RESISTANCE TO PULSED CURRENT MAY INDICATE DORMANCY IN TREE SEEDLINGS

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Abstract.--Nine deciduous and four coniferous species at two nurseries were monitored for variation in electrical resistance during fall 1977. Increasing resistance appeared to coincide with the onset of dormancy in most of the deciduous species. Less indicative patterns of resistance were noted in most of the conifers. A change in electrical resistance was first noted at the terminal bud and then at the root collar.

Additional key words: Shigometer, time of lifting, Juglans nigra.

Hardwood nurserymen often lift seedlings in the fall because it allows them to: (1) schedule work for a longer period, (2) have seedlings ready for early spring planting regardless of local weather conditions, and (3) know how many shipable seedlings are on hand.

For best overwinter storage and transplanting success it is important to wait until seedlings are dormant before they are lifted. Seedlings lifted too early may mold or die in storage or have reduced root regeneration after transplanting. Various dormancy indicators are used by nurserymen--a killing frost, etc.--but none of them are totally reliable.

An instrument to detect seedling dormancy would eliminate depending on less certain indicators to determine when lifting may begin. Therefore, we have been testing a portable DC ohmmeter (Shigometer®, model 7950, Northeast Electronics Corp., Concord, NH)2/ to see if a change in resistance to pulsed electric current can be used to detect onset of dormancy in seedlings of 13 species--9 hardwoods and 4 conifers--at two nurseries (fig. 1). The meter detects changes in resistance as concentrations of cations in plant tissue vary (Skutt et al. 1972). We have already reported a strong inverse relation between resistance to pulsed electric current and root regeneration potential of black walnut seedlings (Rietveld and Williams 1978).

MATERIALS AND METHODS

Seedlings at the Jonesboro nursery in southern Illinois and the Vallonia nursery in southern Indiana were monitored in the seedbeds biweekly from

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2/ Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

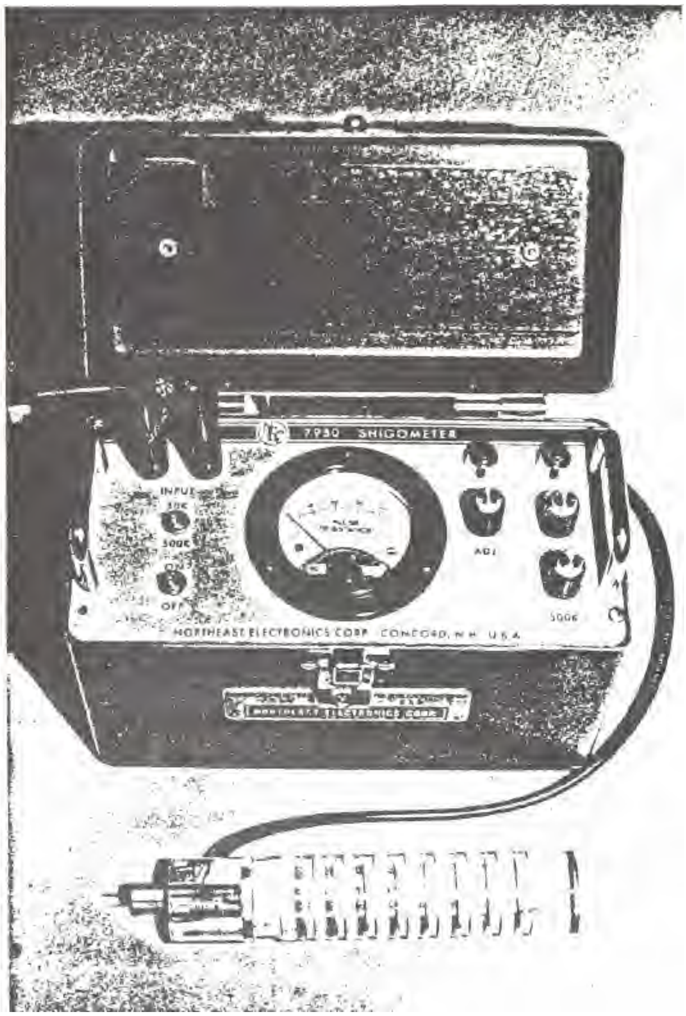

Figure 1.--The Shigometer measures resistance to an introduced pulsed electric current. The meter indicates relative changes in concentration of mobile ions; as ion concentrations increase, resistance to pulsed current decreases and _vice versa._ The electrode handle is fitted with 5 mm long uninsulated stainless steel electrodes set 1.2 cm apart.

