SEASONAL FROST-TOLERANCE OF PINUS RADIATA, PINUS MURICATA, AND PSEUDOTSUGA MENZIESII

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ABSTRACT

Seasonal frost-tolerance of **Pinus radiata** D. Don (radiata pine) was determined at 4-weekly intervals by simulating white frosts in a controlled-environment room. Summer and winter frost-tolerance levels were **c.** -6°C and -12°C respectively. Two consecutive frosts, 24 hours apart, increased the damage although this was not usually significant. Individual seedlings exhibited a range of tolerance suggesting that genetic screening for frost tolerance may be feasible.

The frost tolerance of **Pinus muricata** D. Don (muricata pine) ranged from -5.5°C in the summer to -12.5°C in the winter, and that of **Pseudotsuga menziesii** (Mirb.) Franco (Douglas fir) from less than -4°C in the summer to more than -12.5°C in the winter.

INTRODUCTION

Radiata pine is New Zealand's major exotic species, and frost damage has been a problem in its establishment, particularly with spring and autumn frosts. Other exotic species such as Douglas fir and muricata pine have also been severely damaged by spring or early summer frosts after the buds have flushed. Frosts can occur throughout the year in many parts of New Zealand (Kidson 1932), particularly on inland sites.

Practices have been developed to reduce frost damage during establishment and to improve the early growth of these species (Washbourn 1978; Menzies & Chavasse 1981). However, more detailed information is needed on the seasonal variations in frost tolerance of the species planted, so that meteorological data for planting sites can be applied to advantage (Jackson 1974). The purpose of this study was to determine the seasonal patterns of frost tolerance in radiata pine, muricata pine, and Douglas fir, in order to enable recommendations to be made for siting of species based on known temperature data for the planting sites.

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METHODS

Seedlings were grown at the Forest Research Institute, Rotorua. Planting stock (and seed sources) for the species evaluated were 1½/0 radiata pine (R71/902/1), 2/0 muricata pine (C71/87), and 2/0 Douglas fir (R69/839). Seedlings were lifted, taken to Palmerston North, and potted into 4-*l* containers using a 40 : 40 : 20 (by volume) mix of soil, peat, and pumice. To acclimatise to Palmerston North conditions, the seedlings were maintained outdoors for 4 weeks. They were then frosted at 4-week intervals from March through to December 1974, at the DSIR Climate Laboratory in Palmerston North, using frost rooms described by Robotham *et al.* (1978). For the frosting programmes a day temperature of 10°C was used, reducing to the selected frost temperature during the night period.

The rate of temperature change and duration of the frost were programmed to reproduce those recorded previously at field trial sites in the central North Island region (Fig. 1). Data from 10 field frosts throughout the year at each desired minimum temperature were averaged and the averages graphed. An approximation to the average field frost, using constant rates of temperature change, was selected. For a –10°C frost, there was an 8-hour temperature decline, 8 hours at the minimum temperature, and a 4-hour rise to the day temperature (coded 8 : 8 : 4) (Fig. 1). Programmes for the other temperatures were 4 : 4 : 2 –4° to –5.5°C, 6 : 6 : 4 –6° to –7°C, and 8 : 8 : 4 –10° to –12.5°C. Soil temperature was kept above 5°C at 10 cm depth (monitored by thermocouples placed at half the soil depth) by holding the pots in heated insulated trays during the frost treatments. The controlled-environment room was programmed on a 24-hour cycle using a 12-hour photoperiod, with the lights (producing approximately 175 Wm^{-2} PAR) being switched on 1 hour before the temperature increase began. The vapour pressure deficit was maintained at 0 mbar (100% relative humidity) while the room was below 0°C by injecting steam into the airstream, and during day temperature conditions at 2 mbar (80% r.h.) for the 8 : 8 : 4 programme, 3 mbar (70% r.h.) for the 6 : 6 : 4 programme, and 4 mbar (60% r.h.) for the 4 : 4 : 2 programme.

