IMPACT OF *ARMILLARIA* ROOT ROT IN PLANTATIONS OF *PINUS RADIATA* ESTABLISHED ON SITES CONVERTED FROM INDIGENOUS FOREST

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ABSTRACT

Armillaria root rot, caused by either **Armillariella novae-zelandiae** or **A. limonea**, is the most damaging disease in **Pinus radiata** established on sites freshly cleared of indigenous forest by felling and burning. The incidence is related to the composition of the former indigenous cover. Pine planted on sites occupied mainly by **Beilschmiedia tawa**, **Dacrydium cupressinum**, mixed hardwoods, **Weinmannia racemosa** and **Nothofagus** spp. suffered, respectively, 27%, 19%, 16%, 11% and 5% mortality after 2 years. The mortality was distinctly grouped and may leave by age 6 nearly one-third of the planted area as basically productionless openings surrounded by dead and dying trees. In two severely diseased stands, 15% and 16% of the remaining live trees were infected to a degree shown to significantly reduce diameter growth. This growth reduction is compounded when the trees are also heavily infected with **Dothistroma** needle blight. A financial analysis indicated that, on a severely affected site, disease increased growing costs (break-even stumpage) by 43% in a 15- or 21-year pulpwood rotation and 37% in a 26-year sawlog rotation. Using a 10% discount rate, the amount that could be spent (without increasing the growing costs) on a hypothetical disease control procedure involving root and stump removal during site preparation, was estimated by assuming various improvements in yield. The model indicated that if control achieved a 60% reduction in disease losses then a maximum control cost of $167/ha, $163/ha and $135/ha was theoretically justified in a 15-year pulpwood, 21-year pulpwood, and a 26-year sawlog rotation, respectively.

INTRODUCTION

Armillaria root rot occurs on many hosts in the indigenous and exotic forests of New Zealand (Gilmour, 1966; Dingley, 1969). This report discusses the fungi involved and the effects of the disease in *Pinus radiata* D. Don established on sites freshly converted to pine from indigenous forest. A financial model of disease impact is developed along with hypothetical benefits that may result from a potential control scheme.

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The Fungus

Nomenclature of the fungus is not clear. Here we follow Gibson (1975) and term the disease caused by species of *Armillariella, Armillaria* root rot. *Armillariella novae-zelandiae* Stevenson and *A. limonea* Stevenson, have been described in New Zealand. At least one other undescribed species probably occurs as well (Shaw, unpubl.; Taylor, pers. comm.). Stevenson (1964) also notes the presence of *A. mellea* (Vahl ex Fr.) Karst. in New Zealand plantations, but the senior author has not observed *A. mellea, sensu strica,* in New Zealand forests. Earlier disease reports (Gilmour, 1966; Dingley, 1969) combined all accounts under *A. mellea, sensu lato.* Photographs of sporophores in Gilmour's (1954) report, titled with *A. mellea,* appear to be *A. novae-zelandiae.*

MacKenzie and Shaw (1977) found sporophores of *A. novae-zelandiae* and *A. limonea,* separate and together, on stumps of several species of native trees. However, mortality of *P. radiata* seedlings was most common near stumps of *Beilschmiedia tawa* (A. Cunn.) Benth et Hook (tawa) that had borne sporophores of *A. novae-zelandiae* only. *A. novae-zelandiae,* but not *A. limonea,* has been observed fruiting on killed seedlings of *P. radiata.*

Pathogenicity tests are now in progress; isolates of both species as well as unidentified isolates from Southland and Westland have killed seedlings of *P. radiata.* Both *A. novae-zelandiae* and *A. limonea* have infected 4-year-old *P. radiata* inoculated at the root collar. Both species produce rhizomorphs prolifically.

THE DISEASE

Armillaria root rot is consistently troublesome where *P. radiata* is established on sites freshly cleared of certain indigenous forest types. Gibson (1960) made a similar observation in exotic pine plantations in Kenya. Beveridge (1973, 1974; Beveridge *et al.,* 1973) viewed the disease as serious in *P. radiata* established on sites cleared of cutover podocarp/tawa forest. As 162 000 ha (30%) of the new land to be afforested in New Zealand by the year 2000 is classified as logged indigenous forest (Chavasse, 1969), there is reason for concern with respect to future damage.