October 3 to late December 1977. Species included in the study were:

Jonesboro	Vallonia
Black walnut	Black walnut
Red oak	Red oak
Yellow-poplar	Yellow-poplar
Green ash	Green ash
Autumn olive	Autumn olive
White oak	Sycamore
Sweetgum	European black alder
Eastern white pine	White pine
Loblolly pine	Red pine
	Scotch pine

At each testing date, 15 median-diameter seedlings were sampled at random in the nursery beds; different seedlings were sampled each time. Seedlings were monitored by inserting a two-needle probe into the cork cambium-phloem-vascular cambium-outer xylem region of the stem 3 cm above the ground line and 3 cm below the terminal bud. Uninsulated, stainless steel needle electrodes 5 mm long set 12 mm apart in a cast plastic probe handle (Delmhorst Instrument Co., Boontown, New Jersey) were implanted in a vertical line into the stem. The electrodes were fully embedded in all species except the pines, alder, and olive where they protruded through.

The Shigometer introduces a 0.5 ms pulse of 0.5 A every 10 ms and measures resistance to this current (Skutt et al. 1972). Measurements can be read accurately to the nearest 0.5 K ohm.

Regression curves were fitted to the data using the equation $Y = ab^x$ where Y is resistance and x is days from October 3.

Because temperature significantly influences seedling electrical resistance (ER) (Fensom 1966), it was necessary to adjust resistances to a common base temperature. We determined the relation between temperature and ER and developed a temperature correction as follows:

1. Working inside a controlled-environment room, 6 groups of 10 black walnut seedlings were repeatedly probed at intervals of 10 to 15° F within the range 10 to 90°F. Three groups were tested in separate warming cycles and 3 groups were tested in separate cooling cycles; 2 hours were allowed for seedling temperature to stabilize at each step.

2. The data were best-fitted with two linear regressions; one for temperatures below 32° F and one for temperatures above 32° F (fig. 2). The temperature correction was feasible only for temperatures above 32°F so we used the slope of the regression line, 0.52 K ohm per degree, as the temperature correction factor.

