Mycosphaerella leaf disease reduces growth of plantation-grown *Eucalyptus globulus*

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Summary

Species of *Mycosphaerella* cause significant leaf damage and defoliation in young eucalypt plantations in southern Australia and overseas. The effects on growth, however, have not been adequately quantified, although over 310 000 ha of *Eucalyptus globulus* had been planted in Australia by the end of 2000. In a replicated field experiment (2-y-old *E. globulus* family trial) exposed to natural infection by species of *Mycosphaerella*, we periodically sprayed fungicides (benomyl and chlorothalonil) on half of the trees and not the other half. Quantitative assessments of disease (both severity of leaf spots and defoliation) and measurements of tree height and diameter were conducted periodically over the following 17 mo.

The fungicides effectively controlled the disease caused by the species of *Mycosphaerella* present in the trial (*M. cryptica* and *M. nubilosa*). Even at low levels of infection by the *Mycosphaerella* spp. (less than 10% leaf area affected), the unsprayed trees had significantly poorer growth, with height increment reduced by 13% and diameter increment by 4%. Defoliation of unsprayed trees (61%) was double that of sprayed trees (32%). Severity of leaf spots was positively correlated with defoliation (r = 0.36, P<0.001), and defoliation was negatively correlated with both height increment (r = −0.37, P<0.001) and diameter increment (r = −0.29, P<0.001) — evidence that disease was reducing growth. While spraying controls disease, it is time-consuming and may not be commercially viable. Breeding for resistance to reduce the impact of *Mycosphaerella* leaf disease may be the most economic control strategy.

Keywords: plant pathogenic fungi; fungal diseases; plant pathology; fungicides; defoliation; growth; *Eucalyptus globulus*; *Mycosphaerella cryptica*; *Mycosphaerella nubilosa*; Australia

Introduction

Species of *Mycosphaerella* are among the most damaging pathogens in young eucalypt plantations in southern Australia (Marks *et al.* 1982; Carnegie *et al*. 1994; Dungey *et al*. 1997; Carnegie *et al*. 1998; Park *et al.* 2000). Leaf disease caused by *Mycosphaerella* species reduces the photosynthetic area of surviving leaves and results in premature abscission of severely affected leaves, and may ultimately reduce the growth rate of trees. The two most common and damaging species in Australia are *M. cryptica* (Cooke) Hansf. and *M. nubilosa* (Cooke) Hansf. Both particularly affect the juvenile leaves of *Eucalyptus globulus* Labill. in plantations in southern Australia (Park and Keane 1982a, b; Carnegie *et al*. 1994; Dungey *et al*. 1997; Carnegie *et al*. 1998; Milgate *et al.* 2001; Maxwell *et al.* 2003). Of the two, only *M. cryptica* infects adult leaves of *E. globulus* (Park and Keane 1982a), and this pathogen has been observed causing significant damage in *E. globulus* plantations up to 6 y old (Carnegie 2000; Carnegie and Ades 2001).

By the year 2000, over 310 000 ha of *E. globulus* had been established in Australia for commercial purposes (mainly pulp) (Wood *et al.* 2001), and a planting rate of 5000–20 000 ha y^{-1} is expected to continue in the short to medium term. This large investment in a rapidly expanding plantation estate makes it surprising that losses attributable to *Mycosphaerella* leaf disease have been estimated only very roughly, and remain to be properly quantified.

The little work that has been done (e.g. see Lundquist and Purnell 1987; Carnegie *et al*. 1994) was conducted in infected plantations with no uninfected control. Both studies correlated disease with growth measurements on infected trees only. These indicated that defoliation attributed to *Mycosphaerella* spp. was associated with reduced growth in young plantations of *E. nitens* (Deane & Maid.) Maid. (Lundquist and Purnell 1987) and *E. globulus* (Carnegie *et al.* 1994). Only more recently have studies assessed damage in a controlled field experiment, where differences in growth were measured in the presence and absence of these damaging fungi as well as insects (Stone *et al.* 1998a,b).

In this paper we report a study of the effect of damage (both leaf spot and defoliation) caused by species of *Mycosphaerella* on tree height and diameter in a young *E. globulus* plantation in Gippsland, Victoria. The aim of the study was to more accurately quantify the effects of *Mycosphaerella* leaf disease on growth of plantation-grown *E. globulus* as a basis for determining whether control strategies (e.g. chemical spraying or breeding for resistance) are warranted in relation to the economic impact of disease.

