GROWTH LOSSES IN PINUS RADIATA STANDS UNSPRAYED FOR DOTHISTROMA PINI

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ABSTRACT

Over a period of 5 years a stand of **Pinus radiata** D. Don annually sprayed for protection against **Dothistroma pini** Hulbary showed 6.0 m²/ha more basal area than unsprayed neighbouring stands. This difference arose from losses in diameter increment, as well as mortality, in the unsprayed areas. The growth of dominant trees in the unsprayed areas was not significantly affected. The standard operational treatment, spraying at the 25% level of green crown infection, was only marginally effective in preserving total basal area increment.

INTRODUCTION

The fungal pathogen *Dothistroma pini* was positively identified in New Zealand conifer plantations in 1964 (Gilmour 1967). Major spraying operations commenced in 1966, and in the North Island of New Zealand up to 1982–83 a total of 681 726 ha of immature *Pinus radiata* have been sprayed with copper fungicide (R. Blair, N.Z. Forest Service, pers. comm.).

Quantitative information on growth losses caused by the fungus is important to forest management, but to date there are few reliable data available, particularly over several years. The results given by Gilmour & Noorderhaven (1973) and Whyte (1976), for example, described losses after only 2 years. Van der Pas (1981) gave results from a *D. pini* infection experiment after 6 years, but did not report growth losses on a unit area basis. This paper describes one experiment designed to measure the effect of infection on *P. radiata* stand growth, and gives results 5 years after the installation of the trial.

EXPERIMENTAL METHODS

In 1976, in response to a request for forest owners to hold forest areas for *D. pini* study, 214 ha of 1972 *P. radiata* plantation were selected in N.Z. Forest Products Limited's forests near Tokoroa. In 1975, as part of the annual protection programme, the entire area had been sprayed with copper oxychloride, at a rate of application of 4.16 kg/ha in 50 *l* of water.

The experimental area was logically subdivided into five homogeneous areas of 40 ha, for which the following fungicide treatments were proposed:

(a) Regardless of the assessed infection level (Kershaw *et al.* 1982) spray annually;

(b) Spray when the infection level was assessed at 25% of effective green crown. This was the standard operational criterion.

(c) Spray when the infection level reached 50% of effective green crown;

(d) Two control areas, in which no spraying was done.

In each of the five areas, two randomly chosen points were located in the field, and a cluster of three measurement plots was established 50 m from the point and equidistant to each other. Each plot was 0.04 ha (20 × 20 m) with a 10-m buffer surround. Naturally regenerated trees were removed to leave only same-age planted stock in the plots.

All measurement plots were assessed for Dothistroma infection levels, following the procedure described by Kershaw *et al.* (1982), annually in July or August from 1976 to 1981 (the ratings were allocated as plot averages – no individual tree assessments were recorded). The assessments were carried out by N.Z. Forest Products Limited forestry staff, accompanied by Forest Research Institute forest health officers. Assessors worked independently in teams of two, and plots were re-rated if first estimates differed by more than 5%. Table 1 summarises the assessed infection levels in all plots for 1976–81. Note that the initial infection levels differed in the five treatment areas.

TABLE 1—Summary of plot Dothistroma infection levels (%)

Treatment	1976	1977	1978	1979	1980	1981
Annual spray	12.5	5.4	6.2	5.8	7.1	5.0
25% infection	15.0	19.6	18.3	30.4	16.6	17.1
50% infection	25.4	20.8	26.7	33.8	56.3	30.0
Control 1	35.8	27.5	25.4	41.2	70.8	55.4
Control 2	33.3	23.7	22.1	37.5	63.8	47.1

A 25% infection level was achieved in the block assigned to this treatment in 1979 and was sprayed therefore in November 1979, but not subsequently. By 1980 a 50% infection level had been reached in the assigned area, and fungicide was accordingly applied in November 1980. For all spray treatments the rate of application was 4.16 kg copper oxychloride per hectare in 50 l of water.

In 1976, 1977, and 1981 plot mortality was assessed and the diameter at breast height overbark of all trees in the 30 experimental plots was measured with a diameter tape. Stem height and green crown depth (defined for quantitative measurement as the vertical distance from the tip to a whorl with at least one branch containing some live needles) were measured using a height pole. All measurements were obtained close to the time of infection assessment.

STATISTICAL ANALYSES AND RESULTS

Mortality

After 1 year, one tree in an "annual spray" plot died. By 1981, however, appreciable death had occurred from severe Dothistroma infection, particularly in the two control and the 50% infection blocks. Table 2 summarises the mortality for the five treatments, and presents the linear correlations between annual infection level and tree mortality.

