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BENEFITS OF THE DOTHISTROMA RESISTANT BREED OF RADIATA PINE

by

S.D. Carson, A. Dick, and G.G. West

REPORT NO. 12 JULY 1989

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EXECUTIVE SUMMARY

Potential benefits from using the Dothistroma Resistant Breed are estimated to be a 15% decrease in mean stand infection, a 61% reduction in spraying costs, and recovery of growth loss due to even low levels of Dothistroma infection. GF ratings are based on data from non-Dothistroma sites and should be modified to reflect genetic gain expectations for growth on Dothistroma sites for the Dothistroma Resistant Breed. Data suggest that the Dothistroma Resistant Breed will perform much better than any other Breed on sites where Dothistroma infection is expected to be chronic and severe. The Dothistroma Resistant Breed is recommended for planting on areas where spraying for Dothistroma control is expected.

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BENEFITS OF THE DOTHISTROMA RESISTANT BREED OF RADIATA PINE

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SUMMARY

A seedlot of the Dothistroma Resistant Breed can now be made available that is expected to have a significantly reduced level of Dothistroma infection. Although we do not yet have information from large-plot genetic gain trials to confirm the size of the reduction, the best estimate to date from progeny trials and other information is that the mean infection of a stand of trees planted with the best seedlots of the Dothistroma Resistant Breed will be about 15% less than for other seedlots.

GF ratings given by the New Zealand Seed Certification Service suggest that the Dothistroma Resistant Breed will have reduced growth compared with the Growth and Form Breed (Vincent, 1987). GF ratings are based on growth on non-Dothistroma sites, and the Dothistroma Resistant Breed will probably grow slower on these sites than comparable Growth and Form Breed seedlots with higher GF ratings. However, recent evidence suggests that with equal GF ratings the Dothistroma Resistant Breed will substantially out-perform the Growth and Form Breed for volume production on high-hazard Dothistroma sites.

Savings in spraying costs for the last six years have been estimated for Kinleith forest using the assumption that the forest had been planted with the Dothistroma Resistant Breed and all stands had 15% less infection. The average annual cost of spraying would have been reduced from over three-quarters of a million dollars to about three-hundred thousand dollars, a saving of 61%.

Simulations of stand growth using the growth model EARLY (modified to reflect the effects of Dothistroma infection on growth through a simulated pruning) suggest that a lowering of stand infection by 15% will result in less growth loss from Dothistroma infection. Simulations with data from stands with less than 10% infection, or with heavy infection for only a part of the rotation, suggested that growth recovery of about 4-5% of the mean basal area at age 9 would be obtained using the Dothistroma Resistant Breed. This growth recovery might restore the growth of stands of the Dothistroma Resistant Breed close to their predicted level of improved growth rate on non-Dothistroma sites, while the Growth and Form Breed will not realise its full potential in the presence of the disease.

INTRODUCTION — THE IMPACT OF DOTHISTROMA NEEDLE BLIGHT

Dothistroma needle blight, caused by the fungal pathogen *Dothistroma pini* Hulbary and first identified in New Zealand in 1962 (Gilmour, 1967), has regularly been severe in radiata pine (*Pinus radiata* D. Don) since its introduction to New Zealand (Carson and Carson, 1986; Sweet, 1989; van der Pas *et al.*, 1984). Net value loss from Dothistroma needle cast has been estimated to be $6.67 million dollars per annum (Carter, 1989).

Climatic conditions appear to be largely responsible for high disease incidence. Severe attack appears to arise in the years and on sites in which climatic conditions are conducive to fungus infection, growth, and reproduction, that is, to a high rate of disease increase. Conditions which are conducive to disease increase are warm temperature, high light intensity, and long leaf wetness periods (Gadgil, 1977; Gilmour, 1981).

To reduce losses, aerial spraying of copper fungicide has been carried out since the early 1970's (Gilmour *et al.*, 1973). An annual survey of disease levels in young stands in high hazard areas is followed by spraying if disease levels are over 15-25%. Severely infected stands are often sprayed twice annually (Kershaw *et al.*, 1982). Up to 20% of New Zealand's radiata pine plantations in susceptible age classes have been sprayed with copper fungicide in years with high infection levels. The disease usually occurs on trees younger than 15 years old, and plantation areas requiring control spraying now regularly exceed 100,000 ha/annum (Carter, 1989). Control costs over the last 30 years averaged more than $1.65/ha (in 1989 dollars) for the national radiata pine estate (Carter, 1989).