Seedlings were frosted at two temperatures each month selected from a test frost the previous week, and the seedlings were given either a single frost or two consecutive

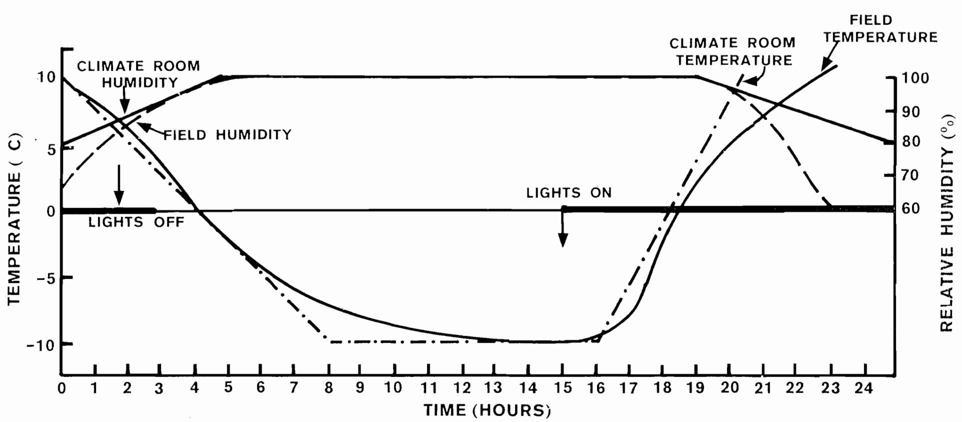

FIG. 1—Comparison between field frosts and controlled-environment room frosts (+10°/–10°C).

frosts at the same minimum temperature, to evaluate the effect of successive frosts on plant damage. Sixty seedlings could be frosted at one time. After the first frost 15 of the seedlings were replaced with a new batch of 15. Thus 22 radiata pine, 4 muricata pine, and 4 Douglas fir seedlings were given a single frost, and 33 radiata pine, 6 muricata pine, and 6 Douglas fir seedlings two consecutive frosts, at each minimum temperature.

After being frosted the seedlings were held in a sheltered outdoor site for a further 2 months for visual evaluation of induced damage, particularly death of needles and buds. Damage was rated on a scale of 0 (no damage) to 5 (dead), based on bud damage and the percentage of needles damaged or killed (*see* Fig. 2). Experience from field