Mortality Levels

Data on mortality of *P. radiata* caused by *Armillaria* root rot over the spectrum of vegetation types that have been planted are sparse, but appear to show differences with the composition of the previous cover (Fig. 1). Mortality was highest, 27% after 2 years, on an area previously covered by nearly pure tawa (site 1), and second highest (19% after 2 years) on site 2, which was formerly covered mainly with large, old-growth rimu (*Dacrydium cupressinum* Lamb.). However, some of the mortality in this plot was spatially related to the few tawa stumps present. Site 4, adjacent to 1 and covered mainly by *Weinmannia racemosa* Linn f. and a scattering of tawa, had only 11% mortality after 2 years. This difference between sites 1 and 4 suggests that abrupt changes in the level of *Armillaria*-caused mortality that occur in some pine plantations may reflect variations in the former indigenous cover. Site 3, a mixed hardwood type showing intermediate damage (16% after 2 years) is described by MacKenzie and Shaw (1977). The low mortality level (5% after 2 years) on site 5, a *Nothofagus* type in Westland, was surprising as localised higher levels have been reported from similar sites (FRI records). Further descriptions of these sites are given in Fig. 1.

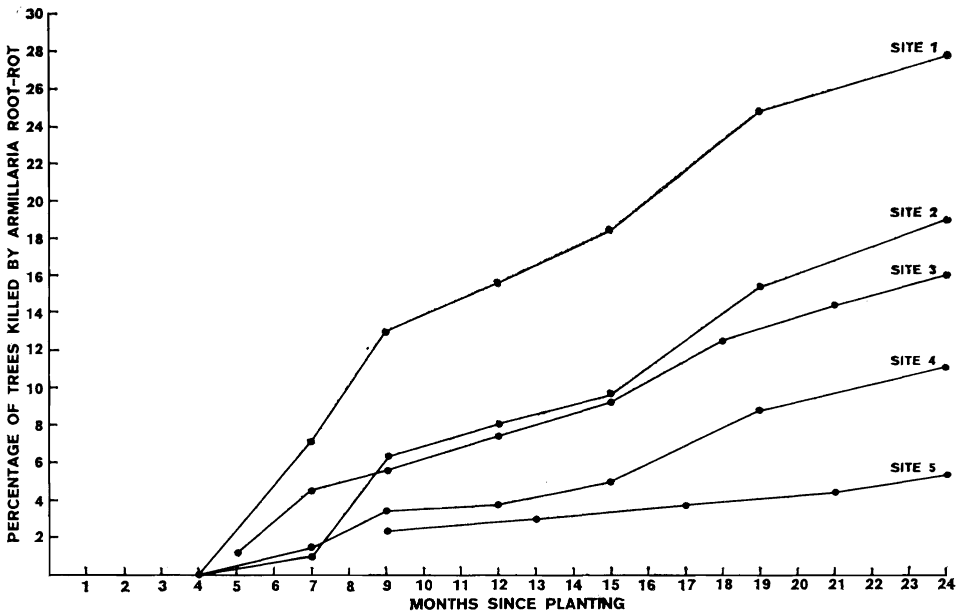


FIG. 1—**Armillaria**-caused mortality of **Pinus radiata** established directly following clearing through felling and burning on five different types of indigenous forest. Site 1 was off Leslie Road in the Mamaku Plateau on an area formerly occupied by high density tawa. The plot was planted at 1 × 1 m spacing (2,490 trees) in July 1975. Site 2 was adjacent to the Pukerimu stream off McPherson Road in the Mamaku Plateau on an area formerly occupied mainly with large, old-growth rimu. The plot was planted at 1 × 1 m spacing (2,398 trees) in July 1975. Site 3 was off Tunnel Road in the Mamaku Plateau on an area formerly occupied by mixed hardwoods with approximately 50% tawa. The plot was planted at 1 × 1 m spacing (3,597 trees) in July 1974 and is thoroughly described in MacKenzie and Shaw (1977). Site 4 is adjacent to site 1, but on an area occupied mainly by **W. racemosa**. The plot was planted at 1.8 × 2.4 m spacing (538 trees) in July 1975. Site 5 is off Donaldson's Creek Road, Wawhere SF Cpt. 63, Westland, on an area formerly occupied by high density **Nothofagus** spp. Two plots were planted at 1 × 1 m spacing (4,499 trees) in June 1975. All plots were examined at intervals of approximately 3 months with dead trees removed and the cause of death (**Armillaria** root rot or other agency) determined as described by MacKenzie and Shaw (1977).

Armillaria mortality has been noted, but not quantified, in *P. radiata* established on former podocarp and beech sites in Southland. *P. radiata* established after felling *P. ponderosa* Laws., known to have a high incidence of *Armillaria* root rot (Gilmour, pers. comm.), showed only 5% *Armillaria*-caused mortality 4 years after establishment. Second rotation pine plantations, in fact, appear to be less damaged by the disease than plantations on cutover indigenous sites.