Dothistroma needle blight appears to cause growth loss in proportion to the extent of the foliage infected (van der Pas, 1981; van der Pas *et al.*, 1984; Woollons and Hayward, 1984). Aerial spraying does not eliminate the disease. In addition to the 100,000 ha requiring spraying, the disease infects an additional 300,000 ha of the forest estate at levels below the historical or current intervention spray levels, causing an estimated periodic growth loss of up to 5% for the first half of the rotation (Carter, 1989). Further, up to an estimated 25% of the annual spray programme is not effective in reducing growth loss of infected stands below a 5% level (Carter, 1989). The economic returns of spraying in terms of growth recovery have been questioned (van der Pas *et al.*, 1984).

WHAT IS THE DOTHISTROMA RESISTANT BREED?

Early in this decade, trial results showed Dothistroma infection to be a moderately heritable trait, and successful field selection was demonstrated (Wilcox, 1982). In 1983, the Genetics and Tree Improvement group at the Forest Research Institute began the development of a Dothistroma Resistant Breed of radiata pine (Carson and Carson, 1986). The Resistant Breed was developed using breeding population parents already improved for growth and form traits. This was the most efficient method for improving overall gains, since the existing breeding population had at least as much *Dothistroma* resistance as any alternative land race or provenance population of *P. radiata*. Since 1983, all the best parents for growth and form in the New Zealand radiata pine breeding population have been successfully screened for Dothistroma resistance, resistant radiata pine parents have been identified, and a strategy has been devised for producing a breed especially suitable for high hazard Dothistroma sites (Carson, 1989).

Dothistroma resistance in radiata pine appears to be a trait very amenable to genetic improvement (Carson, 1989). The trait has been found to exhibit high additive inheritance and is thus well-suited to population improvement using quantitative genetic methods. There appears to be very little non-additive variance, suggesting that parental selection, rather than full-sib family selection, or clonal selection, will yield greatest gains (M. Carson, 1986). In addition, selected families have been found to have stable resistance over years and sites.

Genetic resistance to Dothistroma is a desirable goal if use of the resistant breed can be expected to result in increased value of the final crop. The Dothistroma Resistant Breed can be expected to produce the greatest gain on high hazard sites. Increased value will come from an increased volume at harvest age and from reduced costs of growing the stand. A ten parent control-pollinated seed orchard is recommended for production of highly resistant stock for planting on high-hazard Dothistroma sites.

WHY A 10-PARENT CONTROL-POLLINATED ORCHARD?

A ten-parent control-pollinated orchard represents close to the maximum possible selection intensity that can be applied, and, therefore, the maximum genetic gains which can be obtained using current seed production and propagation methods. Because of the increased risks associated with greater genetic uniformity, this level of selection is being recommended for the Dothistroma Resistant Breed. At higher selection intensities, genetic disease resistance might be overcome by the pathogen. This could occur if strong selection pressure is placed on a virulent strain of the pathogen, and as a result the virulent strain increases its relative population size through time. High selection pressure against host resistance can result from extended exposure of a genetically variable pathogen population to a genetically uniform host population (Horsfall *et al.*, 1972).

Breeding programmes, especially those which emphasise disease resistance, should, therefore, have a strategy for the management of genetic uniformity. Dothistroma resistance appears to behave as a classical quantitatively inherited trait. This could mean that either (1) resistance is controlled by many genes, each with a small effect, or (2) many resistance mechanisms are operating, each controlled by different genes and each with associated pathogen specificity patterns (Carson and Carson, 1989). In either case, random mating of ten highly-resistant parents should produce a seedlot which can be used with confidence throughout New Zealand, since it will contain an adequate level of genetic variability, probably sufficient to prevent resistance from breaking down.