TABLE 2—Stem mortality by treatment

Treatment	1976 (stems/ha)	1981 (stems/ha)	Mortality (stems/ha)
Annual spray	1079	1062	17
25% infection	1325	1270	55
50% infection	1400	1245	155
Control 1	1166	1008	158
Control 2	1245	1079	166

Correlation coefficients: infection levels and mortality

	1976	1977	1978	1979	1980	1981
Annual mortality	0.587	0.544	0.652	0.652	0.760	0.650
Percentage mortality	0.629	0.548	0.636	0.641	0.787	0.710

A contingency table analysis gave highly significant ($p < 0.001$) differences in the proportion of dead and alive trees by 1981. This result and the ramifications of Table 2 are demonstrated by a regression of the logarithm of proportional mortality, against infection level 1980, which is shown in Fig. 1. The mortality incurred in the two control and the 50% infection treatments is considerably higher than in the annual spray and 25% infection treatments.

Growth Variables

From these results, it was necessary to estimate all growth variables on a gross basis. Initial basal area per hectare, mean stand height, and average green crown length were calculated from all trees in each plot for 1976 and 1981. If a tree had died by 1981, the data for 1976 were substituted.

Basal area per hectare

For the five treatments —

(a) Annual spray

(b) 25% infection level

(c) 50% infection level

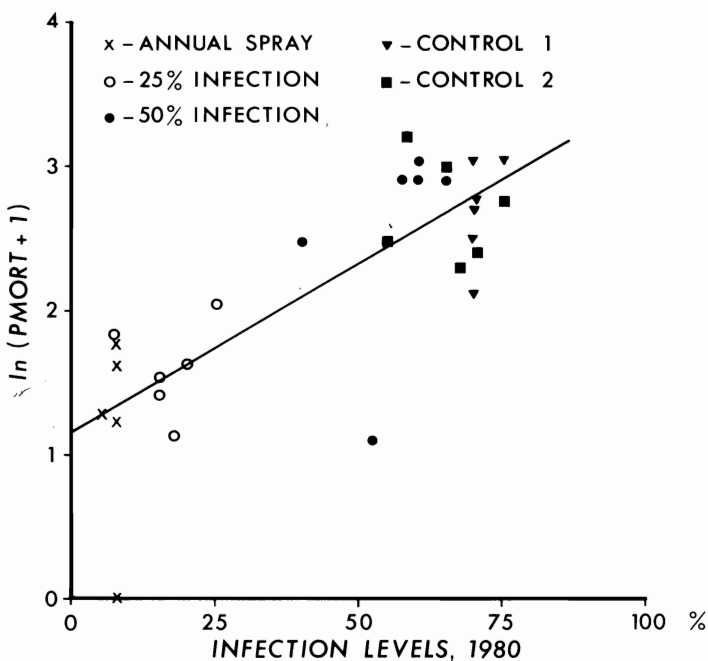(d) Control, area 1

(e) Control, area 2

a linear model was formed.

FIG. 1—Regression of stem mortality and infection levels, 1980

$$E(Y_1) = \alpha_i + \beta_i X_1 + \gamma_i X_2 \quad\text{---} \quad (1)$$

where Y_1 = basal area per hectare, 1977

$\quad\quad X_1$ = basal area per hectare, 1976

$\quad\quad X_2$ = plot infection rating, 1976

$\quad\quad \alpha_i$ = ith intercept

$\quad \beta_i\ \gamma_i$ = ith regression coefficients

$\quad\quad E$ = statistical expectation.

A series of hypotheses could be tested to establish if Equation (1) could be simplified. Applications of covariance analysis (*see* Snedecor & Cochran 1967; Freund & Littell 1981) showed that initial infection rating was completely ineffectual as a covariate, initial basal area was highly significant ($p < 0.001$), but a pooled regression coefficient should be used. This reduced (1) above to

$$E(Y_1) = \alpha_i + \beta X_1 \quad\text{---} \quad (2)$$

Further testing showed that the α_i were best represented by only one intercept, showing that very similar growth had occurred between 1976 and 1977 for all five treatments, dependent only on initial basal area.

A second model was formed

$$E(Y_2) = \alpha_i + \beta_i X_1 + \gamma_i X_2 \quad\text{---} \quad (3)$$

where Y_2 = basal area per hectare (1981) and other terms are as previously defined.

The effect of initial infection level was again completely non-significant, and was omitted. Graphical plotting of Y_2 against X_1 showed a small amount of curvilinearity, so (3) was modified to

$$E(Y_2) = \alpha_i + \beta_i \ln(X_1) \quad \text{---------------------------------------} \quad (4)$$

where $\ln$ = natural logarithm.

