DISEASE CONTROL BY AERIAL SPRAYING OF DOTHISTROMA PINI IN TENDED STANDS OF PINUS RADIATA IN NEW ZEALAND

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ABSTRACT

Disease severity of **Dothistroma pini** Hulbary and growth data on **Pinus radiata** D. Don after aerial spraying with copper oxychloride for 4 consecutive years were analysed at Kaingaroa State Forest, Tiritea Plantings, and Mawhera State Forest, and in a 14-year-old spray trial in Cpt 360 at Kaingaroa State Forest. Reduction of disease levels after the spray treatments was variable between sites and between seasons. The disease levels decreased to trace levels after pruning and thinning, whereafter the rates of reinfection were variable.

Differences in height associated with spraying for disease control could not be demonstrated. Basal area increased in sprayed plots after 1 year or more of substantial disease reduction. Thinning, however, eliminated basal area differences between treatments. Volume differences between treatments in the 14-year-old spray trial were not significant.

A marginal cost analysis and a Silvicultural Stand Model were used to estimate the net financial gain from spraying. It was estimated that volume savings of 3–3.5 m^3/ha/spray would be needed to break even at an average cost of $22.50/ha/spray. The data suggest that in the experimental plots spraying was not justified on purely financial criteria as a response of this magnitude was not obtained.

INTRODUCTION

The needle blight caused by *Dothistroma pini* is a serious disease of *Pinus radiata* in New Zealand; it can cause growth loss through defoliation (Whyte 1968, 1976; van der Pas 1981) and occasionally tree death (Gilmour 1967b). Since its detection in the early 1960s (Gilmour 1967a) the disease has spread to most parts of the country (Kershaw *et al.* 1982). A major factor contributing to this has been without doubt the steady increase in planted area of young susceptible *P. radiata.*

Favourable results obtained in the control of *D. pini* by the application of light dosages of copper fungicides in Kenya (Gibson 1965; Gibson *et al.* 1966) prompted the nationwide spraying of pine plantations in New Zealand from 1966. Excellent disease control was obtained by single and double aerial applications of copper oxychloride (Gilmour & Noorderhaven 1973; Gilmour 1971) and in the period from

1966 to 1973 only 10.6% of the *P. radiata* stands in Kaingaroa State Forest required more than one spray application. Apparently a single spray treatment applied in November–December afforded adequate protection for 3 years or more (Gilmour *et al.* 1973).

Generally accepted practice has been to spray *P. radiata* stands when the over-all infection level of the unsuppressed green crown reaches 25% (or 15% in high-hazard regions) (Kershaw *et al.* 1982). The criterion for spraying is based mainly on findings by Gilmour & Noorderhaven (1973), Gilmour *et al.* (1973), and Whyte (1968, 1969) who noted that subsequent growth losses are detectable only when disease levels exceed 25%. The total area sprayed varies from year to year depending upon seasonal factors, with the greatest area sprayed to date being nearly 120 000 ha in 1981 (Table 1). The question, however, of how much net production can be saved by spraying stands affected by Dothistroma needle blight is still open.

TABLE 1—Annual aerial spray programmes for Dothistroma control in New Zealand pine plantations and the estimated costs*

Spray season	Area sprayed (ha)	Percentage of susceptible age classes sprayed	Consumer Price Index (base 1981/82 = 1000)	Real spray cost (1981 $/ha)
1966/67	32 513	34	197	34.43
1967/68	21 785	23	205	28.36
1968/69	10 727	12	216	33.43
1969/70	11 501	11	230	33.88
1970/71	9 693	8	254	36.47
1971/72	31 195	22	272	28.76
1972/73	28 929	16	294	28.78
1973/74	14 361	6	326	22.97
1974/75	24 865	10	374	24.78
1975/76	62 212	21	437	23.65
1976/77	62 922	19	500	18.66
1977/78	26 646	7	560	19.57
1978/79	6 006	2	637	29.67
1979/80	68 693	15	746	17.87
1980/81	108 784	22	861	18.87
1981/82	119 388	23	1000	15.35
Total	640 299			
Average spray cost/ha				22.50

* Annual spray costs were calculated using cost data given by the Dothistroma Action Committee Trust Fund. Survey and administration costs are estimated at 15% of the annual spray costs and are included in the annual spray costs per hectare. Cost data were converted to 1981 dollar value using the Consumer Price Index as an inflation proxy.

The first experiment designed to investigate the growth response to aerial spraying was established by the late J. W. Gilmour in 1969. Growth data from this experiment, along with those from three other trials established in 1979 (two in the North Island and one in the South Island), and the financial returns from spraying implied by these data, are reported here. Stands involved received standard silvicultural treatment (i.e., pruning and thinning) during the course of the experiment and the spray dosages used in each of the four experiments were varied in accordance with the assessed disease hazard at each experimental site (*see* Kershaw *et al.* 1982).

METHODS

Treatments, Assessments, and Analyses

Copper oxychloride as a 50% wettable powder in 50 *l* water/ha was applied aerially at half dosage (2.5 kg/ha), single dosage (4.16 kg/ha), and double dosage (8.32 kg/ha) (respectively 2, 4, and 8 lbs/acre in the Imperial system used before 1975 – J. Ray pers. comm.). Spraying took place under conditions as recommended by Gilmour (1971) and Kershaw *et al.* (1982). Deposition of the spray was checked in each trial by laying spray traps on the ground in each plot across the line of flight during the spray application. Copper deposits on the traps were analysed on an atomic absorption spectrophotometer (Gilmour & Noorderhaven 1973).