HOW MUCH WILL DOTHISTROMA INFECTION BE REDUCED BY GENETIC SELECTION

Genetic gains can be predicted from progeny test results using quantitative genetic theory (Falconer, 1960). The reduction in the average percent of needles infected has been predicted several times for the Dothistroma Resistant Breed from several different progeny test data sets, and for several different selection strategies (Carson, 1989; Carson and Carson, 1986; Shelbourne *et al.*, 1986). Predicted gains for a 10-parent control-pollinated seedlot have ranged from 9-16% reduction in stand mean infection. Probably the most representative estimate across sites and years was an estimated reduction of 12% in the average stand disease level using seven assessments of four progeny test sites at ages 2-5 years from planting. The stand average percent of the needles infected for these assessments ranged from 8 to 58% (Carson, 1989). The predicted reduction in infection did not, however, appear to be related to the overall level of infection in the progeny test. The predicted reduction in percent of infected needles varied from site to site, the lowest with a 7% reduction and the highest with a 20% reduction. This kind of variation in genetic gain with site occurs for all improved traits and must be accepted as inherent in the nature of tree improvement gains made against a background of variable climatic and site factors

HOW REALISTIC ARE ESTIMATES OF GAIN FROM PROGENY TESTS?

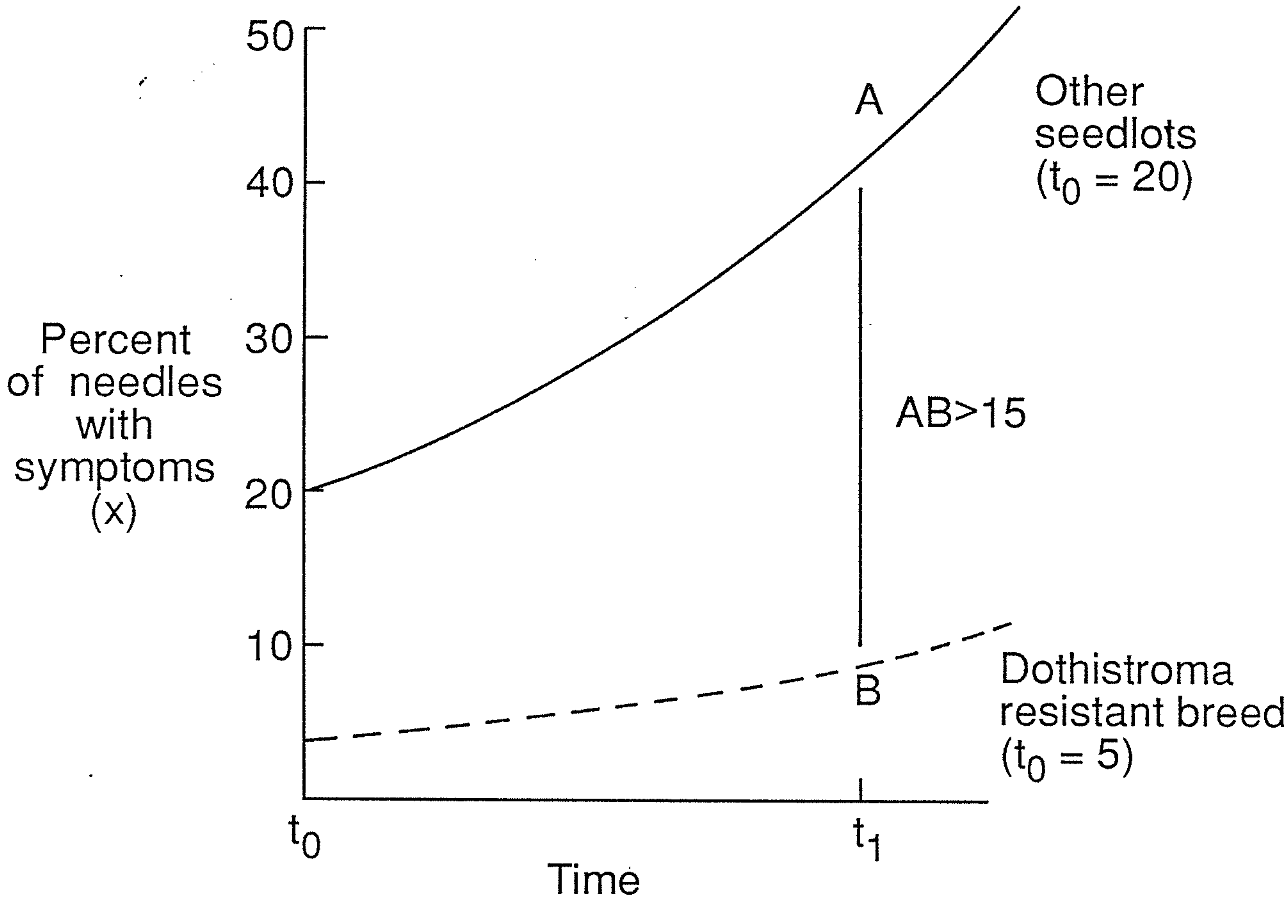
Theoretically calculated predictions of genetic gains are commonly used by tree breeders to compare alternative breeding and selection strategies (M. Carson, 1986; S. Carson, 1988; Matheson and Lindgrin, 1985; King and Johnson, 1989a, 1989b). In order to make predictions, a selection strategy has to be defined, that is, one has to choose (1) the selection criteria and their relative weighting, (2) progeny test assessment results appropriate for use in selection, and (3) the expected method of seed production (which is directly related to the number of individuals to select). A change in any one of these choices will lead to a change in the resulting prediction of genetic gain. For this reason, tree breeders are reluctant to say that theoretical predictions indicate absolute levels of genetic gains which will be realised in the field. Gain calculations are very dependent on the nature and number of the progeny tests from which the calculations were made, and the span of sites and years over which these tests were established and grown. Progeny trials are sited to be as representative of the total forest estate as possible, but only a small proportion of sites can be sampled. Further, theoretical calculations assume that selection is done "by the book", whereas, selection and seed production strategies in operational programmes are always modified by practical considerations like the rooting, grafting, flowering, and seed producing capability of each parent.