The inclusion of the logarithmic transformation reduced the residual mean square by 22%. Linear model analysis of (4) showed that a single regression slope was appropriate, but three significantly different intercepts were justified –

(a) Annual spray $(p < 0.001)$
(b) 25% infection $(p < 0.05)$
(c) All other treatments $(p < 0.001)$.

The final equation was

$$E(Y_2) = \begin{bmatrix} 18.7993 \ (a) \\ 14.0991 \ (b) \\ 12.7416 \ (c) \end{bmatrix} + 11.8861 \ \ln(X_1) \quad \text{-----------------} \quad (5)$$

with the coefficient of determination (r^2) equal to 0.849.

These treatments were adjusted for initial differences in basal area by standard covariance methods (see Ostle 1963, p. 442) and estimated basal area yields for 1981 were –

$$\text{Annual spray} = 31.2 \ \text{m}^2/\text{ha}$$
$$25\% \ \text{infection} = 26.5 \ \text{m}^2/\text{ha}$$
$$\left. \begin{array}{l} 50\% \ \text{infection} \\ \text{Control 1} \\ \text{Control 2} \end{array} \right\} \ 25.2 \ \text{m}^2/\text{ha}$$

Height

Mean stand height in 1977 was examined by a model using mean stand height 1976, stocking, and initial infection level as covariates. Neither stocking nor infection level were shown to be significantly related, but initial stand height was highly significant $(p < 0.001)$. All five treatments had very similar height increments, with no significant differences between them.

An identical model was employed to analyse mean stand height 1981, and initial stand height was again the only effective covariate. Using the equation

$$E(H_2) = \alpha_i + \beta_i H_1 \quad \text{---------------------------------------} \quad (6)$$

where H_2 = mean stand height, 1981
           H_1 = mean stand height, 1976

linear model analysis gave a significantly $(p < 0.05)$ different regression slope for the 50% infection and the two control treatments, and two intercepts justified for the annual spray and 25% infection treatments. The final height equation was (denoting treatments as above)

$$E(H_2) = \begin{bmatrix} 7.7539 & (a) \\ 7.156615 & (b) \\ 3.021055 & (c) \end{bmatrix} + \begin{bmatrix} 2.352095 \ (c) \\ 1.454196 \ (a,b) \end{bmatrix} H_1 \quad \text{-----} \quad (7)$$

with the coefficient of determination (r^2) equal to 0.986.

Equation (7) is depicted in Fig. 2. Estimates of mean stand height 1981 were –

Annual spray   = 12.8 m
25% infection   = 12.2 m
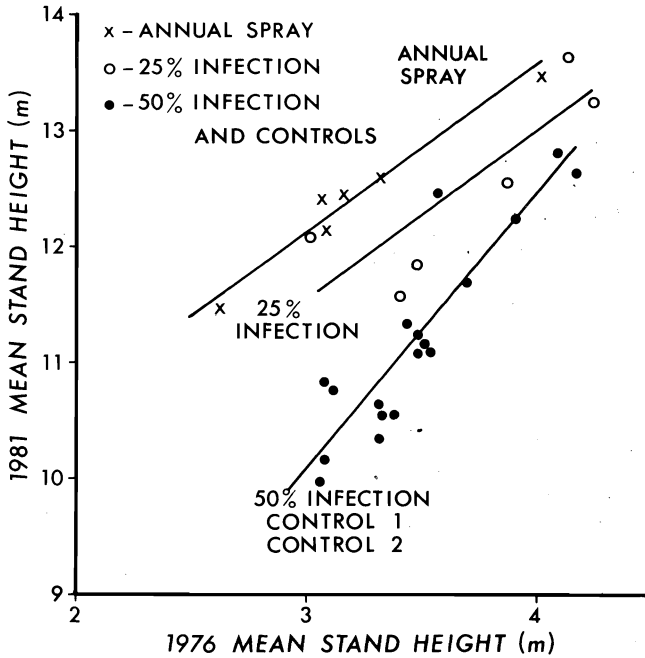50% infection, Controls = 11.2 m

FIG. 2—Regression model of mean stand height

Green crown length

Similar methods of analyses for average green crown length were carried out. In 1977, initial crown length and initial infection level were significant covariates ($p < 0.01$ and 0.05 respectively) but all treatments had equivalent green crown length estimates. By 1981, however, highly significant differences in crown length were evident, with both initial crown length and stocking acting as efficient covariates, but initial infection level was no longer significant.

The final model was

$$E(L_2) = \begin{bmatrix} 8.5493 \ (a) \\ 7.6887 \ (b) \\ 6.9386 \ (c) \end{bmatrix} + 1.4153 \ (L_1) - 0.00212 \ (N_1) \ \dots \ (8)$$

where L_2 = mean crown length, 1981
       L_1 = mean crown length, 1976
       N_1 = stems per hectare, 1976

and other terms are as previously defined.

