ELECTRICAL IMPEDANCE AND ITS RELATIONSHIP TO FROST HARDINESS IN PINUS RADIATA

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ABSTRACT

The seasonal trend of stem electrical impedance in **Pinus radiata** D. Don seedlings over an 18-month period was found to be similar to that in published data for other conifers. Comparison with the seasonal pattern of frost hardiness averaged over three different years at the same site implied that impedance may be related to frost hardiness. However, there was a distinct hysteresis in the relationship between impedance and the hardening and dehardening phases of the seasonal hardiness pattern.

In seedlings induced to harden in controlled environments, a close relationship between impedance and frost hardiness was demonstrated but only for the period when the seedlings were actively hardening. From this relationship, impedance values of outdoor-grown seedlings were shown to correspond to their frost hardiness during the hardening phase (April to June in the Southern Hemisphere).

INTRODUCTION

Electrical impedance has been stated in a number of studies to be related to frost hardiness (Wilner 1961, 1967; Weaver *et al.* 1968; Van den Driessche 1969; Glerum 1973, 1980). These studies have demonstrated or implied that a close relationship exists between impedance and frost hardiness in outdoor-grown material throughout the year.

Glerum (1973, 1980), in extensive studies, has shown seasonal variation of impedance in *Pinus resinosa* Ait., *P. banksiana* Lamb., *P. strobus* L., *Picea glauca* (Moench) Voss, *P. abies* (L.) Karst., *P. mariana* (Mill.) B.S.P., and *Larix laricina* (Du Roi) K. Koch. His data revealed differences in the seasonal trends between species and showed that *Pinus* species generally had a lower winter impedance than the *Picea* and *Larix* species. These differences in maximum impedance were not, however, reflected in differences in maximum frost-hardiness. It was clear that any relationship between impedance and frost hardiness was at least species specific.

In this paper the seasonal trend in stem impedance in *Pinus radiata* seedlings is documented and a predictive relationship between impedance and frost hardiness is examined.

MATERIALS AND METHODS

One-year-old *P. radiata* seedlings from the Forest Research Institute nursery, Rotorua, were potted up at Plant Physiology Division, DSIR, in Palmerston North as described elsewhere (Greer 1983) into 1.2-*l* containers in August 1979 and repotted into 4.5-*l* containers in August 1980. The seedlings were maintained in an outdoor shelter and kept well watered.

Measurements of stem impedance were made at weekly intervals from November 1979 to March 1981. The resistive component of impedance was measured as described by Greer (1983). Each week, 10 seedlings were taken indoors in the late afternoon and equilibrated to room temperature (approx. 22°C). Subsequently, impedance at 100 Hz was measured on basal, middle, and apical sections of each seedling, and the mean stem impedance was calculated for each seedling.

Multiple regression analysis was used to compare seedling impedance with selected environmental factors, such as minimum and maximum air temperature and photoperiod on the day of measurement, and the mean daily minimum and maximum air temperatures of 3 and 7 days prior to and including the day of measurement. Temperatures were obtained from meteorological records collected at the DSIR climatological station at Palmerston North, and photoperiods were taken from Francis (1972, Table 2).

Stem impedance was also measured on *P. radiata* seedlings that were conditioned from early summer to mid-autumn in controlled environments to a range of treatments; frost hardiness was evaluated periodically as the temperature which gave an average visual damage rating of 2 (Menzies *et al.* 1981). The details of treatments simulating climates of the Bulls and Kaingaroa forest nurseries with and without frosts (B+, B−, K+, K− respectively) and frost-hardiness evaluations have been described elsewhere (Greer & Warrington 1982). At the time of each evaluation, stem impedance was measured on 18 seedlings from each treatment. Subsequently, seedling impedance was compared with frost hardiness by regression analysis.

RESULTS

The seasonal trend in mean seedling impedance of *P. radiata* for the period November 1979 to March 1981 is shown in Fig. 1. In Fig. 2, derived from Green & Warrington (1978) and Greer (unpublished), is the monthly frost-hardiness pattern for *P. radiata* at Palmerston North averaged over 3 years (but not the year of study), along with the extreme levels of frost hardiness.