WILL OTHER FACTORS INFLUENCE DISEASE IN RESISTANT STANDS?

There is another reason why theoretical calculations of genetic gain in Dothistroma resistance should not be used directly as estimates of absolute gain. These calculations assume that the performance of selected individuals will be the same when they are planted together in a stand as when planted among non-selected individuals (as in a typical progeny test). The "real" gain which will be achieved for any trait can only be reliably estimated from genetic gain trials where blocks of improved stock are planted on the same site as blocks of non-improved stock.

Large stands planted solely with resistant families may have less infection than would be indicated from the performance of these families in infected progeny tests. Because of a resistant tree's ability to slow or prevent infection and/or sporulation, a highly resistant tree will produce less inoculum than a highly susceptible tree. If spore movement is in large measure within a stand, a stand of highly resistant trees will support a much reduced fungus population than a progeny test or stand containing trees of all susceptibility levels.

The branch of plant pathology which studies populations of pathogens is called Epidemiology. Van der Plank (1963) first applied the equation representing growth of biological populations to plant pathogens. As illustrated by the equation (Figure 1), X_{t_1} represents the size of an isolated fungus population (and thus the amount of disease) at the end of a given period of population growth ($t_1 - t_o$). The final level of disease is directly related to the initial inoculum, that is, the size of the spore population at the beginning of the period (X_{t_o}), which would probably be smaller on resistant trees. Genetic selection may well also reduce the rate of disease increase (r) (which is held constant for the two curves in Figure 1) and thus reduce pathogen population growth even further.



$$x_{t_1} = x_{t_0}\, e^{r(t_1 - t_0)}$$

where e = natural logarithm
r = rate of disease increase

Figure 1: Disease development during the period ($t_1 - t_0$) for the Dothistroma Resistant Breed (with 10% infection) and other seedlots (with 25% infection) assuming a constant rate of disease increase (r). Note that the difference in disease level between the stands is greater at t_1 than at t_0.

The size of the spore dispersal gradient (and thus the extent of isolation of the pathogen population within a stand) has not yet been well quantified for Dothistroma infection. Also, the relative rate of disease increase between resistant and susceptible parents has not been measured. Therefore, we cannot yet accurately quantify the extent of this epidemiological effect.

With spores dispersed via a water-droplet splash mechanism like those of *Dothistroma pini*, however, the distance of dispersal of the bulk of inoculum is likely to be shorter than for many other forest diseases which are disseminated by wind bourne spores. Spores of *D. pini* are liberraged in a film of water and normally do not travel far. Infection in a stand is generally only from neighbour to neighbour (Gadgil, 1984). This is supported by data from Australia (Marks and Smith, 1987) and New Zealand (L. Bulman, unpublished) which showed lower infection levels on widely spaced trees than on closely spaced trees.

