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A BREED OF RADIATA PINE RESISTANT TO DOTHISTROMA NEEDLE BLIGHT

S.D. Carson and M.J. Carson
Forest Research Institute
Rotorua, New Zealand

ABSTRACT

Dothistroma needle-blight, caused by the fungus *Dothistroma pini* Hulbary, affects large areas of *Pinus radiata* D. Don in New Zealand. It is controlled by a costly annual spray programme. Genotypic variability in resistance has been demonstrated, heritabilities have been shown to be moderately high, and successful field screening for resistant trees has been carried out. Genetic gains in resistance can, therefore, be expected from progeny testing and recurrent selection. Work is now under way to develop a *Dothistroma*-resistant breed with as high a resistance as possible, while maintaining the improved growth and tree-form currently being achieved from general-purpose seed orchards.

KEYWORDS

Pinus radiata, *Dothistroma pini*, progeny testing, recurrent selection, seed orchards, general combining ability, specific combining ability.

INTRODUCTION

Extensive areas of New Zealand's forests of *Pinus radiata* D. Don are sprayed annually to control dothistroma needle blight, caused by *Dothistroma pini* Hulbary. Copper fungicide is applied as an aerial spray where the average level of infection exceeds 25% of needles on the green crowns of infected trees (Kershaw *et al.* 1982). In high-hazard regions spraying is usually advisable when infection levels reach 15%. Approximately 100,000 ha were sprayed in the spring and summer seasons of 1984 and 140,000 ha in 1985, at a cost of $10 to $20/ha.

Because dothistroma needle blight in New Zealand usually attacks only trees younger than 15 years, and since peak infection is generally reached at age 2 to 8 years, retardation of growth begins early in the forest rotation. Growth losses on individual trees appear to be directly related to the percentage of foliage infected by *Dothistroma* (Shaw *et al.* 1977; van der Pas 1981). Van der Pas (1981) found that, compared with healthy trees, trees with up to 50% of the crown volume diseased showed a percent volume reduction before canopy closure which equated approximately to the percent of the volume of the crown with disease symptoms. Comparisons of sprayed and unsprayed stands have shown that stand basal area (and therefore volume) increases after disease reduction (van der Pas *et al.*, 1984; Woollons and Hayward 1984).

The impact of dothistroma infection on radiata pine in New Zealand varies considerably with site. Warm temperature, high light intensity, and long leaf wetness period all greatly encourage disease development (Gadgil 1977; Gilmour 1981). In New Zealand dothistroma needle blight appears to be largely confined to areas where the climate is suitable for growth and reproduction of the fungus (Kershaw *et al.*, 1982).

The radiata pine breeding programme in New Zealand started over 30 years ago. Substantial gains in growth and tree-form traits are now being realised in plantations derived from clonal seed orchards (Forest Research Institute 1983). Dothistroma needle blight was first recorded in New Zealand in 1962 (Gilmour 1967), well after the radiata pine breeding programme was initiated. By the late 1960's the incidence of disease was alarming but resistance to *Dothistroma* was not immediately included as a selection criterion in the radiata pine breeding programme. One reason for this was the successful development of a method of disease control with aerial application of copper fungicides (Gilmour *et al.* 1973), which has been logistically feasible in New Zealand (and not elsewhere) mainly because of the prior existence of a large aerial topdressing industry. Also, at the time when dothistroma was introduced into New Zealand, a suitable method of screening for resistance had not been demonstrated, and very little information on heritability of the disease was available.

Aerial spraying does not, however, eradicate dothistroma and in the absence of alternative control measures, current disease levels will probably be maintained. Relative costs of spraying have been constant since the spray programme was initiated (Figure 1), largely because fungicide application methods have been improved (Forest Research Institute 1982). However, control may become more expensive in the future if costs of fungicides, aircraft fuel, or other related items continue to increase. In addition, a re-examination of the effectiveness of aerial spraying programmes in reducing disease has raised doubts about the economics of current control programmes (van der Pas, *et al.*, 1984; Woollons and Hayward 1984). Consideration of these factors, and the recent development of a suitable field screening method for dothistroma resistance (Wilcox 1982), have led to the initiation of a programme to select and breed dothistroma-resistant radiata pine.