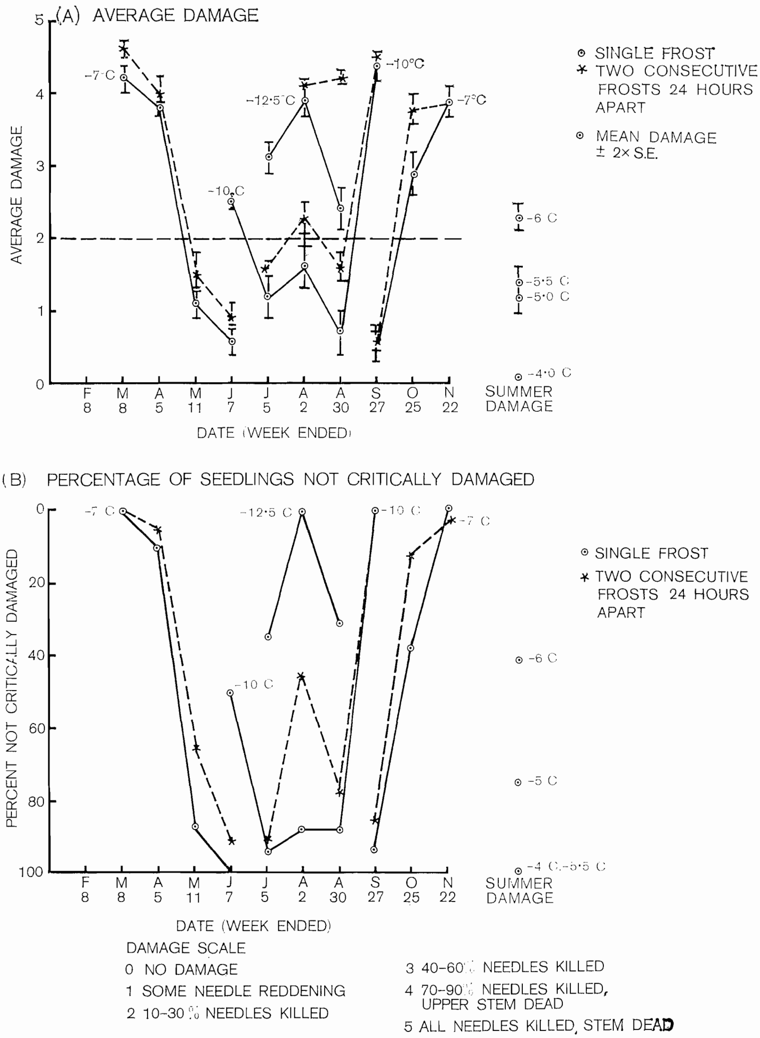

FIG. 2—Seasonal pattern of frost tolerance for radiata pine seedlings.

trials indicated that seedlings would recover from a damage rating of 2 (10–30% needles killed), but seedlings rated 3 or worse would generally be killed by consecutive winter frosts (Menzies & Chavasse 1981).

RESULTS

The results for radiata pine are given in Fig. 2. This includes the average frost damage to the seedlings (Fig. 2a) and the percentage of seedlings rated 2 or less (Fig. 2b). The graphs of average damage and percentage of seedlings not critically damaged show a similar pattern. The summer values are pooled from the November and December runs (the –4° and –5.5°C in November, and –5° and –6°C in December).

In summer, seedlings could tolerate a frost of –4°C with no damage and up to –6°C with an average damage rating and standard error of 2.3 ± 0.1. Development of frost tolerance started in March, and seedlings could withstand –7°C by early May. Hardening continued during the winter, reaching a peak in late August. There was a temporary loss of tolerance in early August, but at the end of that month seedlings could withstand a frost of –10°C with little damage (0.7± 0.3), and a frost of –12.5°C with a damage rating of 2.1 ± 0.2. Loss of winter tolerance occurred rapidly during September, with tolerance to –7°C tapering off by October to reach the summer minimum of –6°C by mid November.

Two consecutive frosts 24 hours apart (2×–n°C) consistently increased the damage, but this was not usually significant except at –12.5°C in late August (5% significance level).

A single graph of the seasonal frost-tolerance of radiata pine during 1974 can be derived from Figs 2a and 2b, using the average damage of 2 from Fig. 2a, and 50% of the seedlings not critically damaged from Fig. 2b. This is shown in Fig. 3, with the

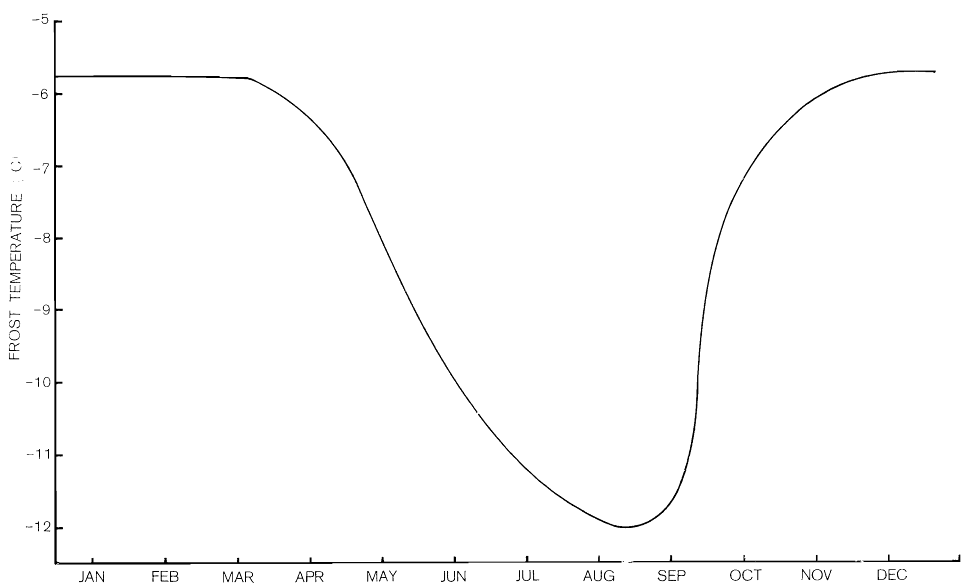

FIG. 3—Average seasonal pattern of frost tolerance for radiata pine.

frost tolerance ranging from slightly less than –6°C in the summer to about –12°C in the winter. Frost tolerance developed slowly in the autumn to a peak in late winter, but was rapidly lost in the spring (late September/early October).