If resistant families support only a reduced rate of disease increase or if dispersal gradients fall largely within a stand, as seems likely, predictions from progeny tests would be underestimates of the real gain in resistance from using resistant selections. In a resistant stand inoculum pressure (that is, the number of spores challenging any individual) will be lower, and, therefore, the overall mean infection will also be lower. This epidemiological effect could be substantial. Because of this, a conservative but a perhaps more realistic estimate of reduction in stand mean infection that may be expected in stands planted with the Dothistroma Resistant Breed might be 15%.

WHAT ARE THE OPPORTUNITY COSTS OF THIS LEVEL OF REDUCTION IN DOTHISTROMA INFECTION?

On the surface there appear to be opportunity costs associated with selecting for a special breed with high Dothistroma resistance. An ideal Dothistroma Resistant Breed would combine maximum achievable genetic gains in all important traits with disease resistance. Unfortunately, the nature of population improvement of trees is that with more selection criteria, the expected gains in each selection criterion will be less than if fewer selection traits were used.. Thus, the addition of Dothistroma resistance as a selection criterion can result in some reduction in the predicted gain in other important traits over the best achievable. Form traits appear to be little affected by the addition of Dothistroma resistance as a selection criterion. The means of different sets of parents selected with varying amounts of emphasis on Dothistroma resistance differed only slightly for both straightness and malformation scores (Carson, 1989). Therefore, tree form gains can be expected to be similar for the Growth and Form Breed produced by the New Zealand breeding programme (Vincent, 1987) and the Dothistroma Resistant Breed.

Predicted gain in growth rate on sites with no Dothistroma infection is, however, reduced when heavy selection emphasis is placed on Dothistroma resistance as reflected by GF rating of seedlots selected with differing emphasis on Dothistroma resistance (Table 1). Since only a proportion of radiata pine plantations in New Zealand are affected by Dothistroma, and these sites can usually be identified, use of Dothistroma resistance as a major selection criterion is only appropriate for those sites. The Growth and Form Breed has little emphasis placed on Dothistroma resistance (Shelbourne *et al.*, 1986), and this should be used for the majority of New Zealand sites with low hazard for Dothistroma infection. The pertinent question then becomes whether or not the benefits of decreased disease levels from a Dothistroma Resistant Breed outweigh these apparent reductions in growth on high hazard Dothistroma sites.

TABLE 1: Predicted gains1/ on sites with no Dothistroma infection and on a site with high infection for six sets of "880" series control-pollinated families2/ selected at different ages and using different selection criteria3/

Selection criteria and year of selection4/	GF	No infection		High infection (1 site)5/		
		Volume	DBH	Volume	DBH	Dothistroma
		(4 sites) Age 4	(average of 3 sites) Age 7	(age 4 ht, Age 5 dbh)	Age 5	Age 3-7
Dothistroma	20	11	1	10	5	16
Growth & Form 86	26	**30**	**8**	8	4	7
Dothistroma + Volume (1) 86	20	16	0	**19**	**8**	16
Dothistroma + Volume (2) 86	24	24	5	**17**	**8**	14
Growth & Form 89	27	**26**	**8**	7	4	-4
Dothistroma + Volume 89	23	22	4	**20**	**9**	12

1/ Volume and DBH gains expressed as a percent of the mean. Dothistroma gains expressed as expected reduction in precent of needles infected.

2/ Each set of families contains six parents, which are expected to represent a 10-parent control-pollinated seedlot selected from all breeding series.

3/ Within column comparisons of seedlot rankings are valid, but comparisons between columns are less precise because of the slightly different assumptions (that is, the number of progeny test sites used) for calculation of heritabilities. The best sets of selection criteria in each column are highlighted.

4/ The 1986 selections used age 4 growth data on 4 sites with no Dothistroma infection. The 1986 selections used growth data at age 7 on 3 sites and age 4 on one site with no Dothistroma infection, and at age 5 on the high infection site.

5/ 30-40% infection from age 2.