The severity of the disease in the sample plots was assessed for each tree once a year during the winter. The percentage of the normal green crown that was defoliated or infected by *D. pini* was estimated visually in 5% steps (Kershaw *et al.* 1982) by three trained observers whose individual scores were averaged.

The total height and the diameter at breast height of the plot trees were measured at the same time as the disease assessments. In the 1969 trial each plot tree was sectionally measured for volume over bark in 1981. Diameters were taped at 0.7 m, 1.4 m, and at mid-internodes immediately above these points (Whyte 1971), and volumes were calculated using the truncated cone formula.

Data were analysed by group and over-all comparisons of treatments using analyses of variance and SNK tests in the conventional way. Analysis of covariance was used to examine the annual plot averages of disease level, height, and diameter growth. The disease level, tree height, or diameter of the penultimate year were subsequently used as covariates.

Experimental and Site Description

The spray trials were established in young stands of *P. radiata* of different ages, and the experimental designs were adapted to fit specific site conditions.

Trial 1 was established in 1969 in a 3-year-old stand in Cpt 360 of Kaingaroa State Forest. The site was divided into four 10-ha blocks separated by 50-m guard strips. Each block received a different spray treatment – respectively no spray (control), half, single, and double dosage. The half and single dosages were applied in November of 1969, 1971, and 1975 when disease levels rose above 25%. The double dosage was given each year from 1969 to 1980 regardless of the disease levels. Within each block, nine 0.04-ha plots were randomly located along a Z-shaped transect. Each plot contained

50 trees initially, 24 after the first thinning (1972), and 12 after the second thinning (1976). Plot trees and the surrounding ones were pruned in early spring to 2.4 m in 1972, 4.2 m in 1974, and 6 m in 1976.

Trial 2 comprised four adjacent compartments (902, 903, 904A, and 904B) in Kaingaroa State Forest. The site is uniform and flat, and each compartment was subdivided into three, approximately equal, rectangular treatment blocks of about 20 to 30 ha. Compartment 902 was planted in 1975, Cpt 903 and 904B in 1976, and Cpt 904A in 1977. The experiment was a compact randomised block design comprising three treatments and four replicates (i.e., compartments). The treatments were no spray (control), and half and single dosage applied in November of each year from 1979 to 1982. The disease severity had reached levels ranging from 7% to 19% in 1979 when the experiment commenced and the compartments were assessed from the air as sprayable. The spray treatments were randomly assigned within each compartment and were separated by buffer strips 50 m wide to prevent possible spray drift. In each block ten 0.01-ha plots were randomly established, in which each tree was measured and assessed for disease annually. Compartment 902 was pruned and thinned in 1982, the other compartments in 1983.

Trial 3 was located in Tiritea Plantings, 12 km south-east of Palmerston North, and comprised neighbouring Cpt 1 to 4 which were planted in 1972 to 1975 successively. Each compartment was thinned and pruned at age 5 years. Disease levels were sprayable in 1979, showing high to medium infection. The site is a water catchment with *P. radiata* planted on ridge crests and short steep slopes into gullies. The experiment was a compact randomised block design comprising three treatments and four replicates (i.e., compartments). The treatments were no spray and single and double dosages applied in December of each year from 1979 to 1981. Each compartment was subdivided into three blocks of approximately equal size ranging from 6 to 12 ha, and treatments were randomly assigned within each compartment. In each block ten 0.01-ha plots were randomly located in the central part to avoid spray interference from neighbouring blocks. Each plot tree was measured and assessed for disease annually.

Trial 4 comprised Cpt 64 in Mawhera State Forest, located 15 km north of Greymouth. The compartment was planted in 1976 with *P. radiata* which showed high infection levels in 1979. The site has a northerly aspect and is moderately to steeply sloping. Annual rainfall is close to 2000 mm. Four blocks of approximately 20 ha each were selected on the basis of comparability of site and growth conditions, and each block contained four plots, i.e., 16 plots in total. The experiment comprised two replicates of four spray treatments – no spray, single dosages applied in November only, in February only, and in both November and February. The spray treatments were applied when disease levels reached either 15% (Blocks 2 and 4) or 25% (Blocks 1 and 3), thus giving eight treatment combinations. In each block four randomised treatment plots were separated by guard strips of at least 50 m. The plots measured 100 × 100 m (1 ha) and contained four subplots of 20 × 20 m (0.04 ha) at a distance of 20 m from the plot borders and neighbouring subplots. In each subplot 25 trees were randomly selected for measurement. Pruning and thinning took place in 1983 after completion of the trial.

