatae* and *Ernobius punctulatus*; Hoover *et al.* 1995; 1996) are the main vectors. Bark beetles (*Ips* spp.) have been shown to transmit the fungus (Fox *et al.* 1990, 1991) and spittle bugs (*Aphrophora permutata*) may also be vectors (Storer *et al.* 1997b). The pathogen has been isolated from other insect pests of radiata pine but transmission has not been demonstrated (Fox *et al.* 1990, 1991; Storer and Dallara, 1992).

Figure 1: Multiple branch infections causing dieback throughout the crown of *Pinus radiata* at Monterey, California.

The pitch canker fungus has been isolated from the surface of *P. radiata* seed collected from healthy cones and both internally (where it can remain dormant until seed germination) and externally on living seeds from infected cones (Storer *et al.* 1997a). *F. subglutinans* f. sp. *pini* has been isolated from seedlings germinating from seed collected from cones on healthy branches (Storer *et al.* 1997a). Seed collections made from healthy trees within an infected area may thus carry dormant pitch canker and the presence of the fungus may not be detected until after seedlings are established in the nursery. *F. subglutinans* f. sp. *pini* can survive in soil and may infect seedlings at or just above the soil-line (Viljoen *et al.* 1994). It may also act as a typical root-infecting pathogen (Dwinell *et al.* 1985).

Effect of pine pitch canker

There have been numerous reports of the seriousness of the outbreak of pitch canker in radiata pine in California (McCain *et al.* 1987; Correll *et al.* 1991; Storer *et al.* 1994, 1995). Much of the literature reports the dramatic effect of the disease on urban and roadside trees. There were no records in the three remaining natural mainland stands until 1992 when the disease was found at Año Nuevo and Monterey (Storer *et al.* 1994). It was reported at Cambria in 1994 (Storer *et al.* 1995). Much of the *P. radiata* seed used for urban planting and in the Christmas tree industry in California is purchased from New Zealand (W. Libby and B. Lyon, pers. comm.). Estimates suggesting that 15% of the radiata pine population of California is resistant to the disease (Storer *et al.* 1995) were derived largely from urban and roadside plantings. A more recent analysis of long-term study plots has provided a revised figure of 3% resistance within the population (T. R. Gordon pers. comm.). Resistance is a quantitative trait with trees demonstrating a wide range of responses to infection and some probably sustaining little damage from the disease.

Individual trees may sustain crown infection for many years. Associated mortality of *P. radiata* follows girdling of the stem by one or more stem cankers and/or attack by bark beetles (*Ips* spp.). The beetles are strongly attracted to stressed trees, including those infected with pitch canker, and it is suggested (D. L.

Wood, A.J. Storer, pers. comm.) that death is usually caused by *Ips* spp. Young plants (up to four years old) may be killed by a single infection at ground level and in the apparent absence of insect attack (A. J. Storer, T. R. Gordon, pers. comm.). This form of infection is particularly common in the Christmas tree plantations near Los Angeles, but has also been observed in one-to-two-year-old regeneration in stands of older trees. Storer *et al.* (1994) commented that no fungicidal or insecticidal treatments were effective in controlling the disease.

In the south-eastern states of the USA limited outbreaks of pitch canker occurred between 1945 and 1973, primarily in stands of *P. elliottii* and *P. virginiana.* However in 1974 shoot dieback caused by the fungus reached epidemic proportions in Florida, Virginia and South Carolina (Blakeslee and Oak, 1979; Dwinell and Phelps, 1977), and disease levels remained high until 1979. The disease was a major problem in *P. elliottii* and *P. taeda* seed orchards (Kuhlman *et al.* 1982) where substantial losses in seed crops were incurred (Dwinell *et al.* 1985). Seedling mortality also occurred in pine nurseries (Barnard and Blakeslee, 1980). Although the 1974-79 epidemic subsided, pitch canker continued to be a problem. The volume of planted *P. elliottii* lost to the disease was estimated by Dwinell *et al.* (1985) to be 385,000 to 870,000 m^3 annually; 70-80% of the loss being caused by growth reduction rather than mortality. It was estimated that 2.5 to 3.4 million logs could not be used for solid timber products because of stem malformation. An outbreak of the disease in *P. taeda* seed orchards in Alabama in 1980 was associated with extensive hurricane damage to the trees. Wounds created by the winds were found to act as infection courts for the fungus (Kelley and Williams, 1982). Subsequent decline in disease levels was ascribed to the lack of wounds.