Stepwise multiple regression selected mean daily maximum air temperature of the 7 days prior to and including measurement as the factor giving highest correlation with impedance. Minimum air temperature on the day of measurement was a minor but significant component of the regression. Together these factors could account for 75% of the seasonal variation in impedance. The regression equation was:

$$Z_0 = 56.7 - 1.07 \, (Tm7) - 0.31 \, (Tn1) \hspace{2cm} (r^2 = 0.745)$$

where Z_0 was mean seedling impedance ($k\Omega$), Tm7 mean daily maximum air temperature of the 7 days prior to and including measurement day, and Tn1 the minimum air temperature on the day of measurement. The value of r^2 denotes the proportion of variance accounted for by the regression.
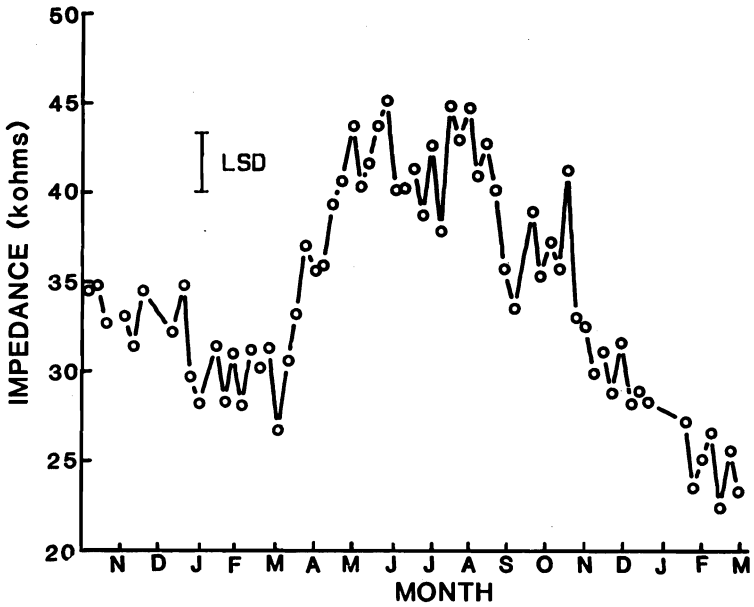
FIG. 1—Seasonal trend of stem resistive impedance of **Pinus radiata** seedlings grown
at Palmerston North. The impedance values were collected between Novem-
ber 1979 and March 1981 (each mean based on 10 measurements; the bar
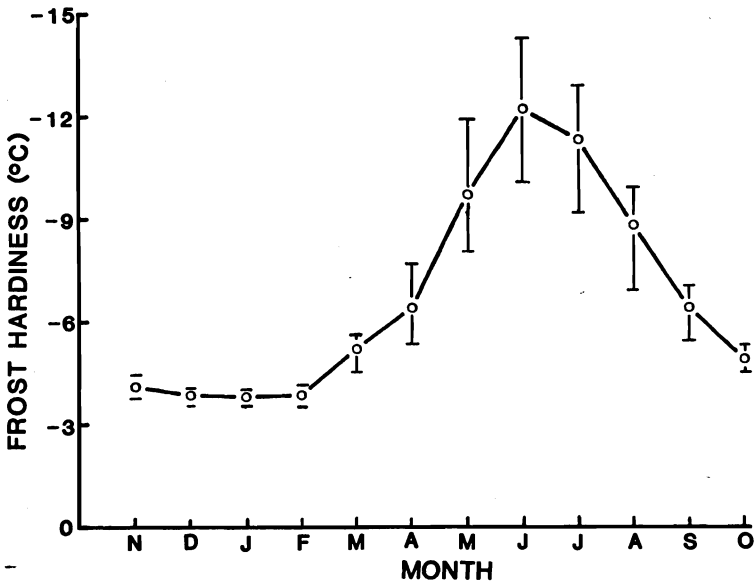indicates least significant difference (p = 0.05)).

FIG. 2—General pattern and extremes of frost hardiness of **Pinus radiata** seedlings
grown at Palmerston North. Frost hardiness values were averaged over 3
years (1977, 1981, 1982), i.e., frost hardiness was not determined concurrently
with the impedance measurements in Fig. 1.

The relationship between mean seedling impedance and frost hardiness of *P. radiata* is shown in Fig. 3. While the seedlings were actively hardening (that is, they increased in frost hardiness by at least 1°C between evaluations) there was a linear relationship between impedance and frost hardiness. However, when hardening stopped, as in the B⁻ and K⁻ treatments, or slowed down, as in the B⁺ and K⁺ treatments, mean seedling impedance continued to increase (Fig. 3).
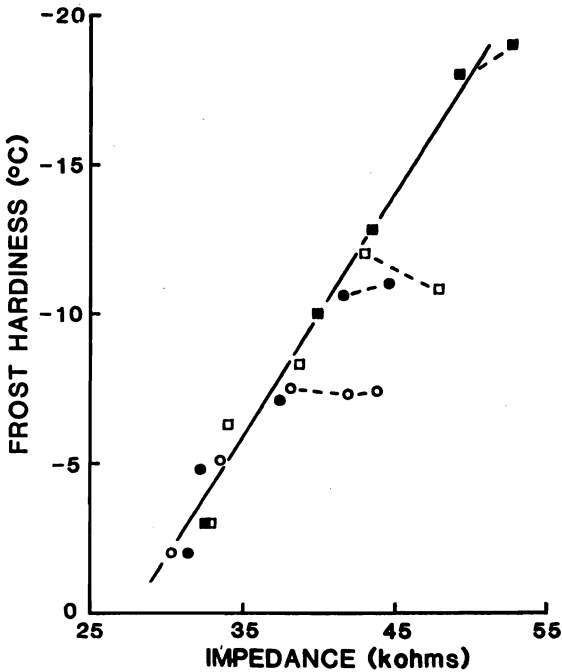