Materials and methods

Description of trial

A family trial (52 families) of *E. globulus* (Jeeralang, Victoria provenance) established in June 1990 by Grand Ridge Plantations Pty Ltd at Glencoe, Victoria, Australia, was used for this experiment. The experimental design for the trial was a randomised complete block with single-tree plots of the 52 families in 20 replicates. Trees were spaced 3.6 m × 2.8 m on an oblique grid. The trial was in two sections: one with 14 replicates (arranged 2 by 7) and the other with 6 replicates (arranged 1 by 6), separated by a buffer of about 6 rows of plantation eucalypts.

Fertiliser was applied in July 1990 as 54 kg ha^{-1} Hi-Fert (22:10:12 N:P:K). The site is undulating, with well drained, sandy soils, and was previously planted with *Pinus radiata* D.Don. There was sparse (less than 50 stems ha^{-1}) weed growth of native shrubs, which grew to less than 1 m tall in the inter-rows during the time of this study. This plantation was situated near a similar plantation that had severe *Mycosphaerella* leaf disease and defoliation in previous years (Reinoso 1992).

Spraying and assessment

Twelve of the 20 replicates (hereafter referred to as the treatment plots) were chosen in such a way as to reduce the effects of inter-plot interference and drift of spray between treatments (i.e. a ‘buffer’ plot separated each pair of ‘treatment’ plots). The twelve were then divided into six pairs with one member of each pair chosen at random to be repeatedly sprayed with fungicide. The other members were left unsprayed to make six replicates each with two treatments containing the 52 *E. globulus* families.

Every three weeks from October 1992 to May 1993, the sprayed plots were treated with a combination of 2.5 kg ha^{-1} of chlorothalonil and 0.5 kg ha^{-1} of benomyl to reduce infection by *Mycosphaerella* species. Chlorothalonil is a protectant fungicide and benomyl is a systemic fungicide. These fungicides have both proved effective in the control of *Mycosphaerella* spp. in eucalypt nurseries and field trials and have suppressed germination of ascospores *in vitro* (Sandberg and Ray 1976; Ganapathi 1979). Trees were sprayed by hand. Both surfaces of juvenile leaves were sprayed to run-off and adult foliage was also sprayed where height permitted.

This experiment relied on natural infection and as only very minor infection occurred in the first year, spraying resumed in October 1993, and was repeated every three weeks until March 1994.

Severity of *Mycosphaerella* leaf disease was assessed, and tree height and diameter over bark at 15 cm above ground were measured, in all 12 plots every six weeks from October 1992 to July 1993, and from October 1993 to March 1994. Diameter was measured at 15 cm because many trees were initially shorter than 1 m. Juvenile foliage was assessed using an assessment scale similar to that developed by Carnegie *et al.* (1994) and used by Dungey *et al.* (1997), but adapted to account for the lower disease severity in this trial by the inclusion of an 0.5% class. Diseases caused by both *M. cryptica* and *M. nubilosa* were assessed together, as it is not feasible to separate them accurately in the field. The severity scale, based on the fraction of the juvenile crown that was infected (leaf area affected), was:

0	=	no infection;	5	=	25%;
0.5	=	1% severity;	6	=	30%;
1	=	5%;	7	=	35%;
2	=	10%;	8	=	40%;
3	=	15%;	9	=	45% and
4	=	20%;	10	>	45% severity.

The fraction of juvenile crown that was defoliated (see Reinoso 1992) rather than the fraction of the whole crown (see Carnegie *et al.* 1994) was assessed in January 1994 and March 1994. Defoliation in this trial was associated with premature senescence of previously infected leaves and blighting infections of newly expanded leaves, and progressed from the lower crown upwards, similar to that described and assessed by Lundquist and Purnell (1987) and Carnegie *et al.* (1994). This ‘bottom-up’ defoliation is the common form of defoliation in 2–3-y-old *E. globulus* plantations in Victoria (Reinoso 1992; Carnegie *et al.* 1994), southern NSW (Carnegie unpublished) and north-western Tasmania (Dungey *et al.* 1997). ‘Top-down’ defoliation, associated with blighting infections of young expanding or newly expanded leaves, is common in 1-y-old plantations in Tasmania where adult foliage is not yet present, and is likely to be the result of a single infection event during a period of epidemic disease (T. Wardlaw, *pers. comm.*). Most trees in the trial at Glencoe had reached the age at which adult foliage was present and disease severity in adult foliage was assessed in July 1993, October 1993, March 1994 and August 1994 using the scale and method that had been developed for juvenile foliage.