SELECTION METHODS

Several methods of screening and selection of radiata pine for dothistroma resistance have been investigated. Intensive phenotypic selection was carried out in heavily infected stands shortly after introduction of the disease and this selection was partially successful in identifying resistant phenotypes. However, few of the selected trees could match seed-orchard trees with respect to growth, stem straightness, and improved branch quality (Wilcox 1982).

Information on the expression of dothistroma resistance has so far been obtained from field progeny trials originally planted for assessment of growth and form traits. Most of these trials have been deliberatley sited to avoid disease problems and opportunities to evaluate resistance of the parents have been limited and somewhat fortuitous. The strongly marked pattern of spot infection within stands at many sites was thought likely to preclude effective screening through field progeny testing. However, it now appears that use of experimental designs with high replication, coupled with careful selection of site and consistent assessment methods (van der Pas, *et al.*, 1984), can give adequate screening for dothistroma resistance (Carson 1986; Wilcox 1982).

Two independent trials have given moderately high estimates of narrow-sense heritability for dothistroma resistance in radiata pine (Table 1). Groups of the best and the worst crosses clearly differed in the percentage of crown infected. General combining ability (GCA) appears to be much more important than specific combining ability (SCA). Estimates of the relative importance of general combining ability (R) (Baker 1978) expressed by

$$R = 2\ \sigma^2_{GCA} / (2\ \sigma^2_{GCA} + \sigma^2_{SCA}) \times 100\%$$

where σ^2_{GCA} and σ^2_{SCA} are the GCA and SCA variances, respectively, were very high (Table 1). Successful selection for dothistroma resistance, therefore, can be expected using GCA of parents rather than information on the performance of specific crosses (Carson 1986).

From limited unpublished data (R.D. Burdon, M.J. Carson, S.D. Carson) it appears that family rankings for dothistroma resistance remain fairly stable from site to site and at differing ages. Confirmation of this pattern awaits further results from existing trials.

Dothistroma pini produces a toxin, dothistromin (Bassett *et al.*, 1970; Shain and Franich 1981), which when injected into excised needles produces typical symptoms (Shain and Franich 1981), sometimes including a rapid necrotic response accompanied by accumulation of the phytoalexin, benzoic acid. This apparent 'hypersensitive' reaction appears to be one of several resistance mechanisms of radiata pine to dothistroma (Franich *et al.*, 1986). Length of lesions produced by injection of dothistromin has been suggested as a trait that could be used for indirect selection for dothistroma resistance (Shain and Franich 1981).

Indirect selection can be effective in screening for disease resistance of forest trees. Indirect selection methods usually take less time than field progeny testing and allow greater numbers of parents to be screened. Success of indirect selection for disease resistance usually depends on there being a higher heritability for the indicator trait than for the target trait, and a high genetic correlation between indicator and target traits (Searle 1978).

Unfortunately, from recent work by Franich *et al.* (1986), selection based on lesion lengths following dothistromin injection does not appear to be useful for indirect selection for dothistroma resistance. In a trial of 50 pine families, narrow sense heritability of the laboratory procedures was low (0.10) when compared wth field progeny tests (Table 1), and the correlation with field assessments of dothistroma infection was only moderate (0.50).

Experiments are in progress which will evaluate the feasibility of progeny testing juvenile seedlings through controlled inoculation. Methods of controlled inoculation

Table 1. Dothistroma infection mean, range, and genetic parameters estimated from two disconnected diallel progeny trials.

		Average percent of needles infected				Relative importance of general combining ability
Progeny trial	age at assessment	five best crosses	stand mean	five worst crosses	narrow-sense heritability	
25-parent[1]	5	-	-	-	0.30	92%
	7	29	40	51	0.19	82%
91-parent[2]	4	4	12	22	0.37	94%

[1] Five complete five-parent half diallels. Five-year assessment (Wilcox 1982) used a 0-4 scale related to infection. Seven-year assessment involves unpublished data (S.D. Carson).