Recent data suggests that sets of parents chosen with different amounts of selection emphasis placed on Dothistroma resistance and growth performed differently when grown on a site with high Dothistroma infection than on sites with essentially no Dothistroma infection (Table 1). Expected genetic gains in growth were higher on non-Dothistroma sites when Dothistroma resistance was not a selection criterion (Carson, 1989). However, in a heavily infected progeny trial expected gains in growth were much higher for those sets of parents where resistance was heavily emphasised. GF ratings are lower for the seedlots emphasizing Dothistroma resistance, but GF ratings are calculated almost exclusively using data from non-Dothistroma sites. Therefore, in the presence of repeated Dothistroma infection, it is likely that the Dothistroma Resistant Breed will perform better for volume than even the best seedlots from the Growth and Form Breed. This is probably a direct result of the differences in disease levels of the different sets of progeny, as reflected in the predicted reduction in average Dothistroma infection for the different sets of progeny (Table 1).

HOW MUCH VOLUME LOSS WILL BE RECOVERED BY A 15% REDUCTION IN DOTHISTROMA INFECTION?

The results presented in Table 1 suggest that growth losses from Dothistroma infection are significant. Each of the investigations of the effect of infection on the early growth rates of radiata pine (van der Pas, 1981; Woollons and Hayward, 1984; van der Pas, 1984) has found that individual trees or stands with less crown infection grow faster than those with more infection. A relationship between disease level and volume loss on individual trees was established by van der Pas (1981), who showed that annual volume increment was reduced in proportion to disease level. Infection levels vary from year to year. How much will the average reduction of 15% in the volume of green crown infected in a stand, as predicted for the Dothistroma Resistant Breed, reduce growth loss due to Dothistroma infection?

The Early Growth Model (EGM) (West *et al.*, 1982; West *et al.*, 1987) can be used to predict growth of radiata pine plantations from age three to about age 15. The model is driven by the relationship between green crown length and growth rate. It is based on a very large data set and is being used extensively by forest managers in New Zealand. We have attempted to quantify the avoidance of growth loss from a 15% reduction in crown infection by simulating the growth of the infected stand studied by van der Pas (1981, 1984) using the EGM.

The EGM was constructed from plots that had little or no *D. pini.* Low disease levels were achieved either by annual copper spray programmes, or because of locality and silvicultural regime. Therefore, in order to take *D. pini* infection into account, the model required adjustment.

The linear relationship between growth increment and disease level reported by van der Pas (1981) was not used, since it was quantified at only one site, and also because van der Pas suggested that, "It may be reasonable to expect non-linearity at higher disease levels...". Further, the basal area increment to crown/ha relationship in EGM indicates that crown and stocking effects are interrelated and cannot be considered separately (Knowles and West, 1986). Also, reductions in basal area growth with low disease levels and high crown length may be very small.

As an alternative approach, the amount of Dothistroma infection was related to loss in green crown length and an adjustment to EGM was implemented as an annual pruning effect. This approach assumes that growth loss from Dothistroma is entirely due to removal of infected needles from the active green crown. The known relationship between green crown length (incorporated in EGM) is thus utilised to predict growth, rather than the relationship between growth loss and different levels of disease. This method required conversion of visual assessments of disease, estimated as the percentage of normal green crown infected on a crown volume basis (van der Pas *et al.*, 1984) to a crown length basis. To relate this score (by volume of crown in 5% steps) to crown length, a crown shape had to be assumed. The green crown of young stands was considered to closely approximate a tear drop shape. To simplify calculations this shape was modified to two cones, with the lower cone pointing downwards with a length of one metre set for all crown lengths. By knowing the height of the tree and the proportion of the crown infected for each year, the effect of Dothistroma infection could be converted to an equivalent annual pruning lift.

To test these assumptions growth data from a trial in Kaingaroa Forest with two levels of Dothistroma infection was compared to model predictions. The data used have been reported by van der Pas (1984). Trial plots were either sprayed annually with copper fungicide or left unsprayed. All trees were pruned to 2.0-2.5 m and thinned from 1250 stems to 625 stems/ha at age 4, and pruned to 4.2 m and thinned to 300 stems/ha at age 6. Infection in the sprayed plots remained less than 12% from age 2. Infection in the unsprayed plots was 55, 36, 34 and 29 percent at ages 1-4, respectively, and less than 10% from ages 5-9. Infection was, therefore, only high in the early years, and only in the unsprayed plots.