Statistical analysis

There was no observable effect of spraying on disease severity until after January 1993 (see Fig. 1), so increase in height and diameter were calculated from January 1993 to March 1994. It was April 1993 before disease severity differed between treatments, so analyses of disease (juvenile severity, adult severity, and defoliation) were conducted on scores made from this date onwards. The scores were averaged for each disease trait (i.e. the average score for each trait on each tree was calculated as a mean of the severity measured in successive measurements between April 1993 to March 1994). Analyses of variance were carried out on all scores at each assessment to test for the effects of spraying on disease and growth, and correlations were calculated between all disease and growth traits. All analyses were carried out using the GLM and CORR procedures in SAS 6.12 (SAS Institute Inc. 1996). Due to the nature of the data (point scores), various transformations were tested, but none improved either heteroscedacity or normality, so raw scores were used.

Results

Effect of fungicides on *Mycosphaerella* leaf disease

Disease caused by *M. cryptica* and *M. nubilosa* was effectively controlled by the combination of the benomyl and chlorothalonil fungicides (Fig. 1 and Table 1). The mean disease severity on juvenile leaves of sprayed trees was about 3% (raw scores

Table 1. Mean severity of *Mycosphaerella* leaf disease on juvenile foliage, severity of *M. cryptica* on the adult foliage, percentage defoliation of the juvenile crown, and height and diameter of *E. globulus* at each assessment time

Variable	Treatment	Date of assessments									
		Oct ’92	Nov ’92	Jan ’93	Mar ’93	Apr ’93	Jul ’93	Oct ’93	Dec ’93	Jan ’94	Mar ’94
Juvenile severity	Sprayed	1.06	1.04	1.02	0.78	0.76	0.71	0.86	0.80	0.77	0.72
	Unsprayed	1.02	1.01	1.03	1.11	1.13	1.33	1.51	1.83	1.76	1.72
Adult severity	Sprayed	-	-	-	-	-	1.18	1.00	-	-	0.69
	Unsprayed	-	-	-	-	-	1.61	1.56	-	-	1.57
Defoliation (%)	Sprayed	-	-	-	-	-	-	-	-	30.3	32.1
	Unsprayed	-	-	-	-	-	-	-	-	55.5	60.7
Height (m)	Sprayed	2.10	2.60	3.13	3.53	4.03	4.49	4.60	5.10	5.40	5.95
	Unsprayed	2.19	2.66	3.24	3.67	4.08	4.37	4.56	4.91	5.16	5.75
Diameter (cm)	Sprayed	-	5.43	6.02	6.01	6.45	7.08	7.50	8.05	8.51	9.27
	Unsprayed	-	5.42	6.00	6.26	6.64	7.16	7.51	7.89	8.21	9.02

converted back to percentage leaf area affected) whereas unsprayed trees had almost three times as much leaf area affected (~8%). This difference was highly significant ($P<0.001$). Disease on adult foliage was also significantly different between spray treatments ($P<0.001$). Mean disease severity on adult foliage of sprayed trees was 4.5% whereas severity on unsprayed trees was 8% (Table 1). The difference in defoliation between sprayed trees (32%) and unsprayed trees (61%) (Table 1) was also highly significant ($P<0.001$).

There was little effect of the fungicide treatment on disease at the first two assessments after spraying had commenced (Fig. 1 and Table 1). However, the severity of *Mycosphaerella* leaf disease decreased in all sprayed plots from January 1993 to July 1993. It increased from July 1993 to October 1993 when no spraying occurred, and then decreased again after October 1993. In contrast, disease became progressively more severe in the unsprayed plots from January 1993 through to March 1994. By the time of the final assessment in March 1994, the juvenile crowns in unsprayed plots were severely defoliated (61% on average), while sprayed plots were only 32% defoliated (Table 1). Defoliation in the sprayed plots is likely to have resulted from leaves being infected before the spraying began, causing premature leaf fall.