RESULTS

Trial 1 – Kaingaroa

Spraying with the double dosage reduced the disease level to 3% in 1971 and kept the stand almost disease-free from 1973 onwards (Table 2). The first application of the single and the half dosage reduced disease levels in 1970 by 12 and 7 percentage points respectively. The second application in 1971 was less effective and the disease levels in 1972 for the single and the half dosage increased by 8 and 7 percentage points respectively. Low pruning and thinning reduced the disease levels to a trace for all treatments in 1973. Thereafter disease levels increased rapidly. They continued to rise in 1975 after the medium pruning. The third application of the single and the half dosage that year reduced disease levels by 36 and 34 percentage points respectively. The stands were high pruned in 1976 and after this the disease levels were reduced to a trace; they stayed low but rose to about 15% in 1979 because of wet weather. The disease levels of the unsprayed control plots were significantly higher than those of the spray treatments from 1970 to 1972 and in 1976.

Spraying for disease control had a minor effect on growth – there was no significant effect on height growth, but the basal area of the control was significantly less than that of each spray treatment in 1972 and that of the double spray in 1976. However, the thinnings in 1972 and 1976 removed most of the contrasts. By 1981 all sprayed treatments had greater volumes per hectare than the unsprayed control, the difference between the control and the double dosage being 20 m^3/ha, and that between the control and the single dosage 10.3 m^3/ha. The volume differences between the various treatments were not, however, statistically significant at the 5% confidence level. Interpretation of this should be cautious since treatments were not replicated and considerable and unexplainable random variation was found in this experiment.

Trial 2 – Kaingaroa

The effect of spraying was not dramatic in this experiment. Spraying had no demonstrable effect in Cpt 904A (Table 3), but it did keep the disease levels down in the other compartments. Disease levels in the control plots rose and the differences in levels between the controls and the spray treatments were significant in 1980 and 1981. There were no significant differences between the disease levels of the single and the half dosage plots. Pruning and thinning reduced disease to very low levels in each treatment.

Spraying for disease control had no apparent effect on height growth, but the basal areas of both spray treatments were significantly greater than that of the control in Cpt 903 and 904B in 1981 after significant disease reduction. Pruning and thinning removed contrasts between treatments.

Trial 3 – Tiritea

The disease levels in 1979 were variable, but there were no significant differences between treatments within compartments (Table 4). The double dosage reduced disease levels significantly in Cpt 1 (1981 and 1982) and in Cpt 3 and 4 in 1982; there was no significant effect in Cpt 2. The single dosage caused no significant reduction of disease level. Disease control had no demonstrable effect on either height or basal area.

TABLE 2—Effect of aerial spraying on disease level, height, basal area, and volume in Kaingaroa State Forest, Cpt 360 Block A (Trial 1)

Treatment	Year												
	1969 *	1970	1971 *	1972	1973	1974	1975 *	1976	1977	1978	1979	1980	1981
Disease level (%)													
1	28	34_b	46_c	61_c	t	39_b	49_b	35_c	t	t	14	t	t
2	29	22_a	24_b	31_b	t	27_b	56_b	22_b	t	t	13	t	t
3	29	17_a	31_b	39_b	t	26_b	47_b	11_b	t	t	15	t	t
4	20	17_a	3_a	3_a	t	t_a	t_a	t_a	t	t	14	t	t
Height (m)													
1	1.5	2.2	3.3	4.6	6.6	8.1	8.9	NA	14.1	NA	16.8	18.4	19.6
2	1.4	2.1	3.4	5.0	6.9	8.1	10.0	NA	13.9	NA	16.9	19.1	20.3
3	1.4	2.0	3.4	4.8	6.8	8.1	10.0	NA	14.2	NA	17.4	19.2	20.1
4	1.4	2.0	3.0	4.8	6.8	7.8	9.6	NA	14.4	NA	17.0	18.7	19.7
Basal area (m^2/ha)													
1	1.5	4.0	5.9	8.5_b	6.0	9.0	12.7	16.9_b	10.0	NA	15.1	18.1	20.0
2	1.5	4.5	6.5	11.8_a	6.5	10.0	13.5	17.0_b	10.0	NA	15.0	17.9	20.5
3	1.4	4.0	6.2	10.5_a	6.8	10.4	14.1	17.9_{ab}	10.7	NA	15.9	19.1	21.3
4	1.2	3.2	6.0	10.0_a	6.1	10.5	14.9	18.8_a	11.4	NA	17.2	20.5	22.5
Volume (m^3/ha)													
1													169.3
2													176.5
3													179.6
4													189.3

Significant differences between treatments ($p = 0.05$) are indicated by different subscript letters.

* = sprayed in November 1969, 1971, 1975
t = trace to 5%
NA = not available
1 = control (no spray)
2 = half dosage
3 = single dosage
4 = annual double dosage

TABLE 3—Effect of aerial spraying on disease levels, height, and basal area in Kaingaroa State Forest (Trial 2)