[2] Sixteen incomplete half diallels with 154 crosses (Carson 1986).

and assessment are being tried similar to those used successfully (Powers *et al.* 1982; Carson 1984) to evaluate resistance of loblolly pine (*P. taeda* L) and slash pine (*P. elliottii* Engelm. var *elliottii*) to fusiform rust, caused by *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*. If these prove successful, it should be possible to develop a more cost-efficient screening method, and to screen progeny of orchard candidates in one year rather than the 5 to 6 years presently required for field testing.

SEED PRODUCTION AND BREEDING PLANS

The goal of the dothistroma-resistance breeding programme is to produce stock for high-hazard sites with as much resistance as possible while maintaining the growth and tree-form gains achieved to date from improved orchards (Shelbourne *et al.*, 1986). In a selection programme, gains achieved in any one trait are likely to be reduced with the addition of a new selection trait. Since disease levels vary considerably with site, dothistroma resistance will be a selection trait only for sites where disease levels are expected to be high, allowing gains in growth and tree form to be maximised for low-hazard sites. For high-hazard areas dothistroma resistance will be the most important selection trait.

Since 1970, two out of every five years have been severe disease years (Fig. 1). In these years control measures have been required on about 20% of the area in susceptible age classes (age 1 to 15 years). Assuming that this trend