Effect of *Mycosphaerella* leaf disease on growth of *E. globulus*

There was a significant effect of disease on both height increment ($P<0.01$) (Fig. 2) and diameter increment ($P<0.05$) (Fig. 3). Trees in sprayed plots increased in height by 90% from January 1993 to March 1994, whereas in unsprayed plots height increased by only 77% (Table 1). There was less of a difference for diameter, with an increase of 54% in sprayed plots and 50.3% in unsprayed plots (Table 1).

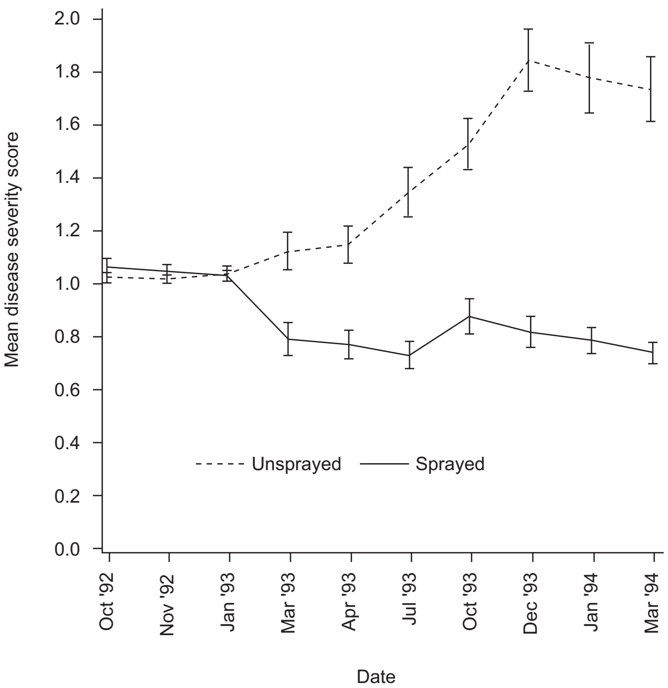

Figure 1. Comparison between sprayed and unsprayed trees (mean of 6 replicates) for severity of *Mycosphaerella* leaf disease on the juvenile foliage, showing 95% confidence intervals.

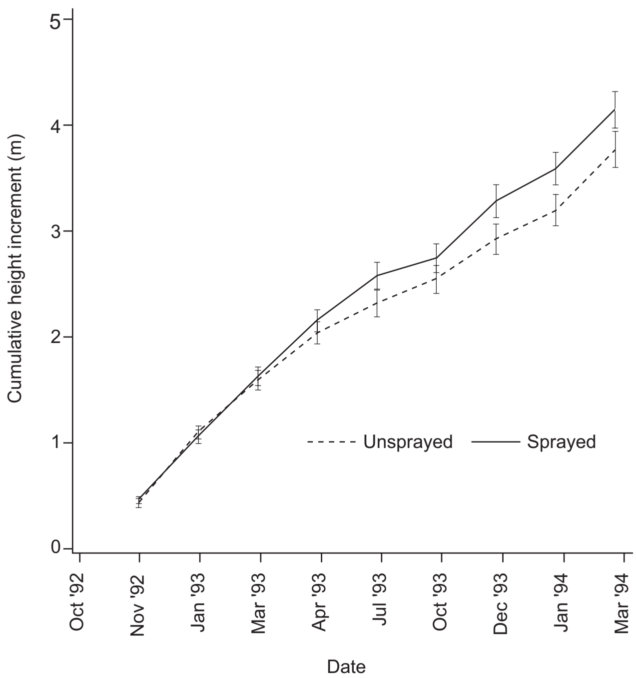

Figure 2. Comparison between sprayed and unsprayed trees (mean of 6 replicates) for cumulative height increment (m), showing 95% confidence intervals