Figure 2: Resin flowing from the infection point down the stem of a young *Pinus radiata* at Monterey. Death of this tree will rapidly follow.

A reduction in pitch canker infection of terminals of *P. taeda* seedlings (and of shoot damage by pine tip moths — *Rhyacionia* spp.) was achieved in North Carolina by application of the systemic insecticide Carbofuran (Runion *et al.* 1993). The systemic fungicide Thiabendazole reduced the effect of *F. s. pini* on both naturally infected and inoculated *P. taeda* seedlings but only repeated foliar applications significantly lowered the percentage of terminals infected (Runion *et al.* 1993). The identification of resistance in the *P. elliottii* and *P. taeda* populations (Dwinell and Barrows-Broaddus, 1979; Kelley and Williams, 1982) has subsequently led to the use of resistant clones and a consequent reduction of disease levels.

The threat to New Zealand

Industrial forestry in New Zealand is based almost entirely on 1.3 million hectares of radiata pine (90.5% of the total forest plantation area). Douglas-fir and other exotic softwoods, many potentially susceptible to pitch canker, occupy a further 99,000 hectares (NZ Forest Owners' Association, 1996). The emergence, anywhere in the world, of a disease of radiata pine which has the potential to cause progressive dieback, stem cankering and mortality must be a cause for concern to New Zealand's forest industry.

Risk of entry

Five possible pathways by which the pitch canker fungus could enter New Zealand have been identified. These are live plant material, seed, timber and wood products, contaminated insects and vehicles and equipment (in particular, used cars, logging machinery and camping equipment).

Live plant material: Quarantine regulations ensure that the likelihood of entry of the fungus on live plant material (other than seed) via the proper channels is extremely remote.

Seed: All pine seed imported into New Zealand (with the exception of shipments with an International Phytosanitary Certificate endorsed that *F. subglutinans* f. sp. *pini* is not known to occur in the country where the seed was produced) is screened at the Forest Research Institute for seed-borne *Fusarium* spp. Because a sampling system is used, there is always a possibility that a consignment containing a small proportion of infected seeds could be accepted and that *F. subglutinans* f. sp. *pini* could thus become established in nursery stock. Seedling mortality caused by the pitch canker fungus has no distinctive characteristics to distinguish it from mortality caused by many other fungal pathogens, and is unlikely to be detected immediately.

Large quantities of Douglas-fir seed from Oregon have been imported into New Zealand in recent years. Results of *P. radiata* seed testing (Storer *et al.* 1997a) raise the possibility that Douglas-fir seed collected from a pitch canker area may carry the fungus even if the parent tree remains asymptomatic.

Although untested, it is possible that spores of the fungus are present on or in pollen (W. Libby, pers. comm.) and collections of pollen from pitch canker areas must also be regarded as potentially containing the pathogen.

Timber and wood products: No sawn timber of *P. radiata* is imported from the USA but the prevalence of pitch canker makes it likely that dead and dying trees may be utilised as dunnage, or other packing material. With the increase in radiata wood becoming available as dead and dying trees are removed there is an increased likelihood of such material being used for crates, pallets and dunnage. These could harbour insects carrying the fungus, or the fungus could be present in the wood if it was derived from stems with bole cankers.

Insects: Species of *Ernobius, Ips, Pissodes* and *Pityophthorus* (the insect genera vectoring the pitch canker fungus) are regularly intercepted by quarantine officers at New Zealand ports. Sources include North America (Forest Research Institute records).

Equipment and machinery: New Zealand receives many visitors from the northern hemisphere who carry their own camping equipment. This is likely to have been used in forested areas or in campsites surrounded by trees which are plantation species in New Zealand. Airport quarantine inspections of arriving passengers target footwear and camping equipment in the search for plant debris, insects and soil. Gadgil and Flint (1983) found that 74% of used tents carried some plant debris. Potentially pathogenic fungi were present on this debris and live insects were also found.

A large amount of plant material (including pine needles and twigs) enters the country in second-hand vehicles which are imported mainly from Japan (Forest Research Institute records). In view of the Japanese record of pitch canker this material poses a potential risk.

In recent years a variety of used logging equipment has been imported from North America. Considerable quantities of plant material and soil have been found in some of this machinery (Forest Research Institute records). Under Section 22 of the 1993 Biosecurity Act the New Zealand Ministry of Agriculture and Fisheries "Import Health Standard: Used Forestry Equipment" now requires inspection of all cavities in such equipment and removal of plant debris and soil. If deemed necessary, the machinery is completely stripped down.

