WOOD CHARACTERISTICS RELATED TO "INJECTABILITY" OF TREES

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ABSTRACT. Water at 0.7 kg/cm^2 (10 psi) was injected through friction-seated spiles into holes 1.1 × 4 cm in stems and roots of 13 angiosperm and one gymnosperm tree species in late June and late September. Flow rates per injection site were greatest for basswood, hawthorn and black cherry (135-176 ml/min); and near zero for butternut, shagbark hickory, white ash and eastern white pine. Injection rates in the deciduous species were positively correlated with an index that could be calculated from published data about the woods: relative frequency of vessels in transverse view ÷ specific gravity. Flow rates were not consistently related to arrangement or size of water-conducting elements or to roots versus stems as injection sites. Rates were greater in late September than in late June.

That trees vary in "injectability" is too often rediscovered. Tree injection has been practiced throughout the past century to control diseases and insects, correct nutritional imbalances, and kill trees or retard their growth (May 1941; Rumbold 1915, 1920). The array of techniques and equipment recently advanced for these purposes is impressive (Brown 1978, Filer 1973, Gibbs & Dickinson 1975, Gregory & Jones 1975, Helburg et al. 1973, Himelick 1972, Kondo 1972, Norris 1967, Pinkas et al. 1973, Prasad 1975, Reil & Beutel 1976). Technology for tree killing, growth control, insect control and correction of micronutrient deficiencies emphasizes application of small amounts of solutions, 2-100 ml (Brown 1978, Norris 1967, Peevy 1972). On the other hand, chemicals for control of diseases must commonly be injected in relatively large volumes of water, 1 liter or more, to obtain acceptably uniform internal distribution of chemical while causing only tolerable amounts of injury to the trees. Pressurized systems speed uptake and enhance the uniformity of internal distribution. But as we and many others (e.g., Prasad & Travnick 1973, Tehon & Jacobs 1939) have noted, significant proportions of pressure-injected chemicals may be forced "off target" into wood several years old.

Within a tree species, injection rates vary with the nature of the solution, tree size and vigor, disease conditions, time of day, and current and recent weather (Reil & Beutel 1976). Injection is quicker and solutes are distributed more uniformly in trees after new leaves expand than during dormancy or early in the growth period. Presumably the negative xylem pressure potential associated with transpiration is responsible for this advantage. In elms, in which the matter has been most tested, solutions introduced into roots are more uniformly distributed into branches and twigs than are solutions injected into trunks (Kondo 1972). Root wood is generally more porous and contacts between vessels are more numerous in roots and the root collar than in stem wood (Riedl 1937, Zimmerman & Brown 1971). These features enhance radial and tangential movement of liquids (Zimmerman & Brown 1971). Root injections are inconvenient, so the butt of the tree near soil line has often been adopted as the next best injection site.

Injection technology developed for specific problems such as the control of Dutch elm disease or pear decline has not proved readily transferable to problems in other tree species because of differences in the nature and biology of pests and pathogens and also because trees vary greatly in structure and arrangement of water conducting elements and seasonal patterns of water content and movement. Reil (1979) mentioned considerable variability in high-pressure injection rates into various tree species in California. Lack of information about "tree factors" is most often cited as the reason for rediscovering that trees vary in injectability. There is no catalog, or even a comprehensive technical review, which the researcher or tree care specialist may consult as an aid in choosing a convenient, effective injection procedure for a given tree species. Here we offer an example of the kind of information needed: variation in injection rates of water into trunks and roots of each 14 species in early summer and early autumn, using a constant, commonly employed injection procedure.

Methods

A 9.5-liter garden sprayer tank equipped with a gas intake tube and with flow meters was used to measure rates of water flow into trees. The tank was partly filled with tap water and during injections was maintained at 0.7 kg/cm^2 (10 psi) with nitrogen supplied from a portable high pressure tank through a pressure reducing valve. Water was dispensed through plastic tubing to one (September injections) or two (June injections) plastic maple sap spiles held by friction in holes 1.1 × ca. 4 cm. The holes were bored perpendicular to the stem or root axis with a sharp wood auger about 60 cm above and below the root collar.

Five trees of each of 14 species were selected. The stem and a major root of each tree were injected with tap water in mid- to late September 1978 and again in mid- to late June 1979. Species and stem diameters are listed in Table 1. The root of a given tree was injected immediately after the stem, or vice versa. In 1979, two sites per stem or root system were injected simultaneously and half the total rate was recorded. Preliminary tests had shown that these matters did not influence injection rates in trees of the

Table 1. Acceptance of injected water by stems and roots of 14 tree species in autumn and summer as related to wood porosity.