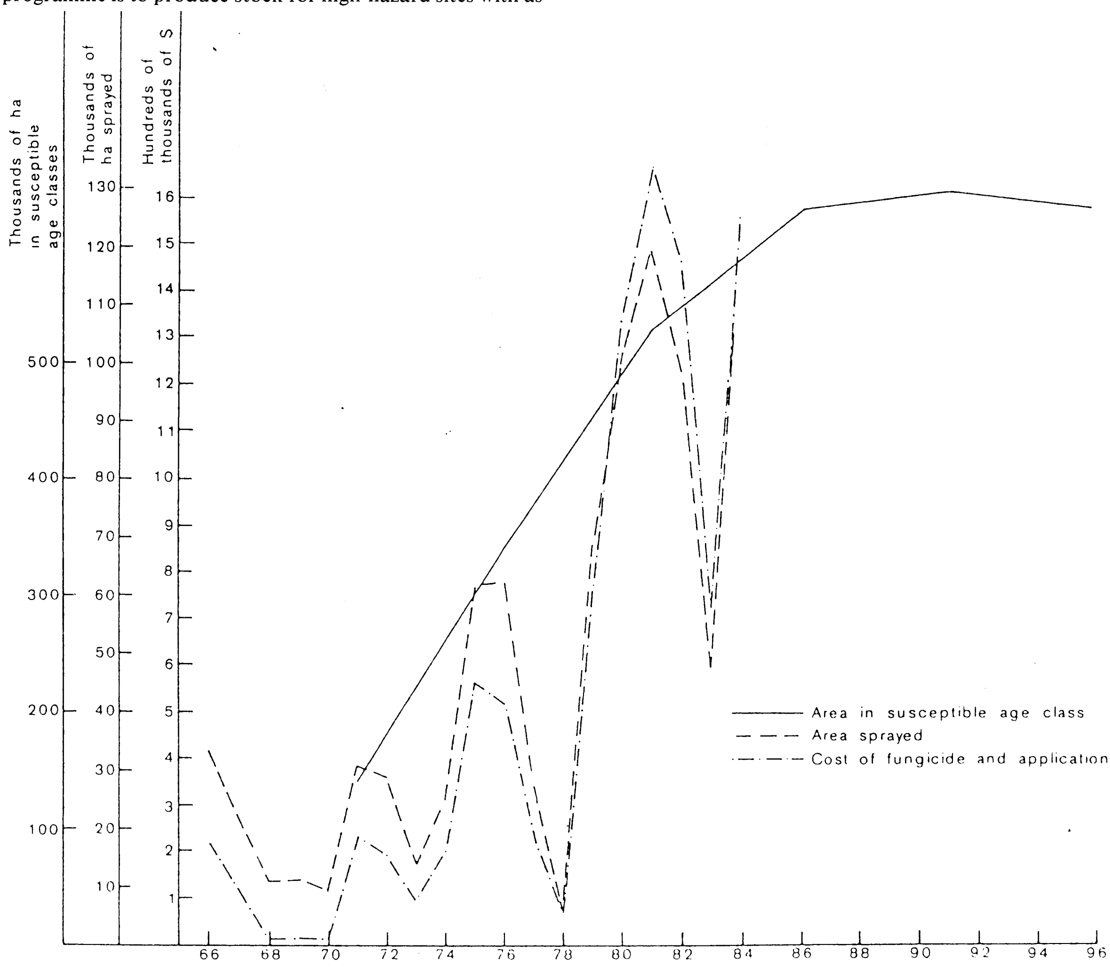

Figure 1. Area of *Pinus radiata* in age classes (1 to 15 years) susceptible to *Dothistroma pini*, area sprayed with Cu fungicide, and cost of fungicide and fungicide application in New Zealand.

continues, it appears, with current planting projections, that propagules sufficient to plant about 8,000 ha per year of high-risk dothistroma sites are required by the forestry sector.

Open-pollinated progeny of about 350 of the best breeding population clones selected for growth and tree-form traits have been established in trials, with 25 to 30 single-tree replications, at five high-hazard dothistroma sites. A conventional open-pollinated seed orchard (18.8 ha) is being established by the New Zealand Forest Service at a coastal Bay of Plenty site at Papamoa. Because of its favourable location, this orchard is expected to give earlier and higher yields of seed than most other seed orchards in New Zealand. Forty parents will be selected for seed orchard establishment using early GCA information from the progeny trials. Selection will be done primarily on dothistroma resistance with little further culling for growth and form traits. The orchard will be planted from 1986 to 1988 and is expected to produce seed in commercial quantities beginning in 1992. After culling in the orchard, seed will be produced from 20 resistant parents. For stands with an average of 12 to 40% crown infection, resistance of seed-orchard progeny is predicted to reduce the average amount of infected crown by about 7 to 10%. This figure was obtained using the data in Table 1 from the equation:

$$G = 2\, i\, \sigma_f\, h_f^2$$

where G = expected gain in resistance,
i = selection intensity (represents the proportion of individuals selected),
σ_f = phenotypic standard deviation of half-sib family means, and
h_f^2 = heritability of half-sib family mean.

(The coefficient has a value of 2 because both pollen and seed parents will be selected). The prediction does not allow for pollen contamination which inevitably reduces gains from open-pollinated orchards, sometimes by as much as 25%.

In addition to the open-pollinated orchard, a second, control-pollinated orchard is being planted at the Papamoa site using a few intensively selected parents with high levels of dothistroma resistance. Seed produced through controlled pollination, which will first become available in 1991, is expected to be grown and vegetatively multiplied before planting in the field. The percentage of the crown infected with dothistroma in plantings of progeny of the ten most resistant parents in the main breeding population will be reduced by an estimated 9 to 12% (cf earlier figures of something less than 7 to 10%). These figures probably under-predict the disease reduction that will actually be achieved because they omit the probable reduction in overall levels of disease that will result from the lowered amount of inoculum in stands of resistant stock. Availability of trees grown from control-pollinated orchard seed will be limited only by our ability to multiply them as cuttings; techniques for doing this have not yet been proven on a commercial scale. If these methods prove successful, then small quantities of seed from control-pollinated orchards may be adequate to supply all high hazard sites with trees, and the open-pollinated orchard will no longer be necessary.

In the interim, before the special-purpose seed orchards begin producing seed and until all parents in the main breeding population are screened, dothistroma-resistant seed is being collected from resistant mother trees in existing open-pollinated seed orchards. The first collection of this type (five parents selected out of 25) was made and distributed in 1983. Gains predicted from this approach are small, a 3 to 5% reduction of total crown infected, but offsetting this the cost of obtaining the seed from existing orchards is very low.