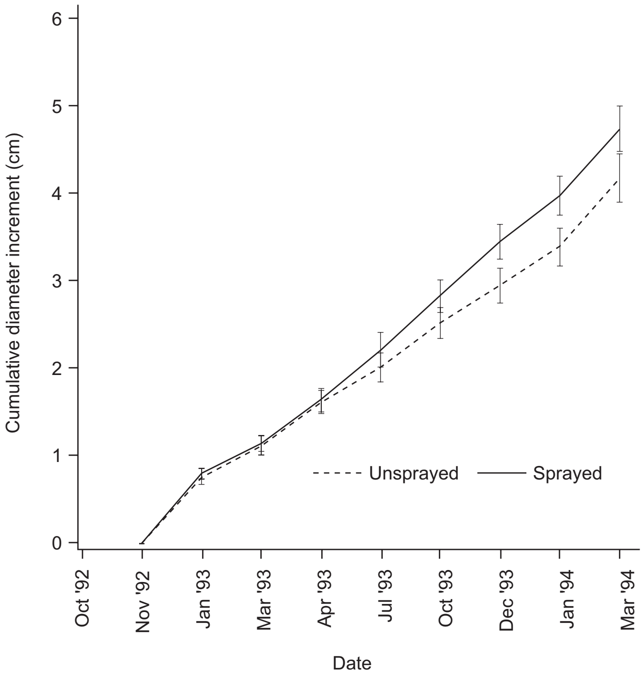

Figure 3. Comparison between sprayed and unsprayed trees (mean of 6 replicates) for cumulative diameter increment (cm), showing 95% confidence intervals

Juvenile disease severity was significantly but only moderately correlated with defoliation (r = 0.36, P<0.001) and with adult severity (r = 0.47, P<0.001). It was not correlated with either height increase or diameter increase (Table 2). Defoliation was significantly negatively correlated with both height increment (r = –0.37, P<0.001) and diameter increment (r = –0.29, P<0.001) (Table 2). This suggests that defoliation was more important than juvenile severity in affecting growth of *E. globulus*, but that juvenile severity was a major contributor to defoliation. The trees in this plantation had not reached canopy closure, and so shading of lower foliage would not have been a major factor in premature leaf fall, although other factors such as leaf age may have been.

Table 2. Phenotypic correlations of individual tree values for various disease and growth traits. The correlation coefficient is above with the probability under the null hypothesis P = 0 in brackets below. Sample size varied from 364 to 416.

Trait	Height increase	Diameter increase	Adult severity	Defoliation
Juvenile severity	0.04 (0.420)	0.07 (0.199)	0.47 (0.001)	0.36 (0.001)
Height increase		0.69 (0.011)	–0.001 (0.980)	–0.37 (0.001)
Diameter increase			0.01 (0.832)	–0.29 (0.001)
Adult severity				–0.15 (0.01)

Discussion

This study showed that the combination of the protectant fungicide Bravo (chlorothalonil) and the systemic fungicide Benlate (benomyl) was effective in controlling disease caused by species of *Mycosphaerella* on *E. globulus* in the field. Trees sprayed with these fungicides had significantly less disease on both their juvenile and adult foliage, and also less defoliation of the juvenile crown, than unsprayed trees.

Chlorothalonil has been effective in controlling a range of fungi in young eucalypt plantations in New South Wales, Australia, including *M. cryptica* and *Aulographina eucalypti* (Cooke & Mass.) Arx & E.Müll. (Simpson *et al.* 1997). Chlorothalonil has also been used to control *Mycosphaerella* species in eucalypt nurseries in New Zealand (Sandberg and Ray 1976), while benomyl was effective in controlling leaf blight caused by *Cylindrocladium* species in eucalypt nurseries in Australia (Bertus 1976). Others have shown that soil-applied and foliar fungicides control *Cylindrocladium* spp. that cause various diseases of *Eucalyptus* in India (Rattan and Dhanda 1985; Sharma and Mohanan 1991).

The current study has shown that *Mycosphaerella* leaf disease affects the growth of young *E. globulus* in plantations. Similar results have been reported for *E. globulus* (Carnegie *et al.* 1994; Stone *et al.* 1998b) and other species of *Eucalyptus* (Lundquist and Purnell 1987; Simpson *et al.* 1997). Diameter growth of *E. nitens* in South African plantations was reduced when more than 25% of the juvenile crown was defoliated by *Mycosphaerella* leaf disease (Lundquist and Purnell 1987). A range of fungi, including *M. cryptica*, were responsible for reduced growth in a number of eucalypt species, including *E. globulus*, in three replicated trials in New South Wales, Australia (Stone *et al.* 1998a,b). Krantz and Rotem (1988) commented that at low levels of disease there may be no outward reduction in growth or yield. However, even at low disease severity (<10% leaf area affected), height growth was 13% lower in diseased *E. globulus* trees at Glencoe than in trees relatively free of disease (~3% leaf area affected). Diameter growth of diseased trees was less affected (only a 4% reduction).