3. Using this correction factor, all resistance measurements taken in the

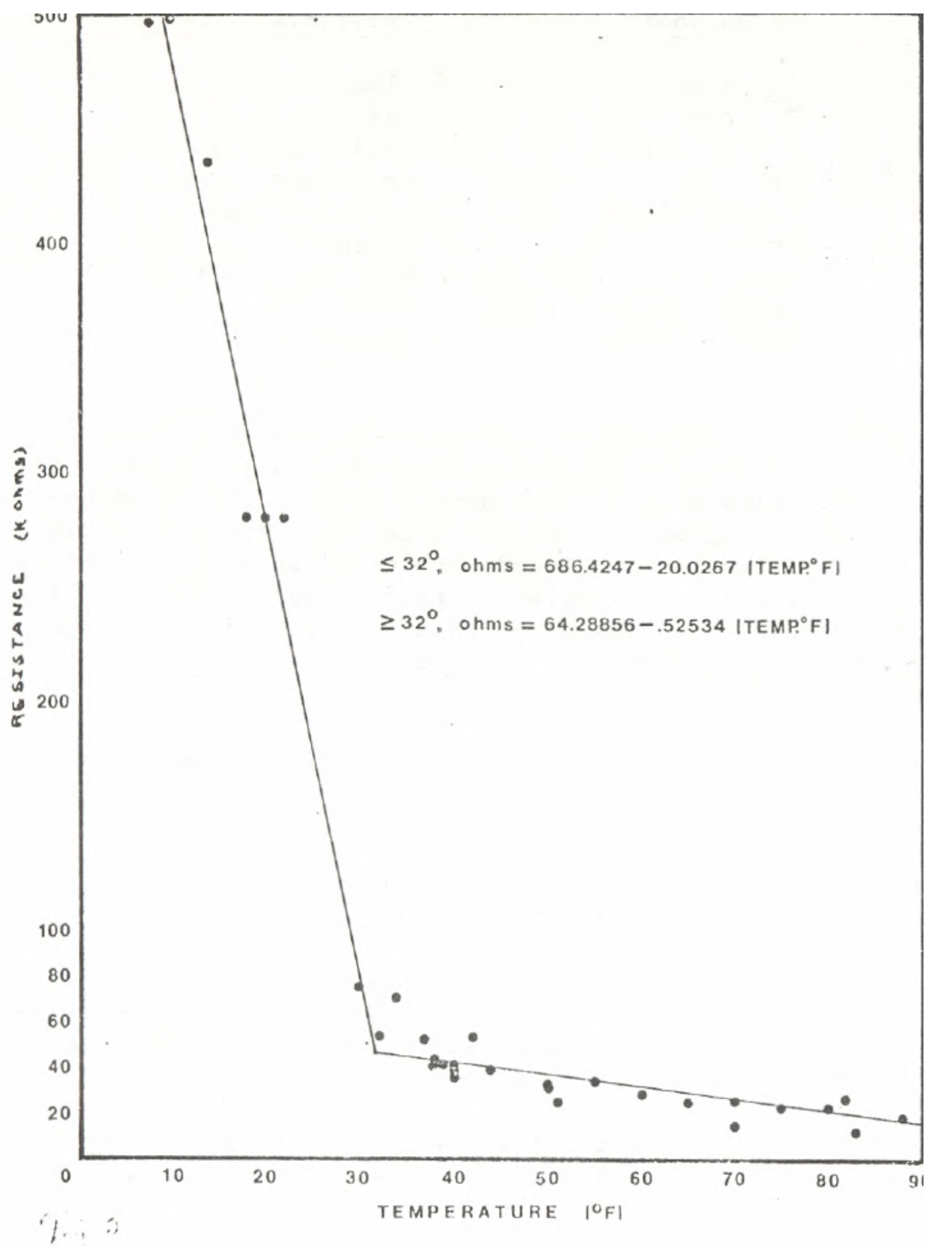

Figure 2.--Effect of temperature on resistance to pulsed direct current. Below about 32° F the effect is marked (20 K ohms per degree); above 32° F the slope is more gentle (0.5 K ohm per degree), but significant. The relation is similar to that reported in red pine, white spruce, and poplar (Glerum 1969).

nurseries were adjusted to a standard temperature of 68° F (20° C).

RESULTS AND DISCUSSION

ER Patterns In Deciduous Species

Several general patterns of ER were apparent in the nine hardwood species probed (fig. 3):