Year	Cpt	Disease level (%)			Height (m)			Basal area (m^2/ha)		
		Treatments*			Treatments			Treatments		
		1	2	3	1	2	3	1	2	3
1979	902	11	8	17	3.9	3.6	3.8	8.5	9.4	7.9
	903	7	15	9	2.9	3.1	3.0	5.5	6.6	6.3
	904A	17	19	18	1.4	1.4	1.3	1.7	1.2	1.1
	904B	13	10	7	2.3	2.6	2.6	6.3	6.4	6.9
1980	902	22_b	6_a	10_a	4.8	4.6	5.2	13.2	14.8	15.6
	903	28_b	14_a	9_a	4.4	4.4	4.1	11.7	12.8	11.7
	904A	20	18	23	3.3	3.2	3.2	8.9	9.2	8.5
	904B	23_b	13_a	11_a	4.1	4.3	4.1	11.0	13.2	12.3
1981	902	t	t	t	6.6	6.4	6.4	4.5	5.0	5.2
	903	40_b	23_a	14_a	5.8	6.1	5.8	9.2_b	10.4_a	11.2_a
	904A	35	27	24	4.4	4.4	4.3	9.2	9.4	9.2
	904B	39_b	15_a	15_a	5.7	6.0	5.9	8.0_b	9.4_a	9.6_a
1982	902	10	t	10	7.4	7.6	7.3	13.0	13.5	12.5
	903	4	8	t	7.1	7.1	7.1	8.4	8.7	9.5
	904A	7	t	8	5.8	6.1	6.1	8.3	9.0	8.8
	904B	7	t	t	6.7	6.7	6.8	8.3	9.0	9.2

Significant differences between treatments ($p = 0.05$) are indicated by different subscript letters. Adusted values of height and basal area from 1980 to 1982. Diameters were taken at ground level in 1979.

t = trace to 5%

* 1 = control (no spray)
2 = half dosage applied in November each year from 1979 to 1982
3 = single dosage applied in November each year from 1979 to 1982.

Trial 4 – Mawhera

The whole compartment was severely infected in 1979 and disease levels prior to spraying were not significantly different between treatments within blocks (Table 5). The disease levels in the control plots decreased over the years in Blocks 3 and 4, whereas that of Blocks 1 and 2 remained constant. Both the November + February spray and the February spray were equally effective and reduced disease levels to less than 10% in 1981. The disease levels for the November + February spray treatments were significantly lower than that of the control from 1980 on (except in Block 4), while the disease levels for the February spray were significantly lower in 1981 and 1982 (except in Blocks 2 and 4) than that of the control. The November spray was apparently less effective than the other spray treatments and disease levels were significantly suppressed only in 1980 in Block 1, and in 1981 and 1982 in Blocks 1 and 3. There was no difference between plots sprayed at 15% and 25% disease level.

TABLE 4—Effect of aerial spraying on disease levels, height, and basal area in Tiritea Plantings (Trial 3)

Year	Cpt	Disease level (%)			Height (m)			Basal area (m²/ha)		
		Treatments*			Treatments			Treatments		
		1	2	3	1	2	3	1	2	3
1979	1	55	67	55	3.8	3.0	4.6	8.8	6.8	10.9
	2	20	35	22	4.2	3.1	3.6	9.5	6.5	8.0
	3	28	42	45	3.6	3.6	3.4	11.5	12.1	12.0
	4	28	25	39	2.9	2.5	2.7	9.7	9.2	9.3
1980	1	44	43	25	4.1	4.0	4.7	11.4	11.3	13.0
	2	36	32	23	4.0	4.1	4.6	12.1	11.5	12.4
	3	39	34	36	4.3	4.3	4.4	8.1	8.1	7.4
	4	74	56	52	4.4	4.6	4.0	7.4	7.2	7.0
1981	1	21_b	19_{ab}	9_a	4.9	5.0	5.6	11.5	11.8	12.3
	2	23	19	16	5.2	5.1	5.5	11.4	11.8	12.4
	3	32	28	27	5.2	5.4	5.1	11.3	11.9	11.5
	4	38	36	33	5.1	5.5	4.9	11.7	11.8	12.9
1932	1	19_b	18_b	6_a	5.4	5.6	6.2	13.5	13.8	14.1
	2	14	15	9	5.6	5.6	5.6	14.0	14.1	13.9
	3	31_b	19_{ab}	14_a	5.3	5.7	5.5	13.8	13.9	13.7
	4	28_{ab}	40_b	19_a	5.6	5.8	5.9	13.4	13.6	13.7

Significant differences between treatments ($p = 0.05$) are indicated by different subscript letters. Adjusted values of height and basal area from 1980 to 1982. Diameters were taken at ground level in 1979.

* 1 = control (no spray)
2 = single dosage applied in December each year from 1979 to 1982
3 = double dosage applied in December each year from 1979 to 1982

Spraying for disease control had no significant effect on height growth. The basal area of the three spray treatments overtook that of the control in 1982, but the differences were statistically not significant at the 5% confidence level.

Financial Aspects

For much of the exotic forest estate the principal economic objective is to encourage sustainable production and to increase the long-term net return to the nation, region, and landowner (New Zealand Forestry Conference 1981). Most of the cost of growing trees (such as site preparation, planting, and management) can for most forests be regarded as fixed. However, a few costs remain variable, one of which is spraying for the control of Dothistroma. One way to examine the question of whether to spray or not is through a marginal analysis which looks at the costs of disease control in relation to the expected returns via increased wood yields.