Disease severity was correlated with defoliation at Glencoe, suggesting that disease caused premature leaf fall. The pattern of defoliation in this trial was associated with premature senescence of previously infected leaves and blighting infections of newly expanded leaves, and progressed from the lower crown upwards. This is the common form of defoliation in 2–3-y-old *E. globulus* plantations in Victoria, and is similar to that described and assessed by Lundquist and Purnell (1987) and Carnegie *et al.* (1994). Since canopy closure had not yet occurred, disease caused by *M. cryptica* and *M. nubilosa* is likely to be the major contributor to defoliation.

Weed competition and low soil nutrient levels can also contribute to premature senescence. Weeds in the trial were not dense enough to significantly cause premature senescence in the trial, but nutrient levels were not tested, so deficiencies cannot be discounted. Although edaphic factors such as low nutrient levels or moisture may have contributed to some premature senescence overall in the trial, the difference between the two treatments indicates the higher disease severity in the unsprayed trees caused additional defoliation.

Unsprayed trees had significantly more defoliation of the juvenile crown (61%) than sprayed trees (32%). This defoliation was negatively correlated with both height and diameter, evidence that *Mycosphaerella* leaf disease was detrimentally affecting growth of *E. globulus* in this trial. Less evidence of disease was observed in the present trial than in similar trials elsewhere (Reinoso 1992; Carnegie *et al.* 1994, 1998), suggesting that the effect of *Mycosphaerella* leaf disease on growth can be even greater than that observed here.

Dothistroma needle blight affects diameter growth of *Pinus radiata* more than height growth (Christensen and Gibson 1964; van der Pas 1981; van der Pas *et al*. 1984; Woollons and Hayward 1984). In contrast, defoliation caused by chrysomelid leaf beetles reduces height growth of *E. regnans* more than diameter growth (Elliott *et al.* 1993). Defoliation caused by *Dothistroma* needle blight results in 'bottom-up' defoliation, which mainly affects diameter, while chrysomelid leaf beetles cause 'top-down' defoliation, which mainly affects height. Artificial removal of new foliage from *P. radiata*, mimicking 'top-down' defoliation, has been shown to reduce height growth (Whyte 1976). The results from Glencoe show that *Mycosphaerella* leaf disease had a greater effect on height growth than on diameter growth of *E. globulus,* although the pattern of defoliation was 'bottom-up' defoliation. Lundquist and Purnell (1987) reported that *Mycosphaerella* leaf disease, causing 'bottom-up' defoliation, had a greater effect on diameter than height of *E. nitens* until defoliation reached more than 60%, after which height was affected more. Defoliation of unsprayed trees in the Glencoe trial was greater than 60%, and so the results agree with those of Lundquist and Purnell (1987).

Removal of new foliage from *P. radiata* caused a reduction of 60% in height growth up to 17 mo after defoliation (Whyte 1976). Similarly, the response in growth of *P. radiata* to defoliation caused by *D. septosporum* (Dorog.) Morelet was delayed by up to two years (van der Pas 1981). This suggests that if growth measurements of the *E. globulus* trial at Glencoe had continued for a longer period, a more significant and long-term effect of disease may have been seen.

The growth-reducing effects of *Dothistroma* needle blight on *P. radiata* can be controlled effectively by aerial spraying with copper-based fungicides (Gibson 1972, 1973; Gilmour *et al.* 1973; Edwards and Walker 1978; van der Pas 1981; van der Pas *et al.* 1984; Woollons and Hayward 1984; Dick 1989). Up to two applications per year may be necessary, depending on the severity of disease, timing of the applications and local rainfall (Gibson 1972; Gilmour and Noorderhaven 1973; Gilmour *et al.* 1973; Kershaw *et al.* 1982; Dick 1989). Chemical control of *Dothistroma* on a large scale can be achieved effectively and economically as spraying can be done aerially and the spray applied in this way covers needles effectively. As the juvenile leaves on most commercial eucalypt species, and especially *E. globulus*, are held predominantly horizontally, aerial application in the field would not be effective in covering the underside of leaves. *Mycosphaerella nubilosa* penetrates through and sporulates on the abaxial leaf surface and *M. cryptica* on both adaxial and abaxial surfaces (Park and Keane 1982a), so both leaf surfaces would need to be sprayed, assuming both systemic and protectant fungicides are used. Therefore, the most effective method of spraying for control of *Mycosphaerella* leaf disease in young *Eucalyptus* plantations would be from the ground.