The seasonal pattern of frost tolerance of muricata pine is given in Fig. 4a. The summer tolerance was –5.5°C and frost tolerance increased in the autumn to *c.* –7°C by early April and –10°C by early June. The peak winter tolerance was maintained from June to late August at *c.* –12.5°C, and frost hardiness was rapidly lost during September. In general two consecutive frosts increased the damage except in the –7°C March to June frosts where differences between one and two frosts were small.

The seasonal pattern of frost tolerance of Douglas fir is shown in Fig. 4b. The summer tolerance was undetermined but was less than –4°C. Tolerance to –7°C is

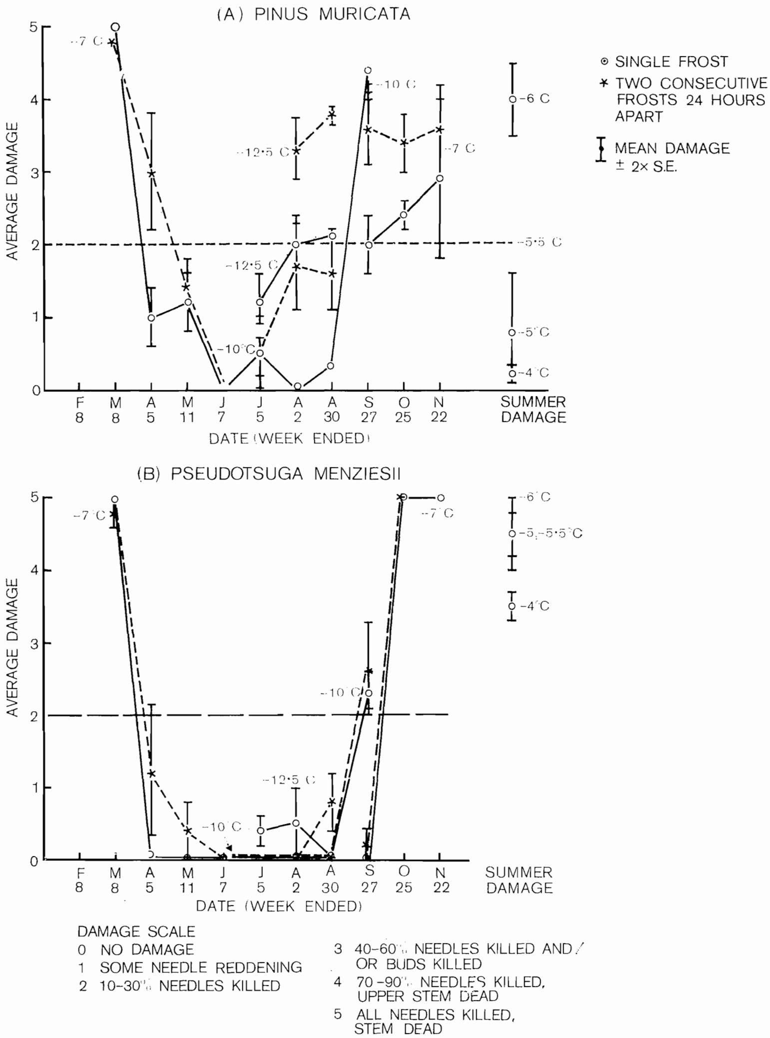

FIG. 4—Seasonal patterns of frost tolerance for muricata pine and Douglas fir.

developed very rapidly in March, and further hardening continues until June. The winter tolerance was also undetermined but was greater than –12.5 °C. Tolerance to –10 °C was lost during September, before the spring flush, and after the seedlings flushed in October frost tolerance returned to the summer minimum.