TABLE 5—Effect of aerial spraying on disease levels, height, and basal area in Cpt 64, Mawhera State Forest (Trial 4)

Year	Block	Disease level (%)				Height (m)				Basal area (m^2/ha)			
		Treatments*				Treatments				Treatments			
		1	2	3	4	1	2	3	4	1	2	3	4
1979	1	30	9	32	27	1.6	1.6	1.8	1.6	2.6	2.0	3.0	2.6
	2	47	46	53	52	1.4	1.1	1.5	1.5	2.0	1.6	1.8	2.2
	3	57	47	57	58	1.6	1.2	1.4	1.2	2.6	1.0	2.0	1.4
	4	27	54	28	63	1.6	1.5	1.6	1.7	2.4	1.8	2.4	2.4
1980	1	33_{b}	1_{a}	20_{b}	6_{a}	1.9	1.9	1.9	2.0	3.2	3.4	3.2	3.4
	2	46_{b}	31_{ab}	38_{ab}	26_{a}	2.0	1.9	1.9	1.9	3.2	3.4	3.2	3.0
	3	56_{b}	35_{ab}	39_{ab}	20_{a}	1.9	1.9	1.9	1.9	3.3	3.2	3.2	3.2
	4	6_{b}	31_{a}	8_{b}	22_{a}	1.9	1.9	2.0	1.9	3.4	3.0	3.6	2.8
1981	1	42_{b}	7_{a}	4_{a}	3_{a}	2.4	2.4	2.3	2.3	3.0	2.4	3.2	2.6
	2	25_{b}	17_{ab}	9_{a}	3_{a}	2.2	2.3	2.3	2.3	2.2	2.4	2.6	2.8
	3	41_{b}	10_{a}	9_{a}	3_{a}	2.3	2.3	2.3	2.3	2.0	2.4	2.4	2.6
	4	15_{b}	26_{b}	4_{a}	4_{a}	2.4	2.4	2.4	2.3	2.6	2.8	3.2	3.2
1982	1	41_{b}	9_{a}	10_{a}	8_{a}	3.1	3.1	3.1	3.3	3.6	4.3	4.0	4.5
	2	45_{b}	33_{b}	21_{ab}	13_{a}	3.1	3.1	3.3	3.2	3.6	4.0	4.9	4.0
	3	36_{b}	15_{a}	11_{a}	6_{a}	3.0	3.1	3.4	3.3	4.0	4.1	4.9	4.9
	4	5	5	4	6	3.1	3.4	3.1	3.4	4.2	5.5	4.5	4.9

Significant differences between treatments ($p = 0.01$) are indicated by different subscript letters. Adjusted values of height and basal area from 1980 to 1982. Diameters were taken at ground level in 1979 and 1980.

* 1 = control (no spray)
2 = single dosage applied in November only
3 = single dosage applied in February only
4 = single dosage applied in November and February

Actual costs of spraying for the control of Dothistroma for the period 1966/67 to 1981/82 were obtained and converted into real 1981/82 dollars by using the Consumer Price Index as an inflation measure (Table 1). This real series shows that costs of spraying with a single dosage rate had fallen by 50% over the period. For the period 1966/67 to 1972/73 real costs varied between \$28/ha and \$36/ha. There appears to be a transition period of 2 to 3 years when costs were around \$22/ha to \$24/ha, and since then they have fluctuated from \$16/ha to \$20/ha. Some of the variation in spray costs is attributable to spreading of survey and administration costs, which have been relatively constant in real terms, over the sprayed areas – ranging from 6006 ha (1978/79) to 119 388 ha (1981/82). These costs currently average \$4.60/ha sprayed, but even in 1966/67 they averaged only \$5.50/ha. The unadjusted average spray cost of \$22.50/ha/spray (Table 1) was used in the main analysis as the cost of a single spray; a low cost (\$15/ha/spray) and high cost (\$30/ha/spray) were used in the sensitivity analysis.

There are as yet no data on the actual wood harvest from each of the various treatments in the trials for use in the marginal analysis. The crop in the oldest trial (Trial 1) is now only 16 years old, while the other trials range in age between 6 and 11 years. Rotations of 30 years are envisaged for the existing plantations (Levack 1979). To provide an estimate of the expected wood yield of each of the various treatments, it is necessary to project stand growth to this age from the existing trial data.

The plot data for Trials 1 and 2 (i.e., stand age, stocking, height, and basal area before and after each silvicultural treatment) were coupled with site index data from Kaingaroa State Forest and used as input to the Kaingaroa Growth Model (KGM 2) (Elliot & Goulding 1976). This model was used to project yields at various ages for the various treatments (Appendix, Tables 1A and 2A). The model predicts small total volume differences between treatments in Trials 1 and 2. If it is assumed that total disease control is achieved by the annual double dosage of Trial 1, or the single dosage of Trial 2, the model predicts this would increase yield at age 30 by 36 m^3/ha (Trial 1) and some 4 m^3/ha (Trial 2). The single dosage of Trial 1 had a predicted increase in total yield of about 15 m^3/ha over the control. In this treatment the trees were sprayed only when disease levels were 25% or higher (i.e., at ages 3, 5, and 9). For most stands, harvested volume is approximately 85% of the total standing volume (C. Goulding pers. comm.) which could imply that the net increase in harvested wood arising from the various treatments in Trial 1 would be of the order of 13 m^3/ha (single dosage) with a maximum of around 30 m^3/ha (double dosage). The increase in harvestable volume would appear to be minimal in Trial 2 (Appendix, Table 2A).