FIG. 3—Relationship between mean seedling impedance and frost hardiness of **Pinus radiata** seedlings conditioned in four controlled environments as described by Greer & Warrington (1982): o = B−; ● = B+; □ = K−; ■ = K+. Those points joined by a dotted line to the regression line indicate increases in impedance of seedlings that were no longer hardening and were excluded from the regression analysis.

The overall regression equation, with those outlying points omitted, accounted for 95% of the variation in frost hardiness and was:

$$F_H = 23.5 - 0.83 \ (Z_0) \hspace{3cm} (r^2 = 0.953)$$

where F_H was frost hardiness (°C) and Z_0 mean seedling impedance (kΩ).

DISCUSSION

Impedance in seedlings of *P. radiata* varied from a summer minimum to a winter maximum and thus conformed to the pattern shown for *Pseudotsuga menziesii* (Van den Driessche 1969) and for *Pinus, Picea,* and *Larix* species (Glerum 1973, 1980). The summer values for *P. radiata* of 24 to 34 kΩ come well within the range of those other conifers and the winter values of 40 to 45 kΩ fall well below (60 to 110 kΩ).

The differences in winter impedance between *P. radiata* and those North American-grown conifers may simply reflect differences in the climate where the seedlings were grown. Daily maximum air temperatures during winter in Palmerston North rarely fall below 7°C (N.Z. Meteorological Service 1977) whereas in Ontario, Canada, daily

maximum air temperatures during winter rarely exceeded 0°C (Glerum 1973). Both the analysis by Glerum (1980) and the present one suggest that temperature was involved in determining seasonal impedance. The low impedance values for *P. radiata* in the summer of 1981 compared with those in 1980 (Fig. 1) certainly reflected differences in temperature. Between January and March, Tm7 averaged 22.5°C in 1981 and 21.0°C in 1980, and Tn1 averaged 14.6°C and 11.4°C respectively.

No evaluations of frost hardiness were made of outdoor-grown *P. radiata* seedlings at Palmerston North while the impedance measurements were in progress. The general pattern of frost hardiness at that site (Fig. 2) and elsewhere (Menzies *et al.* 1981) conformed sufficiently with the seasonal impedance trend to imply some form of relationship between them. This apparent conformity has been sufficient in other species for Wilner (1967), Weaver *et al.* (1968), and Glerum (1973) to suggest that impedance and frost hardiness were related. However, the data in Fig. 2, replotted in Fig. 4A, indicate that for the same level of hardiness the corresponding impedance value in *P. radiata* during the hardening phase was up to 5 kΩ lower than during the de-hardening phase. Glerum's (1973) data for *P. resinosa,* similarly replotted in Fig. 4B, revealed a similar hysteresis in the impedance/frost-hardiness relationship except that impedance values were higher during the hardening phase. Thus the relationship between impedance and frost hardiness in the hardening phase clearly differs from that in the dehardening phase and during the summer when the level of frost hardiness does not vary.

In the *P. radiata* seedlings induced to harden in controlled environments, impedance and frost hardiness were closely related (Fig. 3) but only while the seedlings were actively hardening. When hardening had slowed or stopped impedance continued to increase. This supports the conclusion above that the relationship varies between hardening phases as does Wilner's (1967) observation that the impedance/frost-hardiness relationship in apple became less obvious in spring once growth had resumed.

The impedance values for *P. radiata* in Palmerston North during the hardening phase varied from 31 to 42 kΩ. According to Fig. 3 these correspond to a frost hardiness, between April and June inclusive, of −6°, −10°, and −11.5°C which would be typical values at that site over that period (Green & Warrington 1978; Greer, unpubl. data). Thus the impedance/frost-hardiness relationship should be able to predict frost hardiness quite closely in outdoor-grown pine seedlings during the hardening phase.