Beveridge *et al.* (1973) noted that *P. radiata* plantations on former podocarp/tawa forest types frequently have 40% to 50% total mortality by age 5 with the greatest proportion due to *Armillaria* root rot. Mortality from *Armillaria* root rot in an 86 ha *P. radiata* stand established on a former podocarp/tawa site at Pureora State Forest was

36% after 6 years (Auckland Conservancy and FRI records). This level is undoubtedly an undercounting as records were commenced at age 1 and appreciable mortality occurs before this time (Fig. 1). The highest disease-caused mortality observed by the senior author in *P. radiata,* 33% after 2 years, was in a stand at Pureora immediately adjacent to the above.

The distribution of root rot is most troublesome for management. Measurements with a dot grid of the above-mentioned 6-year-old stand at Pureora (Fig. 2) showed that 30% of the area consisted of basically productionless, root-rot-caused openings surrounded by dead and dying trees. An additional 20% of the stand was in openings from roads, frostflats, and other causes.

Disease-caused openings fill with shrub hardwoods, making access difficult and increasing the time required for tending operations. Knowles (1973) showed that walking time from tree to tree for pruning in a patchy, diseased stand was one-third greater than in a stand clear of understory shrubs. Thinning and pruning may also be more complex as the stand consists of dense groups requiring substantial treatment and widely spaced, difficult-to-reach individuals.

In addition to high mortality levels in the early years of stand development, disease losses continue after initial crop tree selection. Four percent of the potential crop trees in one *P. radiata* stand on a former podocarp/tawa site died from root rot in the 2 years following initial thinning at age 5 (Beveridge, 1974). We remeasured this stand after a subsequent thinning and found 2.7% of the remaining potential crop trees died in the 10th year alone.

In older stands, part of the mortality is from infected trees breaking off at the root collar (Fig. 3). Broken trees do not, however, have extensive trunk rot as has been described for *Armillaria* root rot in some conifers (Peace, 1962). Loss after thinning is critical as each stem is a presumed component of the final crop.

Sublethal Effects

Shaw and Toes (1977) showed that open growing, 10-year-old *P. radiata* with more than 65% of their root collar circumference infected with *Armillaria* root rot grew 14-24% slower than healthy trees. Potentially 15% of the selected crop trees in the stand they studied had growth-retarding infections.

In the stand shown in Fig. 2, 300 living trees on random offset lines of 15 trees

FIG. 2 (right)—Six-year-old stand of **Pinus radiata** at Pureora State Forest severely affected by **Armillaria** root rot. The nearly treeless openings in the lower foreground, far left, and upper centre are due mainly to causes other than **Armillaria** root rot. The brown-foliated crowns and openings throughout the rest of the stand are due to **Armillaria** root rot. The densely stocked area left centre, is mostly unaffected by disease and represents normal, expected stocking. Measurements from similar photographs with a dot grid (10 dots/cm^2) for the entire 86 ha stand showed that 30% of the area was so severely affected by disease that basically productionless openings resulted. Approximately 20% of the stand was out of production due to other causes (frost flats, roads, unplanted faces). Scale approximately 1 : 3200.

each were examined at age 5 for *Armillariella* infections at the root collar. Thirty-three percent of the trees were infected, with 48% of these stems having greater than 60% of their root collar circumference infected. Thus, a portion of the trees that survive attack are infected to a degree that may result in a significant growth reduction.

Controlling needle blight, caused by *Dothistroma pini* Hulbary, in stands of *P. radiata*

heavily infested with *Armillaria* root rot is important. Eight-year-old *P. radiata* heavily infected with both *Armillaria* root rot and *Dothistroma* needle blight had a growth reduction, 55% after 47 weeks, that was greater than the additive effect of the two diseases alone (Shaw and Toes, 1977).

FINANCIAL CONSIDERATIONS

From the above effects of *Armillaria* root rot in plantations of *P. radiata,* estimates have been made of the amount disease adds to the cost of growing wood. A hypothetical stand established on a site cleared of high-density tawa by conventional felling and burning was used as a model. Disease was treated as being either present or absent. Costs in a 15-year pulpwood, 21-year pulpwood, and 26-year sawlog rotation were updated from Fraser and Walker (1973). The sawlog regime is based on Fenton (1972) and the pulpwood regimes are modified from James (1975). The Kaingaroa growth model was applied (Elliot and Goulding, 1976; Shirley, 1976) assuming a site index of 95. A nominal value of $1.00/m³ was assigned to wood yields for the purpose of calculating growing costs. Calculations were independent of stand area.

The stands were planted in a single year and felled in a single year. This simplified approach was considered adequate for evaluating the relativity of growing cost with and without disease and the cost-benefit of a theoretical control. The analysis is from the standpoint of the New Zealand Forest Service. Thus, a 10% discount rate, the rate for new government projects, was used and land values, tax concessions, and forestry encouragement grants were excluded.