Compounded spray costs at 10% per annum (the Government test rate) to rotation age 30 for Trial 1 are $3822 for the double spray and $705 for the single spray. In this trial the estimated cost of producing extra wood by spraying would range from $54/$m^3$ (single spray) to $128/$m^3$ (double spray). Allowing for possible variation in the cost of spraying but keeping the response to spraying constant, this would mean a range of $36/$m^3$ ($15/spray) to $171/$m^3$ ($30/spray). Comparison of these figures with the cost of producing wood without spraying (e.g., Liquid Fuel Trust Board 1983) suggests that spraying may not be cost-effective. Average costs of production without spraying vary from $18–$25/m^3 for fibre wood to upwards of $40/$m^3$ for sawlogs/peelers. In most places these costs are below the cost of producing extra wood by spraying to control Dothistroma.

There are, however, usually a number of outputs of differing qualities per forest. An increase in total harvestable volume may mean (a) increased production of all quality types so that there is no change in their proportions in the total output, or (b) increased production of only a few quality types resulting in a change in the proportion of total output for each type. In the latter, when substantially more valuable quality types than others are favoured by spraying, even small changes in harvestable volumes may be financially significant. This possibility (b) was tested by running the projected yields of Trial 1 at age 30 through program PROD (Shirley & Goulding 1978). This program, which forecasts tree-size distribution and log-size assortment, predicted that the distribution by material type will not change significantly (Appendix, Table 3A). The change in contribution by log size, however, is noticeable with increasing numbers of bigger logs (Appendix, Tables 4A and 5A). Such changes may be significant since larger logs, i.e., increased piece size, will lower both harvesting costs (*see* Terlesk 1980; McConchie 1976) and sawing costs (J. L. van Wyk, pers. comm.). The financial impact of the changes in log-size distribution on the net value of the stand was calculated using Program SILMOD (McGregor & Williams 1982). Gross revenues and costs are predicted using a 10% discount rate (Table 6). On this basis small increases in log size would have significant effects on the net revenue and the single-dosage spray treatment would be marginally profitable.

TABLE 6—Predicted revenue changes as a result of spraying

Treatment	Cost excluding spray cost ($/ha)	Revenue ($/ha)	Spray cost ($/ha)	Net revenue ($/ha)	Net revenue gain from spraying ($/ha)
1 - control	54,214	52,486	—	- 1728	—
2 - half dosage	54,114	52,260	466	- 2559	- 592
3 - single dosage	54,777	53,552	705	- 1630	+ 98
4 - double dosage	55,596	55,766	3832	- 3662	- 1934

Using SILMOD, runs were carried out in which the effect of spraying on yield was simulated by arbitrarily increasing the basal area of the stand at age 13. This estimated changes of net revenue for gross volume responses of up to 20 m^3/ha (Table 7). The range of response is believed to adequately cover possible gains in total yield from spraying, given the experimental spray results.

TABLE 7—Changes in stand worth resulting from changes in harvestable volume using SILMOD for Trial 1 at age 30 (discount rate 10%)

Assumed volume response to spraying (m^3/ha)	Net increase in harvestable volume (m^3/ha)	Total cost excluding spray costs ($/ha)	Estimated revenue ($/ha)	Net change in revenue from spraying ($/ha)
0	—	54,214	52,486	—
6	5	54,462	53,062	319
11	9	54,595	53,403	536
15	13	54,914	54,193	803
20	16	54,777	53,852	1007

The amount of growth response required to cover spray costs is influenced by the ages when spraying is done, because of the effect of compounding. The data suggest that, with a 10% discount rate for most commonly observed spray regimes, in which one to four spray applications are given before age 11, a gross response of 3–3.5 m^3/ha/spray would be needed to break even (Fig. 1a).

Increasing the cost of spraying from \$22.50/ha/spray to \$30/ha/spray will increase the response required to break even to approximately 4–4.5 m^3/ha/spray (Fig. 1b). Likewise, reducing spray costs to \$15/ha/spray will lower the required response to approximately 2–2.5 m^3/ha/spray. Spraying twice during the same season (as, for example, in Trial 4 (double dosage)) doubles the spray costs and consequently the breakeven growth response.

DISCUSSION

It may be reasonable to accept the reduction of disease level as a measure of the effectiveness of spraying. It follows that the effectiveness of the single and the half dosage was about the same in Trials 1 and 2. However, it may not be prudent to apply half dosage rates when disease levels are much greater than 40% since at such levels the half dosage rate was less effective than the single dosage rate (Gilmour & Noorderhaven 1973). In Trial 3 the single dosage had no significant effect on disease severity and a double dosage was needed to reduce disease levels. This was probably caused by the high inoculum levels and wet weather. In Trial 4 the single dosage sprayed only in February was just as effective as the single dosage applied in November + February. This suggests that at this site most infection takes place late in the growing season, probably because of the very wet climate.

The effectiveness of the spray treatments was variable. In Trial 1 the third application of both the single and the half dosage in 1975 was much more effective than the second application in 1971. In Trial 2 spraying of Cpt 903 had no effect on disease levels, while the disease levels of the neighbouring compartments were reduced to significantly lower levels. Similarly, in Trial 3 the double dosage had no effect in Cpt 2 but reduced the disease levels significantly in the other compartments. No plausible explanation can be given for the lack of disease control. All compartments in each trial were sprayed on the same day and spray trap analysis did not show anomalies in the amounts of copper applied, droplet size, or droplet distribution. (Other workers have also sometimes obtained erratic results for which there is no explanation – J. Ray pers comm.). This doest not invalidate the results of the experiments, but shows that disease reduction can not always be expected after spraying.