Risk of establishment and spread of the fungus

In New Zealand species of *Pinus* susceptible to pitch canker are widely planted in commercial forests and in parks, reserves, gardens and shelterbelts. Many potential hosts can be found close to ports where contaminated plant material or insects are most likely to enter the country. The temperate climate of New Zealand is unlikely to hinder the establishment or spread of either insect vectors or the fungus.

Potential vectors in the New Zealand ecosystem: New Zealand does not have any twig or cone beetles, or shoot moths that infest pines. The bark beetles present (*Hylastes ater* and *Hylurgus ligniperda*) generally, though not entirely, feed on one-to-two-year-old trees. The pine adelgid *Pineus laevis* is, in light of the possibility that sapsuckers (spittle bugs) may be vectors of the fungus, a possible carrier of the disease. The paucity of suitable vectors would probably slow the spread of the pitch canker fungus in this country. (*Ips grandicollis* which has been present in Australia since the 1940s would probably be an effective vector in that country, but although reasonably regularly intercepted at New Zealand ports (originating from both Australia and North America) *I. grandicollis* has not become established in New Zealand.)

Damage caused by possums and kaka in the crowns of *P. radiata* could provide entry points for the fungus if airborne spores were to become an important source of infection in New Zealand.

Possible effect on plantation forests

The vulnerability of the forest estate in New Zealand is unknown. Consideration of the intensive selection pressure on *P. radiata* during the last 100 years together with information about infection of trees from New Zealand seed grown in California, suggests a high level of susceptibility in current plantation stock.

In New Zealand the paucity of potential vectors for the fungus, and of aggressive bark beetles, means that the disease would have considerably less effect on our *P. radiata* populations than it does in the USA. If, on the other hand, air-borne infection became as prevalent in New Zealand as it is in the south-eastern USA, the disease could result in serious loss of productivity.

Conclusion

There is reason to believe that pine pitch canker could become a serious disease of pine and possibly Douglas-fir plantations if it were introduced to New Zealand. The extent of its effect cannot be predicted accurately, but the best management strategy present is clearly exclusion through stringent quarantine measures.

References

Barnard, E.L. and G.M. Blakeslee. 1980: Pitch canker of slash pine seedlings: A new disease in forest tree nurseries. Plant Disease 64: 695-696.

Barrows-Broaddus, J. and L.D. Dwinell. 1983: Histopathology of *Fusarium moniliforme* var. *subglutinans* in Four Species of Southern Pines. Phytopathology 73: 882-889.

Barrows-Broaddus, J. and L.D. Dwinell. 1984: Variation in susceptibility to the pitch canker fungus among half-sib and full-sib families of virginia pine. Phytopathology 74: 438-444.

Berry, C.R. and G.H. Hepting. 1959: Pitch Canker of Southern pines. USDA Forest Pest Leaflet 35.

Blakeslee, G.M. and S.W. Oak. 1979: Significant mortality associated with pitch canker infection of slash pine in Florida. Plant Disease Reporter 63: 1023-1025.

Blakeslee, G.M., S.H. Kratka, R.A. Schmidt, and C.S. Moses. 1978: Natural associations of *Fusarium moniliforme* var. *subglutinans* with *Pissodes nemorensis.* (Abstr.) Phytopathology News 12:208.

Blakeslee, G.M., S.H. Kratka, R.A. Schmidt, and C.S. Moses. 1978a: Sporodochia of the pitch canker fungus (*Fusarium moniliforme* var. *subglutinans*) as found in diseased slash pine in Florida. Plant Disease Reporter 62: 656-657.

Correll, J.C., T.R. Gordon, A.H. McCain, J.W. Fox, C.S. Koehler, D.L. Wood, and M.E. Schultz. 1991: Pitch canker in California: pathogenicity, distribution and canker development on Monterey pine (*Pinus radiata*). Plant Disease 75: 676-682.

Dwinell, L.D. and J. Barrows-Broaddus. 1979: Susceptibility of half-sib families of slash and loblolly pine to the pitch canker fungus, *Fusarium moniliforme* var. *subglutinans.* (Abstr.) Phytopathology 69:527.

Dwinell, L.D. and W.R. Phelps. 1977: Pitch canker of slash pine in Florida. Journal of Forestry 75: 488-489.

Dwinell, L.D., J. Barrows-Broaddus, and E.G. Kuhlman. 1985: Pitch canker: A disease complex of southern pines. Plant Disease 69: 270-276.