Effects of disease were accounted for in two ways: (1) The area planted was considered reduced by 30% because of the pattern of disease-caused mortality. For the sawlog regime the area loss was reduced to 25% as wider spacing and the longer rotation should accommodate some of the smaller stand openings. These figures are probably conservative as they are based on the disease-caused openings in a 6-year-old stand (Fig. 2) and the openings increase in size with time (MacKenzie and Shaw, 1977). (2) A diameter growth reduction of 14% p.a. on 15% of the stems from age 10 to 20 (10 to harvest, for the short pulpwood rotation). No account was taken for the possible degrade of sawlog quality on surviving, open-grown stems on the margins of openings. Nor were the possible higher logging costs in handling a smaller average piece size from the disease area considered. In all regimes, a 10% gross volume reduction was included for losses from causes other than *Armillaria* root rot.

Costs, yields, and calculations for the growing costs with and without disease are given in the Appendix. In only two operations were different (marginally lower) costs assigned because of the presence of disease: (1) Thinning-to-waste was considered less costly in the diseased stand because of the smaller proportion of stems requiring treatment (the actual increase in walking time discussed above was considered offset by the 30% area that was lost to production and thus not treated); (2) road maintenance was less costly because of the reduced volumes carted from diseased stands.

Table 1 summarises the volumes produced, discounted costs and revenue, and growing costs for the three regimes with and without disease. Disease increased growing costs (break-even stumpage) by 43% in the pulpwood regimes and 37% in the sawlog regime.

FIG. 3—Ten-year-old **Pinus radiata,** snapped off at the root collar. The tree was severely affected by **Armillaria** root rot showing symptoms and signs of infection around the entire root collar. These fallen trees do not have extensive butt rot.

FIG. 4—Bulldozer clearing indigenous cutover bush for establishment of **P. radiata**. Such stump and root removal should substantially reduce the normally high losses to **Armillaria** root rot that are characteristics of **P. radiata** established on certain indigenous cutover sites cleared by felling and burning without further site disturbance.

TABLE 1—Volumes, discounted costs, and growing costs for the three regimes, with and without disease[1]

Regime	Volume m^3/ha	Total discounted cost $/ha	[2]Total discounted revenue $/ha	[3]Growing cost $/m^3$
Pulpwood:				
Clearfell 15				
without disease	224	614.48	48.75	12.60
with disease	153	600.20	33.30	18.02
Clearfell 21				
without disease	446	609.21	54.79	11.12
with disease	307	600.00	37.71	15.91
Sawlog:				
Clearfell 26				
without disease	501[4]	572.27	38.22	14.97
with disease	357[5]	557.78	27.23	20.48

1 10% interest rate, land values not included.
2 Wood nominally valued at $1/m^3$ to facilitate calculation of growing cost.
3 Equivalent to break-even stumpage.
4 Includes 25 m^3/ha of pulpwood.
5 Includes 18 m^3/ha of pulpwood.

DISCUSSION

Roughly 20 000 ha of podocarp/tawa forest in the central North Island have been or are committed to being converted to *P. radiata* (A. E. Beveridge, pers. comm.). Much of this land is on the Mamaku Plateau and has largely been converted within the last 6 years. An additional 40 000 ha of similar land in state and private ownership in the central North Island is under consideration for conversion to exotics, mainly *P. radiata.* With the potential for substantial losses from disease on large tracts of land, control possibilities need to be considered.

Two reasonable approaches to control in these circumstances are: (1) avoidance of plantation establishment on sites with a high disease potential; (2) reduction of inoculum levels on disease-prone areas during site preparation:

The first approach assumes that alternative land with a low disease hazard is available. While such land (marginal farmland, scrub, and tussock) may exist, it is doubtful that there is enough near established mills to meet planned future expansion by both state and private forestry. Had land values been included in the financial analysis of disease impact (Table 1), growing costs would have been even higher. The purchase price for an alternative land source would likely be higher than cutover indigenous forest; could not part of this cost difference be assigned for disease control and production improvement on the latter sites?

The second approach involves more thorough site preparation techniques that dislodge and remove substantial quantities of stumps and roots (Fig. 4). As Pawsey (1973) noted, "there is no doubt whatever that the infection potential of *Armillaria mellea* on any site is reduced most effectively by the complete removal of all substrate sources in the soil." While quantitative data to support control through inoculum removal are admittedly sparse, the concept serves as the basis for most control recommendations (McGillivray, 1946; Sokolov, 1964; Morrison, 1976; Roth *et al.,* 1977). In New Zealand, initial results suggest that more thorough site preparation will reduce disease losses. Mortality from *Armillaria* root rot in *P. radiata* planted 2 years previously on sites formerly covered with high density tawa (Pureora S.F.) was 33% on a site cleared by conventional felling and burning, and 15% on a site prepared by stump and root removal similar to, but not as thorough as, that depicted in Fig. 4 (Shaw, unpubl.). In addition, the conventially cleared site had 17% mortality due to other causes (50% total in 2 years) while the site with root and stump removal had only 9% loss to other causes (24% total after 2 years). This overall improvement of survival suggests that disturbance through stump and root removal may also be beneficial to general seedling vigor, a finding consistent with other reports (Queensland Dept. of Forestry 1972; Sorochkin, 1972).