There is little extant proof of the beneficial effects of pruning and thinning on disease severity. Pruning may reduce inoculum by removing infected needles, which on the forest floor can produce viable conidia only for a limited period of up to 6 months (Gadgil 1970). However, an unknown quantity of invisibly infected needles may remain on the trees after pruning, since conidial infection can precede visible symptoms by 6 to 8 weeks (Gilmour 1981). It follows, therefore, that the degree of disease reduction resulting from pruning depends on the remaining inoculum and on the weather after the operation. Since both are unknown, predictions about disease reduction resulting from pruning will be speculative at best. The effect of thinning is even less certain, but it may be possible that the microclimate will become less favourable for the fungus when the stand is opened.

In Trial 1 pruning and thinning in 1972 and 1976 reduced the disease levels for all treatments. However, the disease levels rose after medium pruning in 1975. In Trial 2 pruning and thinning reduced the disease levels to a trace. There was no

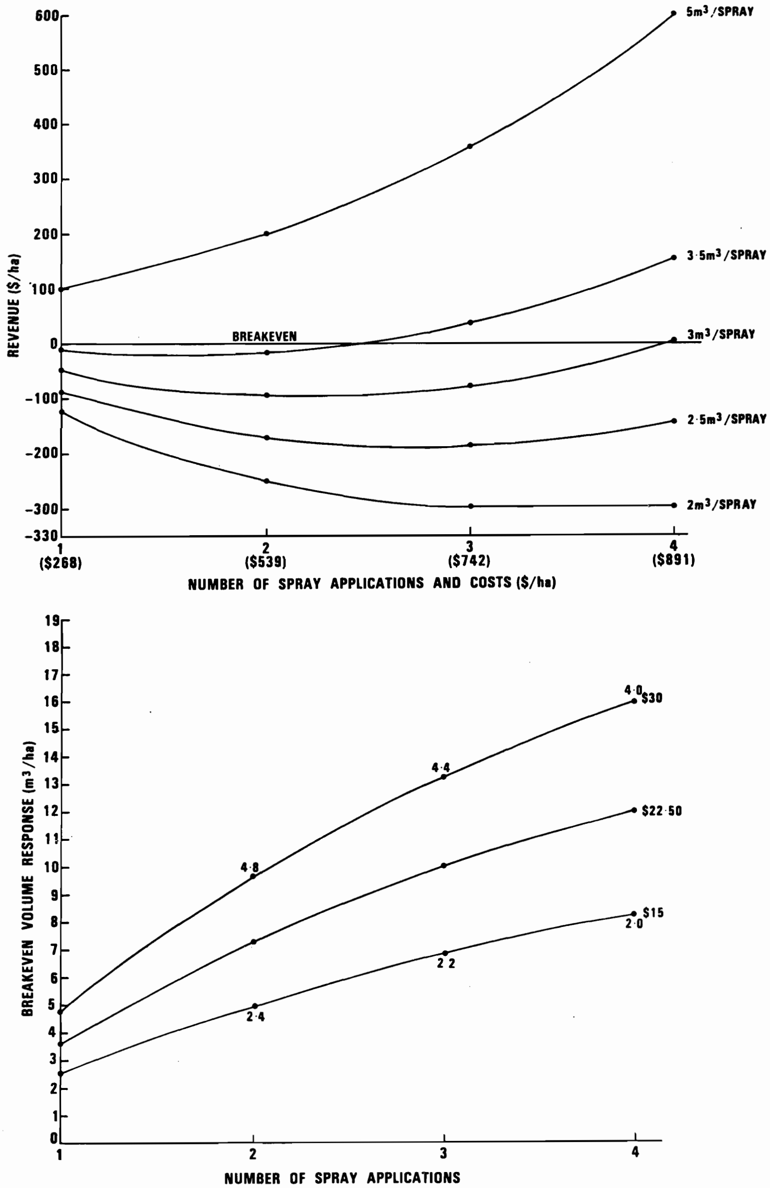

FIG. 1—(a) Revenue required to break even at different growth responses and spray regimes.
1 = one spray application at age 4;
2 = two spray applications at ages 3 and 5;
3 = three spray applications at ages 3, 5, and 7;
4 = four spray applications at ages 3, 5, 7, and 10;
Spray costs were calculated at $22.50/ha/application and at 10% discount to age 30.

(b) Sensitivity of breakeven response to spray costs.

significant reduction of disease levels in Trial 3 where only the final-crop trees were pruned. Trial 4 was pruned and thinned after completion of the experiment. A disease survey in 1983 revealed that the disease levels were reduced to less than 10% for all treatments. These experimental results suggest that pruning and thinning reduce the disease levels at least in the first year after the operation. However, more evidence is required and trials designed to investigate this have recently been established.

The net effect of the different spray treatments on tree growth was small in all trials. There was no significant effect on height growth. This was expected since height is much less affected by the disease than basal area and volume (Whyte 1976). Basal area was increased by spraying only in Trials 1 and 2 after 1 year or more of successful disease control. Although the growth differences were significant they had no great practical value as they were eliminated by pruning and thinning. This is also true for the other spray experiments where spraying for disease control has not as yet increased stand growth, nor is it expected that a growth response will occur at a later date.