Fox, J.W., D.L. Wood, and C.S. Koehler. 1990: Distribution and abundance of engraver beetles (Scolytidae: *Ips* spp.) on Monterey pines infected with pitch canker. The Canadian Entomologist 122: 1157-1166.

Fox, J.W., D.L. Wood and C.S. Koehler. 1991: Engraver beetles (Scolytidae: *Ips* spp.) as vectors of the pitch canker fungus, *Fusarium subglutinans.* The Canadian Entomologist 123: 1355-1367.

Gadgil, P.D. and T.N. FLint. 1983: Assessment of the risk of introduction of exotic forest insects and diseases with imported tents. New Zealand Journal of Forestry 28: 58-67.

Hepting, G.H. and E.R. Roth. 1946: Pitch canker, a new disease of some southern pines. Journal of Forestry 44:742-744.

Hoover, K., D.L. Wood, J.W. Fox, and W.E. Bros. 1995: Quantitative and seasonal association of the pitch canker fungus, *Fusarium subglutinans* f. sp. *pini,* with *Conophthorus radiatae* (Coleoptera: Scolytidae) and *Ernobius punctulatus* (Coleoptera: Anobiidae) which infest *Pinus radiata.* The Canadian Entomologist 127: 79-91.

Hoover, K., D.L. Wood, A.J. Storer, J.W. Fox, and W.E. Bros. 1996: Transmission of the pitch canker fungus, *Fusarium subglutinans* f. sp. *pini,* to Monterey pine, *Pinus radiata,* by cone and twig infesting beetles. The Canadian Entomologist. 128: 981-994.

Kelley, W.D. and J.C. WIlliams. 1982: Incidence of pitch canker among clones of loblolly pine in seed orchards. Plant Disease 66: 1171-1173.

Kobayashi, T. and M. Muramoto. 1989: Pitch canker of *Pinus luchuensis*, a new disease in Japanese forests. Forest Pests 38: 2-6.

Kuhlman, E.G., S.D. Dianis, and T.K. Smith. 1982: Epidemiology of pitch canker disease in a loblolly pine seed orchard in North Carolina. Phytopathology 72: 1212-1216.

McCain, A.H., C.S. Koehler, and S.A. Tjosvold. 1987: Pitch canker threatens California pines. Californian Agriculture 41: 22-23.

Matthews, F.R. 1962: Pitch canker — tip moth association on slash pine seedlings. Journal of Forestry 60: 825-826.
New Zealand Forest Owners' Association/Ministry of Forestry 1996: NZ Forestry Facts and Figures. 22 pp.
Runion, G.B., S.C. Cade, and R.I. Bruck. 1993: Effects of carbofuran and thiabendazole on incidence of pitch canker of loblolly pine. Plant Disease 77: 166-169.
Santos, J.J.G. and D.B. Tovar. 1991: Algunos aspectos sobre el cancro resinoso de los pinos. (Abstr.) VI Simposio Nacional Sobre Parasitologia Forestal. Unidad de Congresos del Colegio de Postgraduatos Montecillos.
Storer, A.J. and P.L. Dallara. 1992: Pitch canker disease in California. Californian Department of Forestry and Fire Protection, Tree Note No. 15. 2 pp.
Storer, A.J., T.R. Gordon, P.L. Dallara, and D.L. Wood. 1994: Pitch canker kills pines, spreads to new species and regions. California Agriculture 48:9-13.
Storer, A.J., T.R. Gordon, D.L. Wood, and P. Bonello. 1997a. Current and future impacts of pitch canker disease of pines. Journal of Forestry. In Press.
Storer, A.J., T.R. Gordon, D.L. Wood, and P.L. Dallara. 1995: Entomological and pathological aspects of pitch canker disease in California. In: Hain, F.P., Salom, S.M., Ravlin, W.F., Payne, T.L. and Raffa, K.F. (eds.) Proceedings of a Joint IUFRO Working Party Conference, Maui, Hawaii, February 6-11, 1994, pp 573-586.
Storer, A.J., K. Wilker, W.R. McNee, D. Cibrian Tovar, T.R. Gordon, and D.L. Wood. 1997b. Recent Research Progress on Pitch Canker Disease. In Adams, David H., and Rios, Jesse E. (eds.) Proceedings, 45th Annual Meeting of the California Forest Pest Council, November, 1996. California Department of Forestry and Fire Protection, 1416 Ninth Street, Sacramento, CA 95814. In Press.
Storer, A.J., T.R. Gordon, D.L. Wood, and P.L. Dallara. 1995: Pitch canker in California. California Forestry Note No. 110 16 pp.
Viljoen, A., M.J. Wingfield, and W.F.O. Marascas. 1994: First report of *Fusarium subglutinans* f. sp. *pini* on pine seedlings in South Africa. Plant Disease 78: 309-312.