A main challenge with disease control by root and stump removal is to balance the quantity of inoculum that must be removed to halt disease with the economic cost of removal that can be justified by the crop's future value. Figure 5 was drawn using costs, revenues, and volumes in the financial analysis. The diagonal lines in the chart are hypothetical yields (m^3/ha) obtainable through stump and root removal during site preparation (year 0). As all costs were discounted to year 0, disease control costs can be added directly to the total discounted costs. The difference in total discounted costs with and without the stump and root removal operation (abscissa, Fig. 5) is the cost of control. The cross-over point of a diagonal volume line and the horizontal growing cost line represents the maximum amount that can be spent on a control yielding that volume, without increasing the growing costs. For example, in the 15-year pulpwood regime up to $184/ha can be spent on site improvement operations without increasing the growing cost above $18.02/$m^3$ (Table 1) if the volume is increased from 153 m^3/ha with no disease control (Table 1) to 200 m^3/ha with control.

The family of volume lines are presented because the actual effectiveness of the control procedure in increasing yields is presently unknown. Trials are now in progress to determine the level of root rot control achievable through root and stump removal during site preparation. The present costs of these operations on indigenous cutover sites, where terrain permits heavy machinery to operate (Fig. 4), are around $120-$140/ha. Thus, to be economically feasible, from our analysis, the practice should increase yield by at least 50 to 60% of the difference between the theoretical maximum volume without disease and the predicted volume with disease (Table 1). From Fig. 5 a 60% improvement (at a discount rate of 10 percent) theoretically* justifies a maximum control cost of $167/ha, $163/ha. and $135/ha for the 15-year, 21-year, and 26-year rotations, respectively. These figures do not include the additional benefits that may

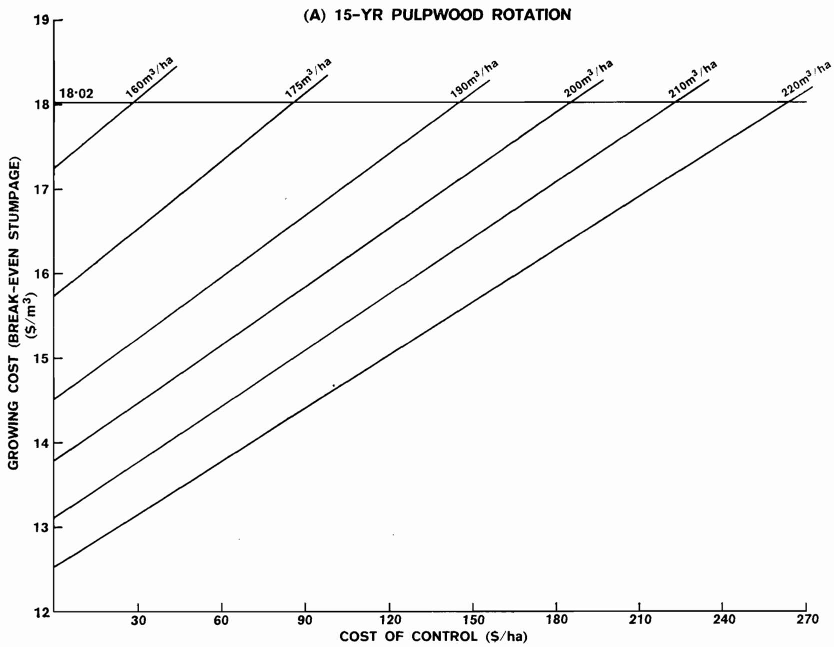
* These calculations do not imply that the wood costs are realistic in market terms.

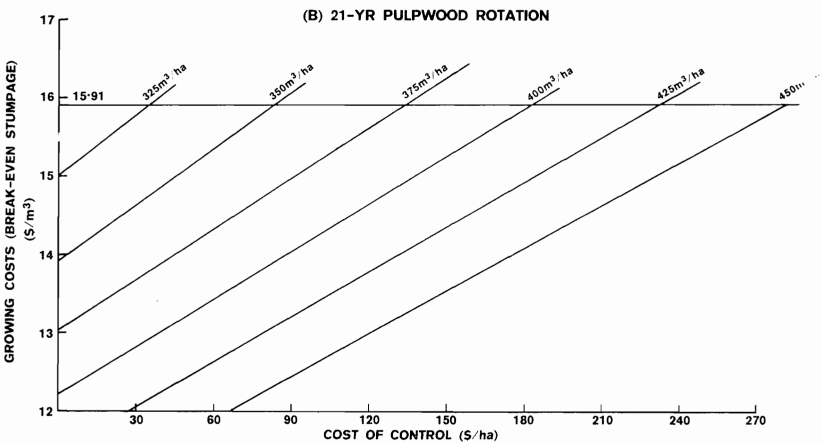
accrue through reduced planting costs and the possible carryover benefit of the initial site preparation into the second rotation.