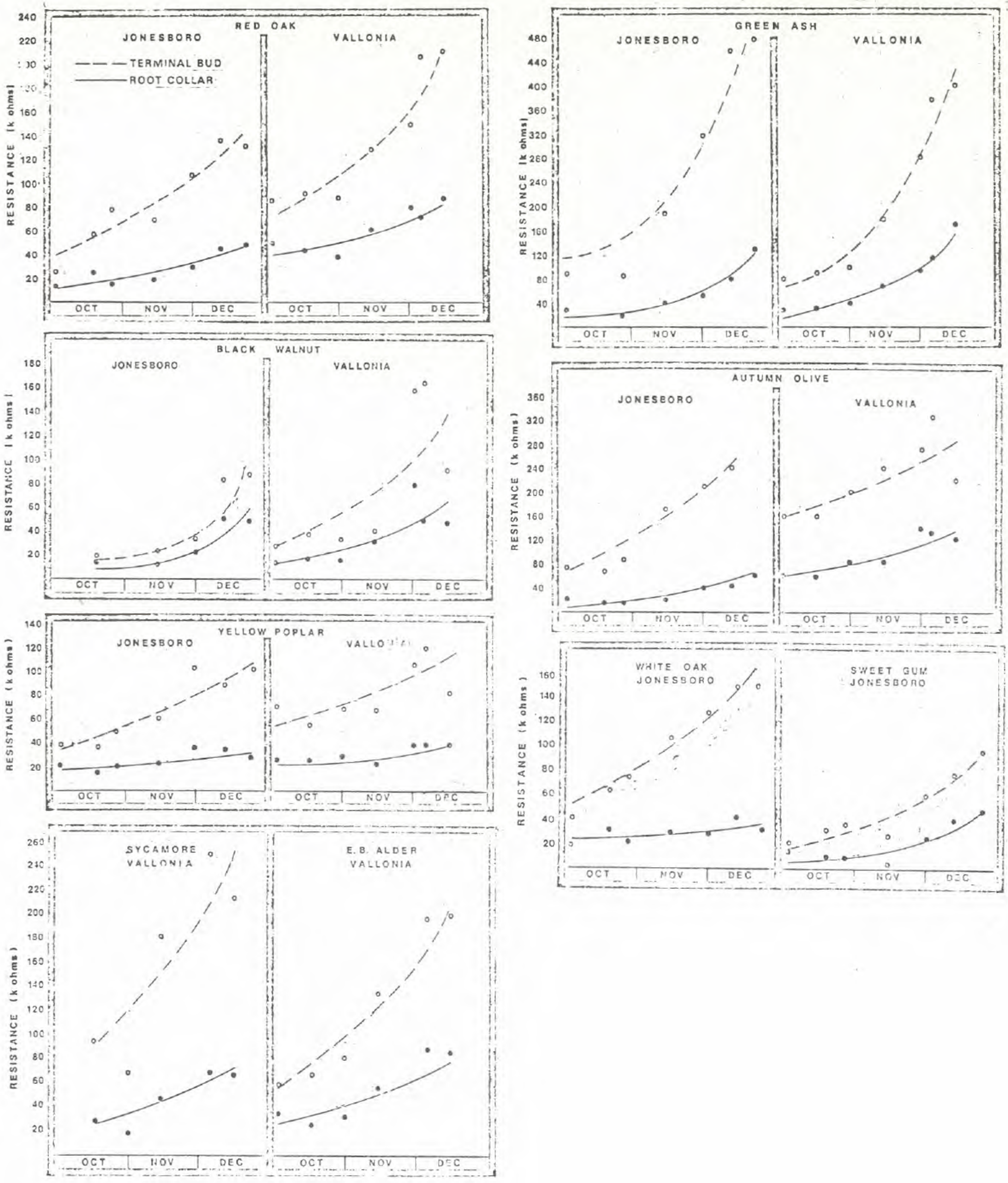

Figure 3.--Patterns of resistance to pulsed current at the terminal bud and root collar of nine hardwood species during the fall of 1977. Each point is the mean resistance of 15 seedlings adjusted to *a* standard temperature of 68° F (20' C). Regression curves were fitted to the data using the equation Y = ab^x, where Y is resistance and X is days from October 3.

ER was higher at the terminal bud than at the root collar.

An upward inflection in the terminal bud ER curve occurred 2 to 4 weeks earlier than it did in the root collar curve.

ER's varied more at the terminal bud than they did at the root collar.

In most species, a substantial change in resistance occurred in late October to early December, which appears to correspond to the onset of dormancy (table 1).