The dothistroma resistance programme will be kept within the framework of the main breeding programme, rather than separating off an independent breeding population. In order to do this we propose using three-stage tandem selection. In the first stage, control-pollinated families which are progeny of the most dothistroma-resistant parent stock will be identified from the general-purpose breeding population. In the second stage, individuals will be selected from within these families on the basis of growth and form traits. In the third stage, offspring of these selected individuals will be screened for dothistroma resistance using indirect screening methods (if available) or otherwise through field trials. Parents having the most resistant offspring will be established in orchards for production of resistant seed. In this way we hope to make continued genetic gains in growth and form traits, as well as substantial second-generation gains in dothistroma resistance.

Biological and genetic information available to date suggests that inherited resistance is likely to be stable. It is hoped that radiata pine forests planted with trees from the dothistroma-resistant breed will have reduced disease levels throughout the life of the forest stands.

CONCLUSION

The selection and breeding programme for dothistroma resistance will produce moderately resistant seed from mother-tree collections in existing seed orchards to meet immediate demands, while providing for more highly resistant seed supplies from special-purpose orchards (both open-pollinated and control-pollinated) in the near future. Advanced-generation breeding among resistant clones should eventually yield seed-orchard progeny with substantially increased genetic gains in resistance along with additional gains in other important traits.

REFERENCES

Baker, R.J. 1978. Issues in diallel analysis. *Crop Science 18:* 533-536.

Bassett, C., Buchanan, M., Gallagher, R.T., Hodges, R. 1970. A toxic difuroanthraquinone from *Dothistroma pini. Chemistry and Industry 52:* 1659-1660.

Carson, M.J. 1984. Breeding for resistance to fusiform rust in loblolly pine. PhD thesis, North Carolina State University, Raleigh, North Carolina, USA. 110p. (University Microfilms).

Carson, M.J. 1986. Control-pollinated seed orchards of best general combiners — a new strategy. Proceedings Plant Breeding Symposium, DSIR, Lincoln, New Zealand, Feb 17-20, 1986. *Agronomy Society of NZ Special Publication 5:* 144-149.

Forest Research Institute. 1982. Aerial spraying of forests for the control of *Dothistroma. Forest Research Institute Annual Report.* 121p.

Forest Research Institute. 1983. Genetic improvement from present and future seed orchard stock. *Forest Research Institute Annual Report.* 120p.

Franich, Robert A., Carson, Michael, J., Carson, Susan D. 1986. Synthesis and accumulation of benozic acid in *Pinus radiata* needles in response to tissue injury by dothistroma, and correlation with resistence of *P. radiata* families to *Dothistroma pini. Physiological and Molecular Plant Pathologys 28:* 267-286.

Gadgil, P.D. 1977. Duration of leaf wetness periods and infection of *Pinus radiata* by *Dothistroma pini. New Zealand Journal of Forestry Science 7:* 83-90.

Gilmour, J.W. 1967. Distribution, impact and control of *Dothistroma pini* in New Zealand. *Proceedings 14th IUFRO Congress Section 24:* 221-247.

Gilmour, J.W. 1981. The effect of season on infection of *Pinus radiata* by *Dothistroma pini. European Journal of Forest Pathology 11:* 265-269.

Gilmour, J.W., Leggat, G.J., Fitzpatrick, J. 1973. Operational control of *Dothistroma* needle blight in radiata pine plantations in New Zealand, 1966-73. *Proceedings 26th NZ Weed and Pest Control Conference:* 130-138.

Kershaw, D.J., Gadgil, P.D., Leggat, G.J., Ray, J.W. and van der Pas, J.B. 1982. Assessment and control of *Dothistroma* needle blight, revised edition. *NZ Forest Service Forest Research Institute Bulletin 18.*

Powers, H.R. Jr., Hubbard, Susan D., Anderson, Robert L. 1982. Testing for resistance to fusiform rust of pine. *In* Resistance to diseases and pest in forest trees. Proceedings of the Third International Workshop on the Genetics of Host-Parasite Interactions in Forestry. H.M. Heybroek, B.R. Stephan and K. von Weissenberg (eds). Wageningen, the Netherlands, 14-21 Sept. 1980: 427-434.