We suggest that on certain central North Island sites this financially required level of disease reduction may be achieved.

CONCLUSIONS

Few of the many previous recommendations for control of *Armillaria* root rot through inoculum reduction have attempted to financially analyse the procedure. Hopefully, these data on disease impact and the financial model provide a base from which to make decisions concerning establishment and disease control in plantations likely to suffer from *Armillaria* root rot.





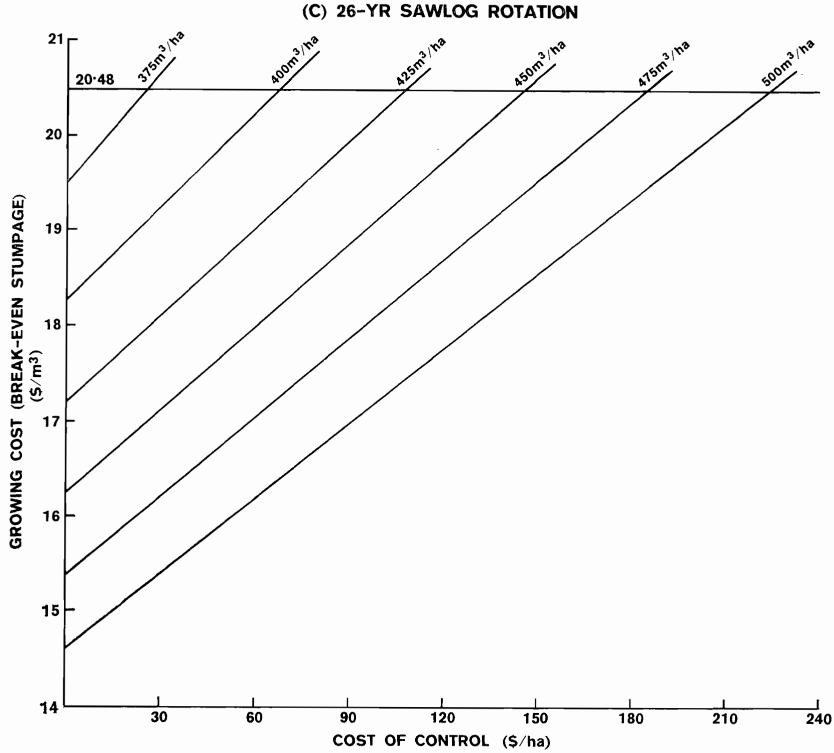


FIG. 5—Chart to determine the maximum amount that can be spent on more thorough site preparation to reduce losses to **Armillaria** root rot. Horizontal lines represent the growing cost with disease for the 15-year (A), 21-year (B), and 26-year (C) rotations, respectively (Table 1). The volume lines were determined by calculating a new discounted revenue derived from that volume, and increasing the discounted costs in increments to calculate a new growing cost (total discounted costs divided by total discounted revenue). Abscissa values are the difference between total discounted cost with disease (Table 1) and total discounted cost plus an additional cost due to the increased site preparation expenses.

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APPENDIX—Financial analyses, with and without *Armillaria* root rot, for a 15-year pulpwood, 21-year pulpwood, and 26-year saw log rotation of *P. radiata* established by clearing and burning an indigenous cutover site with a high component of tawa. Pulpwood regimes are modified from James (1975) and the saw log regime from Fenton (1972).

Financial analysis (excluding land value and using an interest rate of 10%) for a pulpwood regime of **Pinus radiata** with or without **Armillaria** root rot, clearfelled at 15 years