Table 1.--Coefficients for regression equations and standard errors of estimate, Y = **abX** where Y = resistance in K ohms and X = days after October 3

		Root collar			Terminal bud		
Nursery	Species	a	b	SE_E	a	b	SE_E
Jonesboro	Black walnut	8.9607	1.0129	4.1830	10.4729	1.0184	7.9452
	Red oak	11.3092	1.0160	9.8131	37.8749	1.0148	24.1734
	Yellow poplar	16.3640	1.0079	7.3515	31.7194	1.0136	15.8749
	Green ash	8.3274	1.0300	18.1893	55.5371	1.0250	54.6387
	Autumn olive	8.4670	1.0221	10.7029	54.3970	1.0194	44.6598
	White oak	20.6170	1.0063	8.9340	46.4980	1.0141	25.8112
	Sweetgum	3.5796	1.0292	8.2057	15.1831	1.0204	17.6516
	Eastern white pine	23.3001	1.0131	22.1099	28.5814	1.0140	27.8843
	Loblolly pine	16.1076	1.0127	18.7533	24.2094	1.0160	20.5958
Vallonia	Black walnut	12.9403	1.0198	17.7498	23.7246	1.0217	39.7755
	Red oak	34.4475	1.0109	17.8700	61.2067	1.0150	39.3966
	Yellow poplar	22.4135	1.0067	11.6239	51.0337	1.0096	24.5215
	Green ash	12.1920	1.0312	31.7596	46.6690	1.0273	20.1416
	Autumn olive	47.4424	1.0132	37.7255	151.3565	1.0077	64.9895
	Sycamore	15.7395	1.0187	21.2089	62.2263	1.0168	53.6229
	European black alder	21.0325	1.0182	19.5191	47.1867	1.0177	32.0176
	Eastern white pine	54.4737	1.0017	23.4582	52.3812	1.0071	28.4075
	Red pine	46.7596	1.0079	24.5925	44.1953	1.0110	28.4600
	Scotch pine	18.9715	1.0124	14.8850	20.2895	1.0145	20.9310

Individual species varied in the point of inflection of the resistance curve, slope, date of change, and magnitude of resistance. Yellow-poplar increased slowly in resistance compared to other species, and both green ash and autumn olive showed generally higher resistances.

The actual resistance on a particular date differed at the two nurseries; however, it is the change in resistance that we are interested in. **Specifically, it is** the time when resistance changes significantly that may indicate dormancy.

As one would expect, the greater the variability among seedlings and sample dates, the greater the change in resistance required to be significant and the later lifting may begin as indicated by ER. As measuring conditions and technique become more refined, variability will be reduced and the method will be more sensitive. Some species appear to vary more than others, e.g., black walnut and sycamore at the Vallonia nursery (fig. 3). Other species, e.g., yellow—poplar, show such a slow rate of increase in resistance that the present instrument and method may not work to detect dormancy.

ER Patterns in Coniferous Species

In contrast to the hardwoods, the increase in resistance at the terminal bud in conifers was more gradual and variable (fig. 4). With the possible exception of loblolly pine, there may not be enough change in resistance by mid—December to detect a significant increase. Perhaps the stability of the conifer curves is related to the frequency of introduced current. According to Glerum and Krenciglowa (1970), tissues with large cells (as in conifer phloem—cambium tissue) have larger membrane capacitances than those with small cells. Thus, because of a larger reactive component, introduction of lower frequency current should result in high resistance.

We emphasize that this paper reports preliminary findings. We will not attempt to infer when the seedlings are ready for lifting from the ER curves. Because the study included no measure of actual dormancy status of the seedlings we probed, e.g., forcing in the greenhouse or oscilloscope observations, we cannot specifically state that the seedlings entered dormancy at the times suggested by the resistance curves. The time seedling ER increased sharply appears to coincide with the time we expected the seedlings to be entering dormancy. However, during the fall many independent physiological changes occur in plants, and any one of them may be correlated with changes in ER. Because ER of plant tissue is determined by concentrations of mobile cations, it is possible that changes in it are the result of changes in the mobility of cations associated with hardening processes, i.e., changing from an unbound to a bound state, rather than translocations. What this suggests is that ER may be detecting the progress of other physiological processes, such as tissue hardening, but still may be strongly correlated with and indicative of dormancy.

FACTORS INFLUENCING SHIGOMETER READINGS

During the course of the study we identified a number of variables that affect ER measurements. This resulted in several modifications of our equipment and refinements of our technique.