When actual height, Dothistroma infection levels, and silvicultural operations were input to the modified EGM, predictions of basal area (BA) at age 9 were quite close to the actual age 9 BA, representing errors of 5% for the sprayed plots and 3% for the unsprayed plots. These errors were considered well within the expected error limits set by West *et al.* (1987). The model therefore was used unadjusted to test other scenarios. Two scenarios were simulated, each with the same inputs to the model except for (1) Dothistroma infection levels 15% less than the actual levels, and (2) no simulated Dothistroma effect.

Table 2: Basal area (age 9) predicted using the EARLY growth model for a trial with two levels of Dothistroma control , the Dothistroma Resistant Breed if it had been planted on the same site1/, and the same site with no Dothistroma infection.

Spray treatment	Predicted basal area		
	With measured infection	Dothistroma Resistant Breed	No Dothistroma
Sprayed annually (less than 10% of the needles infected)	7.5	7.8	7.8
BA loss2/	4%	0%	0%
Unsprayed (29-55% of needles infected at aged 1-4)	6.9	7.3	7.6
BA loss2/	9%	4%	0%

1/ Assuming 15% less infection each year.
2/ % of BA predicted with no Dothistroma.

Simulated use of the Dothistroma Resistant Breed (assuming 15% reduction in annual disease level) produced an increase of 4 percent in predicted BA of the sprayed (low infection) plots and 5 percent in BA of the unsprayed (high infection) plots (Table 2). The simulation of stand growth with no Dothistroma was considered to represent the maximum possible growth for these comparisons. The simulated growth loss of 4-5% may be considered substantial, given the short time during which the disease had a significant impact on the unsprayed plots, and the low level of disease in the sprayed plots. These results suggest that growth losses may still occur even with low levels of infection. A stand in Kinleith Forest is sprayed an average of 5.4 times during its life time and some stands have been sprayed as many as 10 times. These stands may be experiencing something like 5% growth losses due to Dothistroma infection.

Another study examined growth losses from Dothistroma infection on a stand basis in a nine year old stand with a higher stocking (1079-1400 stems/ha) and with no pruning or thinning (Woollons and Hayward, 1984). With increasing disease levels mortality increased and losses were recorded in both stand basal area and height (Table 3). The three treatment groups which were significantly different for stand growth traits also had consistently different infection levels.

Table 3: Age nine stand growth 1/ calculated by Woollons and Hayward (1984) and change in average infection which would have been expected with use of Dothistroma Resistant Breed

Treatment		Mortality (stems/ha)	Estimated growth		Percent crown infected	
			Basal area (m^2/ha)	height (m)	Actual average	Dothistroma resistant breed 2/
(a)	Annual spray	17	31.2	12.8	7.0	0.0
(b)	spray at 25%	55	26.5	12.2	19.5	4.50
(c)	spray at 50% or no spray	159	25.2	11.2	36.5	21.50

1/ from 1976-1981, ages 4-9.
2/ assuming 15% reduction in crown infection

If disease levels had been reduced by 15% to simulate use of the Dothistroma Resistant Breed for this study, the effect might be equivalent to moving a stand from one treatment group to the next best treatment group. Under this assumption, the stand with an average of 25% infection was estimated to have a 5% greater basal area and to be 9% taller at age 9 than the stand with an average of 37% infection. The stand with 7% infection was estimated to have 18% more basal area and to be 5% taller than the stand with 20% infection (Table 3).

WILL A 15% REDUCTION IN INFECTION AFFECT AERIAL CONTROL COSTS?

A further investigation was carried out to determine the effect of a reduction in crown infection of 15% on the NZFP control programme. The effect on spray programmes from 1983 to 1988 was examined. Since 1983, the NZFP Forests Ltd prescription for the copper spray control programme has been to spray all radiata pine stands aged 2-16 that have an infection level of 15% of the green crown length or greater. Any stand that exceeds 30% infection is sprayed twice. The control programme is preceded by a survey of levels of infection over extensive areas of forested land. Stands surveyed fall into one of three categories: no spray, single spray, or double spray. No attempt is made to score and record an individual infection level for each stand.

Because of the lack of survey detail, the following assumptions were made:

1. Stands sprayed once were equally distributed over the range for each infection score between 15 and 30.

2. The same assumption of equal distribution was applied to stands that required a second spray. For second spray stands it was assumed that the maximum possible infection level was 80%.