Previous spraying regimes for control of *Mycosphaerella* leaf disease have used fortnightly (Sandberg and Ray 1976) and monthly applications (Stone *et al.* 1998a,b), as in the present study. Juvenile foliage is prone to more severe damage from *Mycosphaerella* leaf disease, due to both *M. cryptica* and *M. nubilosa* infecting them, so spraying would need to be done until age 3–4 y. The cost of disease control was not estimated in the field experiment at Glencoe, but would be large, considering the costs of chemicals, hiring of equipment and especially labour (each spray session, including travel time, took 3–4 days for one person). In East and Central Africa, control of *Dothistroma* needle blight in *P. radiata* plantations proved impracticable due to logistical complications, such as non-availability of suitable aircraft and landing grounds, and restricted accessibility to plantations due to altitude and topography (Gibson 1973). As a consequence, *P. radiata* was replaced by species that were unaffected by the disease, although these had a much lower yield (Gibson 1973).

To reduce spraying costs in New Zealand, Dick (1989) suggested that *Dothistroma*-resistant *P. radiata* be established in areas where frequent spraying of copper-based fungicides is historically necessary. The use of resistant cultivars has also been suggested as an option for the re-establishment of *P. radiata* in Africa (Barnes 1970; Ivory and Paterson 1970; Gibson 1973). Considerable work has been conducted on the genetics of *Dothistroma* resistance in *P. radiata* (e.g. Wilcox 1982a; Carson 1989; Ades and Simpson 1990, 1991), as well as on resistance to other pathogens such as *Phytophthora cinnamomi* Rands (Butcher *et al.* 1984; Simpson and Ades 1990). These studies showed that there was wide variation in the capacity of *P. radiata* (both provenance and clonal) to resist infection and needle cast caused by *D. septosporum*, that resistance was moderately heritable, and that moderate genetic gains could be achieved by selection.

Both inter- and intra-species variation in severity of *Mycosphaerella* leaf disease has previously been reported for *Eucalyptus* (Zandvoort 1977; Wilcox 1982b,c; Lundquist and Purnell 1987; Simpson *et al.* 1997; Carnegie *et al.* 1998), and especially within *E. globulus* (Reinoso 1992; Stefanatos 1993; Carnegie *et al.* 1994; Dungey *et al.* 1997). This was also observed in the present study, with significant variation among the 52 *E. globulus* families at Glencoe. All three disease traits recorded on *E. globulus* at Glencoe — disease severity in adult and juvenile foliage and defoliation of the juvenile crown — have been shown to be moderately heritable (Reinoso 1992; Stefanatos 1993; Dungey *et al.* 1997; Carnegie 2000). Disease severity on the juvenile foliage has also been shown to be genetically correlated with disease severity on the adult foliage (Dungey *et al.* 1997; Carnegie 2000), which was also observed in the present study (data not shown). This has implications for indirect selection for disease on the adult foliage, since it is easier and more reliable to assess disease in the juvenile growth phase than in the adult phase.

This experiment has provided evidence that *Mycosphaerella* leaf disease can have a serious detrimental effect on growth of *E. globulus* in young plantations, reducing height by up to 13%, even at low levels of disease severity. Although it is possible that the application of the fungicides had some direct effect on growth, regardless of their effect on disease, there was no such evidence in this trial. Spraying with fungicides reduced disease caused by *Mycosphaerella* species, but repeated spraying as conducted here is unlikely to be cost-effective on a large scale. One or two applications during short periods of epidemic infection could be cost-effective, provided the time during which epidemic infection occurs can be identified. Resistance to *Mycosphaerella* leaf disease in both the juvenile and adult foliage phases is moderately heritable, and highly correlated between foliage phases. Experience with *Dothistroma* needle blight in *P. radiata* indicates that breeding for resistance is a viable alternative to chemical spraying. Results reported here indicate that breeding for resistance is likely to be the most economical and effective strategy to reduce the impact of *Mycosphaerella* leaf disease in *Eucalyptus* plantations.

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