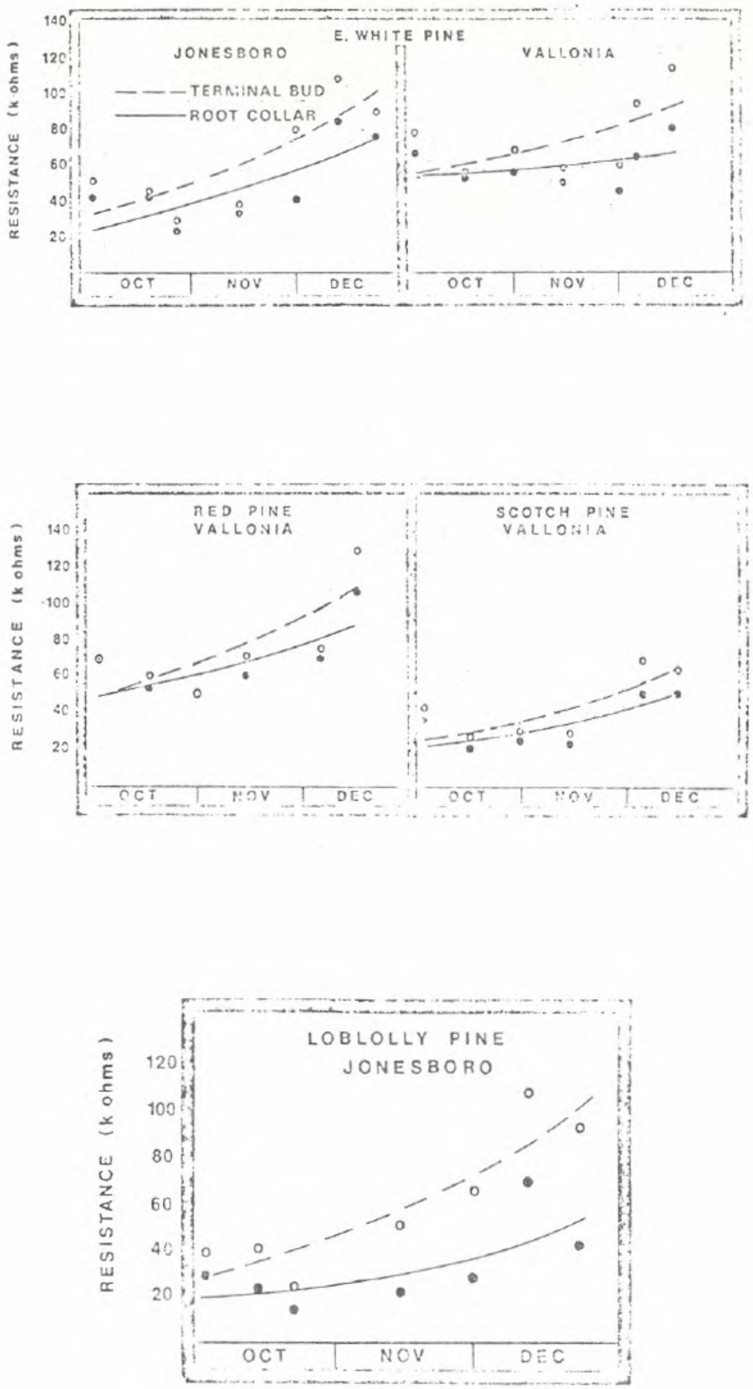

Figure 4.--Patterns of resistance to pulsed current at the terminal bud and root collar of four coniferous species during the fall of 1977. Each point is the mean resistance of 15 seedlings adjusted to a standard temperature of 68° F (20° C)® Regression curves were fitted to the data using the equation $Y = ab^X$, where Y is resistance and X is days after October 3.

Temperature

The most obvious variable is temperature. Lowering the temperature lowers the activity of ions along the circuit. Although the temperature correction discussed earlier was effective in reducing variation, there are several other temperature effects:

1. The temperature correction was based on black wlanut seedlings and may not be applicable to other species.

2. It would be preferable to measure tissue temperature, rather than air temperature, because there is undoubtedly a lag between the two.