3. Using the 15% reduction figure, it was postulated, for example, that a stand of unimproved breeding stock scored at 29% would score 14% if established with the Dothistroma Resistant Breed. The stand, therefore, goes from requiring a single spray to requiring none. Likewise, a stand that would have scored 44% with unimproved stock is reduced to 29% and goes from a double to a single spray.

4. The cost of the aerial control programme includes cost of copper and oil, flying, supervision, ground control, and survey.

Reallocation of stands to spray categories with 15% lower infection levels results in a substantial reduction in the area which would have required aerial control measures (Table 4). The average cost for the annual control programme would be reduced from over three-quarters of a million dollars to about three hundred thousand dollars, a saving of 61%, or almost a half million dollars per annum.

Table 4: Area sprayed (thousands of ha) and costs (thousands of 1988 dollars) of spraying Kinleith Forest with copper fungicide and estimated area and costs required if Dothistroma Resistant Breed had been planted 1/

Year	Actual		Dothistroma Resistant Breed		Savings	
	Area sprayed	Cost	Area sprayed	Cost	Area sprayed	Cost
1983	19	464	15	384	4	80
1984	59	1230	14	338	45	892
1985	32	673	7	195	25	478
1986	58	1160	27	563	31	597
1987	40	655	8	163	32	492
1988	31	477	10	168	21	309
Mean	40	777	14	302	26	475

1/ Assuming 15% reduction in mean infection of all stands.

WILL THERE BE OTHER BENEFITS FROM USING THE DOTHISTROMA RESISTANT BREED?

Concern has recently been expressed that the health of New Zealand's radiata pine plantations has deteriorated over the last 30 years (Sweet, 1989). There is evidence from research trials indicating that high levels of one disease can cause increased susceptibility to another. For example, growth reduction in trees heavily infected by both *Dothistroma* and *Armillaria* measured in one study was greater than the sum of the losses attributable to heavy infection by each fungus alone (Shaw and Toes, 1977). Also, in the study of growth loss from Dothistroma infection reported by Woollons and Hayward (1984), a significant agent in the loss of growth was mortality due to *Armillaria* sp. infection.

The importance of identifying contingency species for situations in which radiata becomes uneconomic to grow has been emphasized (Sweet, 1989). However, because of the high performance of radiata pine compared to other species in New Zealand, use of contingency species would involve a very large opportunity cost. Use of the Dothistroma Resistant Breed even on milely infected sites in New Zealand would enhance the health of radiata pine, and, thus, may reduce the risk that radiata pine will succumb to other disease and insect agents.

WHAT IS THE OUTLOOK FOR THE FUTURE?

Gains in Dothistroma resistance are expressed in this paper as an absolute reduction in the stand mean infection. Genetic gains for other tree improvement traits are usually expressed as a percent of the unimproved population mean (Anon, 1987). When compared on a similar basis, genetic gains from this first generation of selection for Dothistroma resistance are substantial, and compare well with gains expected in other traits.

Further, since resistance can be identified in progeny tests by age 3 (as opposed to growth and form traits, which cannot be reliably identified until about age 8), genetic gains in resistance from a single generation of breeding and selection can be made in a shorter time than for most other traits. All the information necessary to achieve an expected 15% reduction in disease levels from the first generation of selection has been obtained since 1983. Given current technology (Menzies *et al.*, 1988), it would be possible to deliver these gains in planting stock, through control-pollination and multiplication of juvenile cuttings, in about three years.

There is no reason to believe that as much gain in resistance will be made in the next generation as in this first generation. The short time required for selection of Dothistroma resistant parents would allow two generations of breeding and selection for resistance to be carried out during the time required for selection of parents for the Growth and Form Breed, thus increasing gains in resistance. This strategy should be considered in planning the New Zealand breeding programme.

There is evidence that substantial further gains in resistance are available. Resistance of a group of selections made in Kenya (Ivory and Paterson, 1970) for their Dothistroma resistance and growth and form in Kenya (the "867" series) and selections made in heavily infected stands in New Zealand during the mid-sixties (the "869" series, Wilcox, 1982) was higher than for any other parents in the current breeding population. Although these parents were not included in the 10-parent CP orchard seedlot because of uncertainty of their performance for growth and form relative to New Zealand selections, they are now being crossed with other parents in the New Zealand breeding population. Their value will be realised in the next breeding generation, when their good performance for resistance will be combined with good performance for growth and form.

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