Operation	Year	Without disease $/ha Cost (actual)	Without disease $/ha Cost (discounted)	Affected by disease $/ha (actual)	Affected by disease $/ha (discounted)
Felling standing trees		155.00		155.00	
Felling light bush		100.00		100.00	
Formation Road		120.00		120.00	
Cost		—375.00		—375.00	
Harvesting tawa revenue		+207.50		+207.50	
	0	—167.50	—167.50	—167.50	—167.50
Firebreaks		6.35		6.35	
Dessication		30.00		30.00	
Burning		30.00		30.00	
Release spray thistles		14.71		14.71	
Plants (1530 stems/ha)		45.90		45.90	
Planting (1530 stems/ha)		64.64		64.64	
Delivery plants		0.75		0.75	
Fencing and gates		6.25		6.25	
Annual cost { Overhead		2.00		2.00	
Fire protection		1.50		1.50	
Goat control		0.30		0.30	
	1	—202.40	—184.00	—202.40	—184.00
Blanking (20% pl)		22.22		22.11	
Opossum control		5.00		5.00	
Annual cost		3.80		3.80	
Hand releasing fern		—135.00		—135.00	
	2	—165.91	—137.12	—165.91	—137.12
Annual cost	3	— 3.80	— 2.85	— 3.80	— 2.85
Dothistroma control	4	17.92		17.92	
Opossum control	4	5.00		5.00	
Annual cost	4	3.80		3.80	
	4	— 26.72	— 18.25	— 26.72	— 18.25
Annual cost	5	— 3.80	— 2.36	— 3.80	— 2.36
Annual cost	6	— 3.80	— 2.15	— 3.80	— 2.15
Dothistroma control (2nd)	7	35.43		35.43	
Annual cost	7	3.80		3.80	
	7	— 44.23	— 22.70	— 44.23	— 22.70
Annual cost	8	— 3.50	— 1.63	— 3.50	
Thinning-to-waste	9	75.00		63.80	
Annual cost	9	3.50		3.50	
	9	— 78.50	— 33.29	— 67.30	— 28.54
Annual cost	10	— 3.50	— 1.35	— 3.50	— 1.35
Opossum control	11	5.00		5.00	
Dothistroma control (3rd)	11	35.43		35.43	
Annual cost	11	3.50		3.50	
	11	— 43.93	— 15.40	— 43.93	— 15.40
Annual cost	12	— 3.50	— 1.12	— 3.50	— 1.12
Annual cost	13	— 3.50	— 1.01	— 3.50	— 1.01
Annual cost	14	— 3.50	— 0.92	— 3.50	— 0.92
Improving roading	14	80.00		50.00	
	14	— 83.50	— 21.99	— 53.50	— 14.09
Annual cost	15	— 3.50	— 0.89	— 3.50	— 0.84
TOTAL DISCOUNTED COST			—614.48		—600.20

	Discounted present values per ha Without disease	Affected by disease
Yield	224 m^3/ha	153 m^3/ha
Total discounted cost at 10% interest rate	$614.48	$600.20
Total discounted revenue (at $1/$m^3$)	$48.75	$33.30
Break-even growing cost	$12.60/$m^3$	$18.02/$m^3$

Financial analysis (excluding land value and using an interest rate of 10%) for a pulpwood regime of **Pinus radiata** with or without **Armillaria** root rot, clearfelled at 21 years

Operation	Year	Without disease $/ha Cost (actual)	Without disease $/ha Cost (discounted)	Affected by disease $/ha (actual)	Affected by disease $/ha (discounted)
Felling standing trees		155.00		155.00	
Felling light bush		100.00		100.00	
Formation road		120.00		120.00	
Cost		—375.00		—375.00	
Harvesting tawa revenue		+207.50		+207.50	
	0	—167.50	—167.50	—167.50	—167.50
Firebreaks		6.35		6.35	
Dessication		30.00		30.00	
Burning		30.00		30.00	
Release spray thistles		14.71		14.71	
Plants (1530 stems/ha)		45.90		45.90	
Planting (1530 stems/ha)		64.64		64.64	
Delivery plants		0.75		0.75	
Fencing and gates		6.25		6.25	
Annual cost — overhead		2.00		2.00	
Annual cost — fire protection		1.50		1.50	
Annual cost — goat control		0.30		0.30	
	1	—202.40	—184.00	—202.40	—184.00
Blanking (20% pl)		22.22		22.11	
Opossum control		5.00		5.00	
Annual cost		3.80		3.80	
Hand releasing fern		—135.00		—135.00	
	2	—165.91	—137.12	—165.91	—137.12
Annual cost	3	— 3.80	— 2.85	— 3.80	— 2.85
Dothistroma control	4	17.92		17.92	
Opossum control	4	5.00		5.00	
Annual cost	4	3.80		3.80	
	4	— 26.72	— 18.25	— 26.72	— 18.25
Annual cost	5	— 3.80	— 2.36	— 3.80	— 2.36
Annual cost	6	— 3.80	— 2.15	— 3.80	— 2.15
Dothistroma control (2nd)	7	35.43		35.43	
Opossum control	7	5.00		5.00	
Annual cost	7	3.80		3.80	
	7	— 44.23	— 22.70	— 44.23	— 22.70
Annual cost	8	— 3.50	— 1.63	3.50	— 1.63
Thinning-to-waste	9	75.00		63.80	
Annual cost	9	3.50		3.50	
	9	— 78.50	— 33.29	— 67.30	— 28.54
Annual cost	10	— 3.50	— 1.35	3.50	— 1.35
Opossum control	11	5.00		5.00	
Dothistroma control (3rd)	11	38.43		38.43	
Annual cost	11	3.50		3.50	
	11	— 43.93	— 15.40	— 43.93	— 15.40
Annual cost	12	— 3.50	— 1.12	— 3.50	— 1.12
Annual cost	13	— 3.50	— 1.01	— 3.50	— 1.01
Annual cost	14	— 3.50	— 0.92	— 3.50	— 0.92
Opossum control	15	5.00		5.00	
Annual cost	15	3.50		3.50	
	15	— 8.50	— 2.03	— 8.50	— 2.03
Annual cost	16	— 3.50	— 0.76	— 3.50	— 0.76
Annual cost	17	— 3.50	— 0.69	— 3.50	— 0.69
Annual cost	18	— 3.50	— 0.63	— 3.50	— 0.63
Annual cost	19	— 3.50	— 0.57	— 3.50	— 0.57
Improving roading	20	80.00		50.00	
Annual cost	20	3.50		3.50	
Annual cost	20	— 83.50	— 12.41	— 53.50	— 7.95
Annual cost	21	— 3.50	— 0.47	— 3.50	— 0.47
TOTAL DISCOUNTED COST			—609.21		—600.00