3. Weather fluctuations, specifically weekly temperature and rainfall patterns, affect ER both directly and indirectly. We can correct for direct temperature effects. However, sharp increases or decreases in temperature indirectly affect resistance through their effect on seedling physiological processes--specifically those affecting the mobility and activity of ions.

4. Measurements should be taken when temperature is stable and closest to 68° F.

Resistance Meter Ranges

The early fall measurements were taken with the 0 to 50 K ohm range. When resistance increased, we changed to the 0 to 500 K ohm range. Even with rezeroing the meter when changing ranges, we found a discrepancy between readings taken with the two meter ranges. This is due to the fact that the pulse resistance meter (fig. 1) is most accurate near full scale deflection (far right). To reduce error from this source, we modified our Shigometers to include a 250 K ohm range, which allowed us to take all of the measurements during the transition period without changing to a higher range.

Seedling Caliper

When the probe needles protrude through the seedlings, larger caliper seedlings tend to give lower resistance readings. This is primarily due to (1) area of contact--the amount of tissue in contact with the needles, and (2) phloem thickness. Larger and more vigorous seedlings have thicker phloem. Carter and Blanchard (1978) found that phloem thickness is strongly and inversely correlated with ER in red maple. To reduce variation from this factor, we sampled seedlings of uniform caliper (6 to 10 mm at 3 cm above the root collar for most hardwoods) using probe needles 5 mm long so they were fully imbedded in most hardwood seedlings. We are considering going to still shorter electrodes because ideally we want to penetrate the cork cambium-phloem-vascular cambium-outer xylem region on one side of the seedlings.

Plant Water Content and Potential

Extreme scarcity of water usually does not occur in the nursery environment, but the degree of hydration and water potential vary daily, weekly, and seasonally. ER is inversely correlated with percent moisture content above fiber saturation point (about 30 percent). The pattern is similar to the temperature/ER relation, with the inflection at fiber saturation point (personal communication with Dr. Alex L. Shigo, Northeastern Forest Experiment Station, Durham, New Hampshire). Dixon et al. (1978) reported a strong inverse correlation (-0.94) between plant water potential and resistance in avocado and white spruce. To reduce the effect of weather fluctuations it is necessary to maintain adequate soil moisture and take measurements in mid-morning when both atmospheric stress and plant moisture stress are low. The influence of seasonal patterns in physiological processes on seedling moisture content and water potential and resultant effects on ER is unknown.

Plant nutrition

Because resistance to a pulsed electric current decreases as concentrations of cations increase, we could expect variations if nutrient uptake differs. Changes in soil fertility and soil moisture availability may result in corresponding changes in nutrient uptake. Moreover, seasonal changes in nutrient uptake occur. The relation between cation concentration and ER is similar to the temperature/ER relation; the inflection is at about 10^{-6} M (personal communication with Dr. Alex L. Shigo). Normally fertilizer is not applied in the fall and soil moisture is adequate, so we would expect little variation in input of cations into the seedlings. However, we may find that seedling resistance readings vary among nurseries and years because of differences in soils and climate.

Variation Among Seedlings

Because of competitive differences and other inherent factors, the ER will vary among seedlings of one species. A recent sampling experiment indicated that a sample of 27 seedlings is needed. Standardization of measuring conditions and refinements in the instrument and techniques will reduce the number of samples needed.

CONCLUSIONS

The pattern of increasing resistance to pulsed electric current appears to coincide with the onset of dormancy in most of the deciduous but not the coniferous species probed. The pattern is detectable earlier and more distinctly at the terminal bud than at the root collar. In addition to seasonal physiological changes, ER varies with a number of environmental and physiological factors--including water content, water potential, temperature, and ion concentration.

The important point is that ER measurements must be used cautiously to be sure that changes in resistance are a true reflection of seasonal physiological changes rather than daily thermal or water potential trends. Additionally, studies of ER to detect dormancy should correlate readings with some measure of the actual dormancy status of the probed seedlings.

We are optimistic that a convenient method to correct or compensate for temperature will be found and measuring conditions and technique will be refined so that ER can be used to detect dormancy in nursery stock.

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