Glerum (1980) has suggested that there may be a direct relationship between impedance and frost hardiness but the evidence presented here could neither refute or support that. In outdoor-grown material impedance and frost hardiness may merely have each been correlated with some interrelated environmental factors as Svejda (1970) suggested. Weaver *et al.* (1968) demonstrated a linear relationship between impedance and percentage bud survival in a number of peach cultivars grown and measured outside yet could only obtain an r^2 of between 0.31 and 0.54 in different months. In Greer & Warrington's (1982) controlled-environment study, where only night temperature varied between treatments, it was probable that impedance and frost hardiness were at least correlated to the same environmental factor. The relationship was therefore more precise ($r^2 = 0.95$) under such conditions.
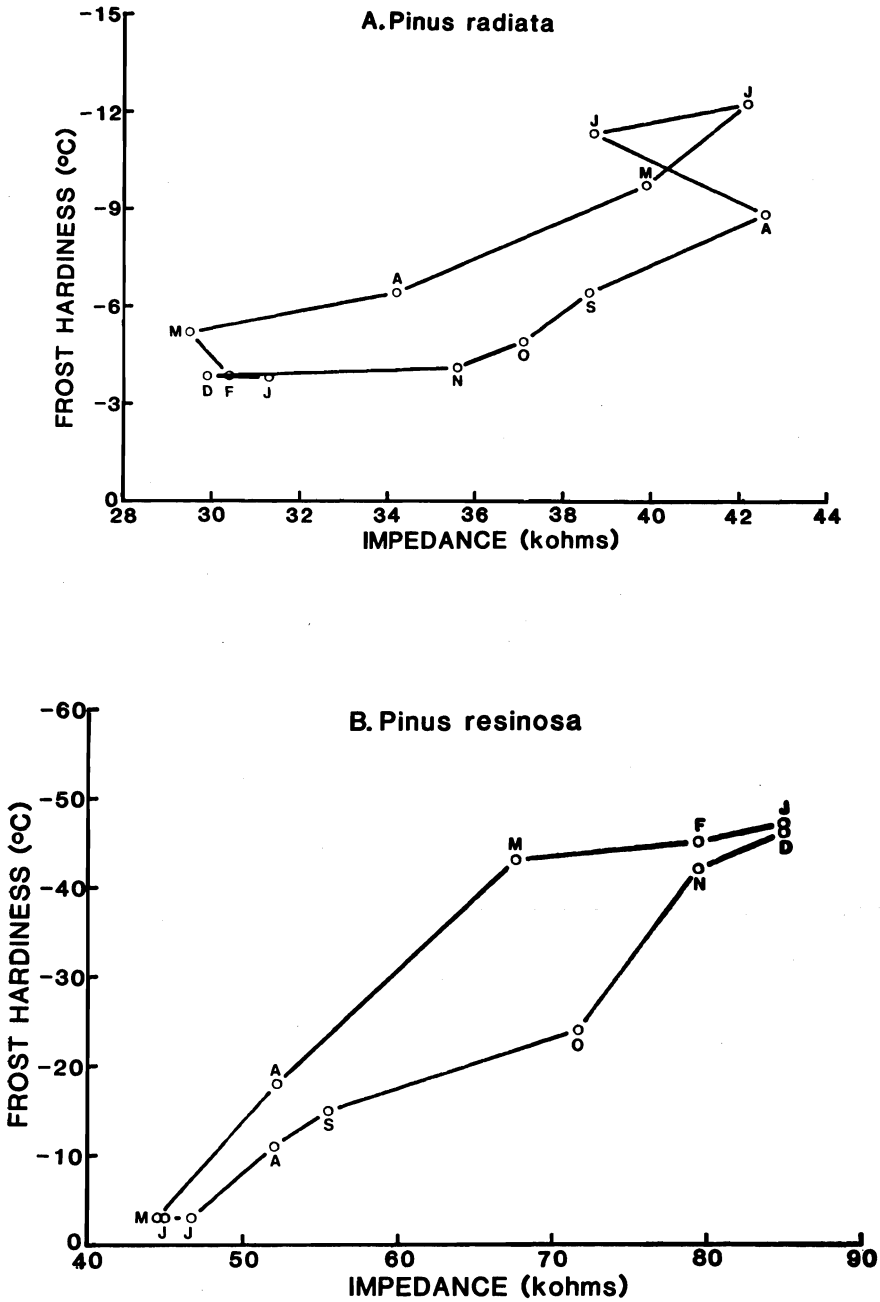
FIG. 4—Sequential plot of seasonal frost hardiness in relation to seasonal stem impedance. Only impedance values from the end of each month were plotted to coincide with evaluations of frost hardiness.

A. **Pinus radiata** from Fig. 1; B. **Pinus resinosa** after Glerum (1973, Figs 2a and 3a).

It is clear from the evidence presented here that during the hardening phase (April to June), impedance and frost hardiness in *P. radiata* are closely related. It also seems likely that a relationship would hold during the dehardening phase but needs to be documented. Impedance measurements therefore appear to have considerable merit in being able to predict frost hardiness. This would be of considerable benefit in nursery and screening applications where an indication of frost hardiness could be obtained without having to resort to costly and time-consuming artificial frost techniques.

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