	Discounted present values per ha — Without disease	Affected by disease
Yield	446 m³/ha	307 m³/ha
Total discounted cost at 10% interest rate	$609.21	$600.00
Total discounted revenue (at $1/m³)	$54.80	$37.71
Break-even growing cost	$11.12/m³	$15.91/m³

Financial analysis (excluding land value and using an interest rate of 10%) for a domestic sawlog regime, of **Pinus radiata** with or without **Armillaria** root rot clearfelled at 26 years

Operation	Year	Without disease $/ha Cost (actual)	Without disease $/ha Cost (discounted)	Affected by disease $/ha (actual)	Affected by disease $/ha (discounted)
Handfelling	0	160.00		160.00	
Overhead	0	2.00		2.00	
Sub-total	0	—162.00	—162.00	—162.00	—162.00
Burn	1	5.00		5.00	
Access and fire breaks	1	2.00		2.00	
Plants	1	45.90		45.90	
Planting	1	64.64		64.64	
Release spray (thistles)	1	14.71		14.71	
Release spray (grass)	1	47.78		47.78	
Overheads	2	2.00		2.00	
Sub-total	1	—182.03	—165.48	—182.03	—165.48
Blanking (5%)	2	6.00		6.00	
Overheads	2	2.00		2.00	
Sub-total	2	— 8.00	— 6.61	— 8.00	— 6.61
Overheads	3	— 2.00	— 1.50	— 1.50	— 1.50
Dothistroma control	4	17.92		17.92	
Overheads	4	2.00		2.00	
Sub-total	4	— 19.92	— 13.61	— 19.92	— 13.61
Overheads	5	— 2.00	— 1.24	— 1.24	— 1.24
Prune (0-2.2 m) 600 stems/ha	6	112.49		112.49	
Thinning-to-waste to 600 stems/ha	6	75.20		54.00	
Overheads	6	2.00		2.00	
Sub-total	6	—189.69	—107.08	—168.49	— 95.11
Dothistroma control	7	35.43		35.43	
Overheads	7	2.00		2.00	
Sub-total	7	— 37.43	— 19.21	— 37.43	— 19.21
Prune 2.2 m to 4.0 m (370 stems/ha)	8	87.63		87.63	
Overheads	8	2.00		2.00	
Sub-total	8	— 89.63	— 41.81	— 89.63	— 41.81
Prune 4.0 to 5.8 m (200 stems/ha)	9	52.78		52.78	
Thinning-to-waste to (200 stems/ha)	9	40.00		40.00	
Overheads	9	2.00		2.00	
Sub-total	9	— 94.78	— 40.20	— 94.78	— 40.20
Overheads	10 to 25	— 2.00	— 6.65	— 6.65	— 6.65
Improving roading	26	80.00		50.00	
Overheads	26	2.00		2.00	
Sub-total	26	— 82.00	— 6.88	— 52.00	— 4.36
TOTAL DISCOUNTED COST			—572.27		—557.78

	Discounted present values per ha Without disease	Affected by disease
Yield	476 m³/ha sawlogs 25 m³/ha pulpwood	339 m³/ha sawlogs 18 m³/ha pulpwood
Total discounted cost at 10% interest rate	$572.27/ha	$557.78 ha
Total discounted revenue (value $1/m³ average price)	38.22/m³	27.23/m³
Break-even growing cost	$14.97/m³	$20.48/m³