The coefficient of determination (r^2) for Equation (8) was 0.811. Estimates of green crown length, adjusted for initial crown length and stocking were –

Annual spray	= 9.8 m
25% infection	= 8.9 m
50% infection, Controls	= 8.2 m

Final-crop Trees

The response of potential final-crop trees was examined by analysing components of each plot diameter distribution. All sets of trees were ranked by 1981 diameter size, and the stems representing the largest 100, 200, up to 500 stems/ha were extracted from the total plot data.

The basal area and mean top height of the five crop classes were tested for treatment differences by covariance analyses. Infection levels and stocking were totally ineffective covariates, but initial basal area and height (corresponding to the chosen trees) were highly significant. The top 100, 200, and 300 stems/ha classes showed no differences in basal area or height. The 400 and 500 stems/ha components, however, had significantly higher basal area associated with the annual spray treatment; height development was also superior for this treatment for the top 500 stems/ha.

DISCUSSION

This trial was designed to examine the effect of different field applications of copper fungicide to combat *D. pini* infecting immature *P. radiata*. Because the objective of the experiment was to study the performance of treatments in operational conditions, the study area was unavoidably large, and some experimental problems arose. For example, it was unknown when the selected blocks would reach, if at all, their intended infection levels. It transpired that during the period reported on there were 2 years of low infection (1977 and 1978) and 3 years of very high infection (1979, 1980, and 1981). Dense weed growth emerged in the unsprayed areas during this time (notably *Rubus fruticosus* agg.) and the experimental plots became very difficult to reach and measure.

To ensure that any treatment responses were not seriously confounded with variables such as stocking, site, or differences in initial infection levels, it was necessary to conduct thorough statistical analyses of the data. Examination of the 1977 analyses indicated that mortality, basal area, height, and crown length were very similar in all five blocks, giving some assurance that no appreciable site differences were present. Initial infection level was associated only with crown length, but its effect was negligible. Analyses of the 1981 data gave further evidence in this respect; initial infection levels were completely unrelated with any response variable, while the unsprayed controls in two independent blocks had equivalent growth.

The single spray, annually applied, irrespective of disease level, has given satisfactory control of infection and a clear advantage over the unsprayed controls in basal area (6.0 m²/ha or 24%) and height (1.6 m or 13%). The former N.Z. Forest Products Limited prescription of a single spray at the 25% level of green crown infection was considerably lower in growth than the annual spray, with a response of 1.3 m²/ha in

basal area, and 1.0 m in height. In part, this result has influenced a Company operational decision to spray when infection ratings rise above 15%. The experimental treatment at an infection level of 50% of the effective green crown has completely failed to preserve increment.

Figure 3 illustrates the experimental area, photographed in July 1980. The lighter crown colour, and sparser stocking in the unsprayed blocks is quite conspicuous.

FIG. 3—The experimental area, showing the state of the blocks after heavy infection in 1979 and 1980: A = annual spray; B = 25% infection; C = 50% infection; D = control 1; E = control 2.

The analysis of mean stand height is noteworthy for the greater variation in the non-annual spray plots, and the different regression slope, applicable for the 50% and control treatments. This result suggests that smaller sets of trees are more vulnerable to loss of height growth through Dothistroma infection, but they can be protected from retardation by regular spraying.

The quantitative measure of green crown length, to the lowest whorl containing some green needles, was chosen for consistency, but in hindsight it is not particularly useful, and very probably under-estimates the true loss of crown from the disease. For example, Whyte (1976) used the tip of the tree down to a point in the crown where Dothistroma was not plainly evident, as a measure of crown length. Although harder to assess accurately, this makes more biological sense and highlights the past disease status more forcefully. Whereas we were only able to detect crown loss to be 1.6 m. Whyte demonstrated a loss of 3.9 m in a comparable experiment.

The finding that there is no significant difference in dominant trees is not at variance with van der Pas (1981) who showed that increment loss can be related to individual tree infection. Our results suggest that there is a final-crop element in a stand which does not show an increment loss when the stand shows a high disease rating.

If the results are accepted there are obvious implications. If the final crop is the major objective, then even in relatively high hazard areas spraying is unnecessary, but this proposal would have to reconcile additional logging costs, caused by very dense undergrowth, and production thinnings would probably not be feasible.

CONCLUSIONS

The trial, to date, has shown that in a relatively high hazard area a single spray (4.16 kg copper oxychloride per hectare in $50\,l$ of water) annually applied has achieved satisfactory control of the fungal disease *D. pini*. The operational prescription of a single spray when infection is rated at 25% has not given adequate protection, while spraying at 50% infection has been shown to be totally ineffectual.

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