Searle, S.R. 1978. The value of indirect selection II Progeny Testing. *Theoretical and Applied Genetics 51:* 289-296.

Shain, Louis, Franich, Robert A. 1981. Induction of *Dothistroma* blight symptoms with dothistromin. *Physiological Plant Pathology 19:* 49-55.

Shaw, Charles G. III., Toes, Elizabeth H.A. 1977. Impact of *Dothistroma* needle blight and *Armillaria* root rot on diameter growth of *Pinus radiata. Phytopathology 67:* 1319-1323.

Shelbourne, C.J.A., Burdon, R.D., Carson, S.D., Vincent, G. 1986. Radiata pine development plant. *Forest Research Institute Bulletin* (in press).

van der Pas, J.B. 1981. Reduced early growth rates of *Pinus radiata,* caused by *Dothistroma pini. NZ Journal of Forestry Science 14:* 14-22.

van der Pas, J.B., Bulman, L., Horgan, G.P. 1984. Disease control by aerial spraying of *Dothistroma pini* in tended stands of *Pinus radiata* in New Zealand. *NZ Journal of Forestry Science 14:* 23-40.

van der Pas, J.B., Kimberley, M.O. and Kershaw, D.J. 1984. Evaluation of the assessment of dothistroma needle blight in stands of *Pinus radiata. NZ Journal of Forestry Science 14:* 3-13.

Wilcox, M.D. 1982. Genetic variance and inheritance of resistance to Dothistroma needle blight in *Pinus radiata. NZ Journal of Forestry Science 12:* 14-35.

Woollons, R.C., Hayward, W.J. 1984. Growth losses in *Pinus radiata* stands unsprayed for *Dothistroma pini. NZ Journal of Forestry Science 14:* 14-22.

SYMPOSIUM DISCUSSION

Dr H.S. Easton, Grasslands Division, DSIR

Does the question raised by the economists indicate that loss of yield due to the disease has not been very great?

Carson

I think it is more a question of the effectiveness of the control. Disease losses can be demonstrated if disease levels are reduced by spraying many times, but the level of spraying may not be worthwhile for the disease reduction that is gained.

Mr I.B. Staples, Queensland Department of Primary Industries.

Do these trees ever recover from the disease, or do they get weaker and die?

Carson

There were tree deaths in the 1960's, but we don't see many trees dying now.

Staples

Is it possible that older trees have acquired resistance through a previous attack of the disease.

Carson

I don't think so — the chemist who did the work on *Dothistroma* believes that it has something to do with the waxes in the stomata.

Dr M.D. Wilcox, Forest Research Institute

A comment on the way forest tree breeding seems to differ from apple breeding. In tree breeding, we are not drawing on genes for resistance from anywhere else, such as another species — there seems to be enough variation within the present population; and the method of screening and testing relies heavily on natural infection.

Mr H.K. Hall, Crop Research Division, DSIR

You said that you found quite a number of green trees in brown stands, but you discarded them and went back to find some degrees of tolerance rather than resistance in these initially selected trees. Are you using these green trees from brown stands in further crossing?

Carson

Of over 60 trees only five were of good enough growth and form to be included in the breeding programme. These five are in our progeny trials, so we will be able to see if they are much more resistant than others.

Dr R.D. Burdon, Forest Research Institute

A further comment on the differences between forest tree breeding and fruit tree breeding. With forest trees, we are concerned with stability of population resistance whereas the fruit tree breeders are concerned with stability of clonal resistance. As stability of population resistance does not seem to depend too closely on the stability of evolutionary genotype resistance, the fruit tree breeder has a more difficult task than the forest tree breeder.

Dr S.A. Menzies, Plant Diseases Division, DSIR

Has there been any information to show segregation from progeny of the green trees in brown stands?

Carson

We do not know yet — the clonal tests we have are very small and that is all the work that has been done.