Soil impacts of afforestation in the high country

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Abstract

Afforestation of South Island high-country grassland soils with exotic conifer species influences the amounts of plant nutrients in topsoils, nutrient availability and soil acidity. The effects are dependent on soil type and tree stand age. Under young stands levels of total nitrogen (N) and phosphorus (P) and Bray-2 extractable potassium (K) and magnesium (Mg) are generally lower than under adjoining grasslands – an effect attributed to greater nutrient uptake by trees. Under older stands total N and P and extractable cation levels are sometimes lower, but may be similar or higher than under grassland. Afforestation stimulates mineralisation of organic matter in topsoils, leading to increased levels of mineralisable (potentially available) N and of sulphate sulphur (S) in hygrous high-country yellow-brown earth soils, and to increased availability of P in all soil groups examined. Under mature pine stands on drier Mackenzie Basin soils mineralisable N is commonly lower than under grassland. Vegetation growing under young pine stands prior to canopy closure contains markedly higher concentrations of N, P, and S in foliage than similar vegetation in adjoining unplanted grassland. Such vegetation may also contain higher concentrations of K and Mg, which is not consistent with results of soil analyses. Soil pH is reduced by afforestation. Productivity of pasture established after harvest of plantations at three sites was found to be 1.5 to 14 times greater than that in adjoining grassland.

Access to organically bound nutrients means that growth of conifers is less likely than pasture growth to be limited by N, P or S supply. Improved availability of nutrients to understorey species may increase the potential for grazing in high-country forests.

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[2] *Soil chemical analyses were as follows:*
Total P: P extracted in sulphuric acid after ignition of the soil at 550°C
Inorganic P: P extracted in sulphuric acid without ignition of the soil
Organic P: The difference between total and inorganic P
Olsen P (=plant available P): P extracted in alkaline sodium bicarbonate
Total N: N extracted by Kjeldahl digestion (boiling sulphuric acid)
Mineralisable N (=potentially available N): N extracted in potassium chloride after aerobic incubation of samples in the laboratory
Sulphate S (=available S): S extracted in potassium phosphate
Bray-2 K, Ca, and Mg: Cations extracted by the Bray-2 reagent (hydrochloric acid and ammonium fluoride)

Introduction

Annual productivity of unimproved South Island high-country pastoral grasslands is low, often around 0.1 – 2 t dry matter/ha (O'Connor, 1966; Sinclair and McIntosh, 1983; Scott *et al.* 1985). Productivity of grasslands can be greatly increased with the use of fertilisers. On the other hand, pines (*Pinus* spp.) and other conifers, notably larch (*Larix* spp.) and Douglas-fir (*Pseudotsuga menziesii*), are capable of rapid early growth and high productivity in the absence of fertiliser once they have achieved canopy closure. For example, Nordmeyer and Ledgard (1993) found that total above-ground annual production levels in 15-year-old stands of larch, *Pinus ponderosa, P. nigra,* and Douglas-fir at a montane site in Canterbury ranged between 15 and 24 t dry matter/ha. Coupled with this high productivity, vegetation in the immediate vicinity of young conifers often appears more vigorous than similar vegetation in nearby unplanted grassland. This paper reviews studies on the impact of afforestation on chemical properties of high-country topsoils, and presents new information on productivity of grassland after a rotation of pines. Possible mechanisms for increased nutrient availability in soils under conifers are discussed.

Soil chemistry under conifers and grassland

Influence of afforestation on soil nutrients

The first indication that conifers may influence nutrient availability in high-country soils came from a survey by Ledgard and Belton (1985) of productivity of conifers (mainly pines) growing in woodlots on farms in the Canterbury high country. Analyses[2] of topsoil samples collected under the stands showed levels of inorganic P to be higher than those normally found under unimproved grassland in soils of the same groups in the region. The samples were subsequently re-analysed using the Olsen extractant, commonly used in agriculture as a measure of plant-available P, to allow comparison with a wider range of existing grassland data (O'Connor 1986; Belton *et al.* 1995). Over a range of terrace, fan, and downland terrain, Olsen P levels were found to be consistently two to four times higher in soils under the conifers than in those under grasslands in the region (Table 1).

Further analysis of topsoil samples collected in the Canterbury and Otago high country from pine stands paired with