CONCLUSION

These experiments do not provide grounds for the view that spray costs will always be more than covered by the volume of wood saved. Nor, however, do they provide proof for those tempted to conclude that all spraying is unjustified and should cease immediately. The experiments canvassed only a narrow range of the management practices used in New Zealand forests – the experimental plots were all managed on "board", i.e., solidwood regimes, and their initial stockings were such that each final-crop tree was selected from four or more initial trees and all thinnings were to waste. Most of the differences between sprayed and unsprayed plots disappeared at the waste thinnings. If, however, initial stockings were so low that few if any trees could be culled, or should the stands have been managed to provide material for a production thinning, the conclusions as to the importance of spraying could be different.

While the financial benefits of spraying stands whose only output is likely to be low-valued fibrewood may be very questionable – particularly if there is no shortage of such material – the consequences of leaving large contiguous areas of forests unsprayed are unknown. Conceivably, inoculum could build up to extremely high levels after long spells of wet weather, with perhaps disastrous consequences to the forest. Equally, it may be that although inoculum levels increase during wet periods they subside during the periodic dry spells, with little over-all impact on forest health (this is being investigated in a recently established long-term project). Until the results of experiments designed to monitor the long-term health of large areas of unsprayed forest are known, prudence may well dictate that regardless of the management being employed spraying should be continued, particularly in the high-hazard areas. Other reasons why spraying should continue can be advanced, e.g., the concerns expressed about the health hazards posed by dothistromin which were first voiced after this paper was drafted.

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APPENDIX

TABLE 1A—Predictions of volume growth for Trial 1 using the Kaingaroa Growth Model (Cpt 360, site index 30)

Age (yr)	Top height (m)	Stocking (stems/ha)	Basal area (m^2/ha)	Mean d.b.h. (cm)	Volume (m^3/ha)
Treatment 1 (control)					
15	21.4	300	22.94	31.2	168
20	29.4	299	35.90	39.1	349
25	36.0	298	46.81	44.7	547
30	41.1	295	56.40	49.4	746
Treatment 2 (half dosage in 1969, 1971, 1975)					
15	22.0	300	23.38	31.5	176
20	30.0	299	36.10	39.2	357
25	36.4	298	46.87	44.8	554
30	41.4	294	56.36	49.4	751
Treatment 3 (single dosage in 1969, 1971, 1975)					
15	21.9	300	24.21	32.1	180
20	29.8	299	37.05	39.7	365
25	36.3	298	47.89	45.3	564
30	41.3	294	57.43	49.8	761
Treatment 4 (double dosage every year 1969–80)					
15	21.5	300	25.47	32.9	187
20	29.5	299	38.52	40.5	376
25	36.0	298	49.50	46.0	580
30	41.1	295	59.13	50.6	782

TABLE 2A—Predictions of volume growth for Trial 2 using the Kaingaroa Growth Model (final volume at age 30, top height 40 m, site index 28)

Treatment	Stocking (stems/ha)	Basal area (m^2/ha)	Mean d.b.h. (cm)	Volume (m^3/ha)
Cpt 902				
1 - control	295	62.01	51.9	807
2 - half dosage	295	63.06	52.2	815
3 - single dosage	295	62.89	52.1	812
Cpt 903				
1 - control	295	62.03	52.0	809
2 - half dosage	295	62.83	52.1	810
3 - single dosage	295	62.86	52.1	811
Cpt 904A				
1 - control	295	59.64	50.7	770
2 - half dosage	295	60.09	50.9	776
3 - single dosage	295	59.39	50.6	767
Cpt 904B				
1 - control	295	63.02	52.1	814
2 - half dosage	295	63.91	52.4	822
3 - single dosage	295	63.92	52.5	825

TABLE 3A—Projected volume production (m^3/ha) by log type for Trial 1 (percentages in parentheses)

Treatment	Pulp	Unpruned sawlogs	Pruned sawlogs	Total harvested volume
1 - control	28.9	367.8	219.5	616.2
	(4.7)	(59.7)	(35.6)	
2 - half dosage	29.1	366.1	218.8	614.0
	(4.8)	(59.6)	(35.6)	
3 - single dosage	28.1	377.3	223.7	629.1
	(4.4)	(60.0)	(35.6)	
4 - double dosage	25.2	391.7	229.4	646.3
	(3.9)	(60.6)	(35.5)	

TABLE 4A—Projected number of logs produced (by small-end diameter) for Trial 1

Treatment	Log small-end diameter (cm)										
	10	15	20	25	30	35	40	45	50	55	60
1	87	174	174	340	218	263	76	41	18	2	0
2	87	175	175	340	217	260	77	40	18	2	0
3	84	168	174	332	221	271	81	44	20	2	0
4	80	149	182	326	225	281	87	48	22	2	1

TABLE 5A—Projected percentage of total logs for Trial 1, by three size categories

Treatment	Small	Medium	Large
	s.e.d. 20 cm or less	s.e.d. 20–40 cm	s.e.d. >40 cm
1	31.23	58.94	9.83
2	31.39	58.70	9.83
3	30.50	58.99	10.52
4	29.27	59.26	11.40