DISCUSSION AND CONCLUSIONS

Woody species characteristically harden off in the autumn, initially in response to shortening photoperiods, with a second stage of acclimatisation induced by low temperatures, particularly frosts (Weiser 1970). Juvenile radiata pine does not form a true dormant bud during winter, and seedlings can continue growing during the winter if conditions are suitable (Jacobs 1936; Jackson 1974). Thus radiata pine hardens off slowly during autumn/early winter, whereas muricata pine and Douglas fir, with their more defined growth periods and dormant winter buds, harden off rapidly in the autumn. All three species rapidly lost their winter frost tolerance in the spring, with some loss of tolerance apparent before bud expansion, and rapid loss of tolerance with flushing.

A temporary loss of frost tolerance was apparent for all three species in the middle of winter (Figs 2 and 4, week ending 2 August). The reason is unknown, but it is possibly related to the water status of the seedlings. They were kept outdoors until frosting, and there was more rain in the week before frosting in early August (684 mm) than in July (0 mm) and late August (361 mm). In one study, radiata pine seedlings with a predawn plant water potential of –12 bars exhibited about twice as much frost damage (3.4) as seedlings with a water potential of –24 bars (1.8) (Menzies, unpubl. data) and, in another study, seedlings with a water potential of between –22 and –25 bars were at least 2.5 °C more frost-tolerant than seedlings with a water potential of –7 to –10 bars (Holden, unpubl. data). Another factor could be the outdoor temperatures before frosting, since the climate was milder preceding the late August frosting time (because of the rain). However, the temperatures were not very different in July and August, with four frosts in July (minimum –2.3 °C) and five frosts in August (minimum –2.8 °C) and the mean and extreme minimum and maximum air temperatures were within 1 °C for the two periods (N.Z. Meteorological Service 1974).

The frost tolerance of radiata pine ranged from *c.* –6 °C in the summer to *c.* –12 °C in the winter, that of muricata pine from –5.5 °C in the summer to –12.5 °C in the winter, and that of Douglas fir from less than –4 °C in the summer to more than –12.5 °C in the winter. This frost-tolerance range for radiata pine agrees closely with that derived from field trials (Menzies & Chavasse 1981) and other controlled-environment frosting studies (Green & Warrington 1978). However, the frost tolerance at any given time is dependent on the climate preceding frosting, so that the maximum frost tolerance can vary by up to 2 °C at any time, and the graph of seasonal frost tolerance (Fig. 3) can be displaced by a month either way (Menzies, Chavasse, Bowles & Balneaves 1981; Menzies, Holden, Green & Rook 1981). The main frost damage to young plantations in New Zealand has occurred in spring and early summer, when frosts are still frequent, and the seedlings have dehardened and flushed. Thus in the field frost tolerance outside the main winter frost period has been critical. There is only a small difference in summer tolerance between radiata and muricata pines up to –5.5 °C but radiata pine appears to be more tolerant at –6 °C. The slight advantage of radiata pine has also been reflected in better survivals on hard-site field trials (Menzies & Chavasse 1981). Muricata pine has a higher tolerance than radiata pine to winter frosts, and this could be an advantage on cold winter sites. Often, however, the very cold winter sites are on flat lands with poor air drainage, at higher elevations, and these sites are also prone to spring and summer frosts. The lack of summer frost tolerance in Douglas fir precludes its use in New Zealand on sites with inadequate air drainage.

Two consecutive frosts 24 hours apart (2 × –n °C) increased the damage to all three species but this was not usually significant except at –12.5 °C (Figs 2 and 4). Green & Warrington (1978) found that multiple frosts increased the damage more than a single frost only when the first frost caused considerable damage (frost damage rated greater than 2), whereas in this study there was generally increased damage over the range of damage ratings. Since field frosts rarely occur singly, it does mean that extrapolation of single-frost, controlled-environment data to the field situation must be used with caution, particularly when weekly or monthly minimum temperature statistics are used, and frost-frequency is unknown.

There was a range in frost tolerance of the seedlings of all three species to a given frost, and this is reflected in the size of the standard errors (Figs 2 and 4). Earlier field trials also showed a range in frost tolerance between clones of radiata pine (Menzies & Chavasse 1981). These indicate that there is a possibility of screening cuttings and controlled-pollinated seedlings to select for frost tolerance. The development of controlled-environment facilities capable of simulating frosts makes this feasible.

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