Tree species	*Trunk diameter range (cm)*[a]	*Injection rate ± SD*[b]		*Injection rate in roots ÷ rate in stems*		*Wood porosity index*[c]
		Autumn	*Summer*	*Autumn*	*Summer*	
Basswood Tilia americana	35-70	164±77	188±97	0.8	0.9	14.0
Cockspur hawthorn Crataegus crus-galli	20-50	200±69	107±84	0.8	0.4	12.0[d]
Black cherry Prunus serotina	25-70	227±78	43±17	0.7	0.6	10.6
American Elm Ulmus americana	16-25	108±48	87±45	1.1	0.9	10.8
American beech Fagus grandifolia	26-55	107±30	86±29	0.9	0.6	7.1
Red oak Quercus rubra	40-90	116±56	45±43	1.6	0.4	2.6
Black birch Betula lenta	15-42	88±59	63±13	1.2	1.2	5.4
White oak Quercus alba	40-50	91±45	22±17	1.6	1.4	5.0
Sugar maple Acer saccharum	45-60	32±13	31± 7	0.8	0.9	5.4
Black locust Robinia pseudoacacia	25-38	27±24	1±0.1	1.2	e	3.0
White ash Fraxinus americana	20-40	8± 7	3± 1	e	e	1.9
Butternut Juglans cinerea	21-38	4[e]	4± 3	e	e	2.0
Shagbark hickory Carya ovata	21-28	3[e]	0	e	e	1.6
Eastern white pine Pinus strobus	26-60	0	1±0.1	e	e	f

[a]Diameter 1.4 m above soil line.

[b]ml/min/injection hole at 0.7 kg/cm^2; avg. of stem plus root injections; 5 trees per species; ± standard deviation.

[c]Index = specific gravity of green wood^{-1} X relative frequency of pores in cross section; data from Panshin et al. (1964), whose frequency terms were converted to numbers where "very few" = 1 and "very numerous" = 6.

[d]Data for index provided by authors.

[e]Data too few or volumes too small to justify calculation.

[f]Index can not be calculated for gymnosperm woods.

sizes in our study. The flow rate into the tree was recorded as soon as injection began and at 1-minute intervals for 6 minutes. These values were averaged for each injection site. Preliminary tests had shown that 6-minute averages were as useful as those from much longer injection periods. Briefer injection periods were not used because the rate often declined dramatically during the first 2 minutes.

Thick (50 um) transverse sections of stem wood and root wood from one injected tree of each species were prepared and photographed as an aid to interpretation of interspecific differences in injection rates.

Results and Discussion

Xylem characteristics related to injectability. The tree species are arrayed in Table 1 according to injection rates from greatest to least. The rates were not related to stem diameter, to arrangement of xylem vessels (ring porous versus diffuse porous), or to diameters of the largest vessels. Cross sections of wood from four species which had rapid, intermediate and slow uptake rates are shown in Figure 1.

An inverse relationship between wood density and injection rate was evident. For example, basswood and black cherry, in which injection rates were high, have wood of much lower specific gravity than black locust and sugar maple, in which injection rates were low. But there were exceptions. Butternut, which has wood of low specific gravity, was among the poorest acceptors of injected water. This discrepancy was resolved by considering not only the specific gravity but also the relative frequency of vessels in cross sections of wood. Vessels in butternut are infrequent in relation to those in basswood or hawthorn.

We considered whether an index which takes specific gravity and relative frequency of xylem vessels into account might be related to injection rates across the array of tree species. For each species except cockspur hawthorn a value which we call wood porosity index was calculated using published data about the woods: relative frequency of xylem vessels in cross section ÷ specific gravity. The data were obtained from a standard wood technology reference (Panshin et al. 1964). Descriptive terms for vessel frequency were converted to integers such that "very few" = 1 and "very numerous" = 6. We provided the data for hawthorn. The wood porosity index of 13 angiosperms was significantly correlated with average injection rate ($r = 0.93$, $p = 0.01$). Thus, published data about wood characteristics can serve as a general guide to the quickness with which injection can be accomplished in a given species. For ring porous species like oaks, published descriptions of vessel frequency consider only the latewood; thus the porosity index may be low in relation to the actual capacity of the wood to accept water. Even with this limitation, the wood porosity index provided a basis for reasonable expectation about the injectability of most tree species in our study.

Stem versus roots. In species such as white oak and black cherry in which stems and roots differed in apparent porosity (Fig. 1), flow rates also differed between stems and roots in relation to porosity. But we saw no differences in flow rate great enough or consistent enough to justify recommending one site above the other. If there are advantages in using roots as injection sites, these may be related to considerations of wound impact and solute distribution in trees but not to injection rates.

Summer versus autumn. Injection rates were greater in September than in June for most of the species we tested, but our data provide no basis for explaining this difference. Rates at either time would have been adequate for practical injection in nine species, and our procedure gave negligible uptake of water at both times in four species. In black cherry, oaks and black locust, the difference between seasons was large enough for potential practical importance, especially if our results are extrapolated to gravity fed injection systems. Data for several seasons or several injection methods would be required for detection of any differences attributable to seasonal behavior of trees amid weather-related variability in their water status.

Injection technique. That the injection technique influences flow rate is generally understood. Friction-seated spiles, although fine for injecting

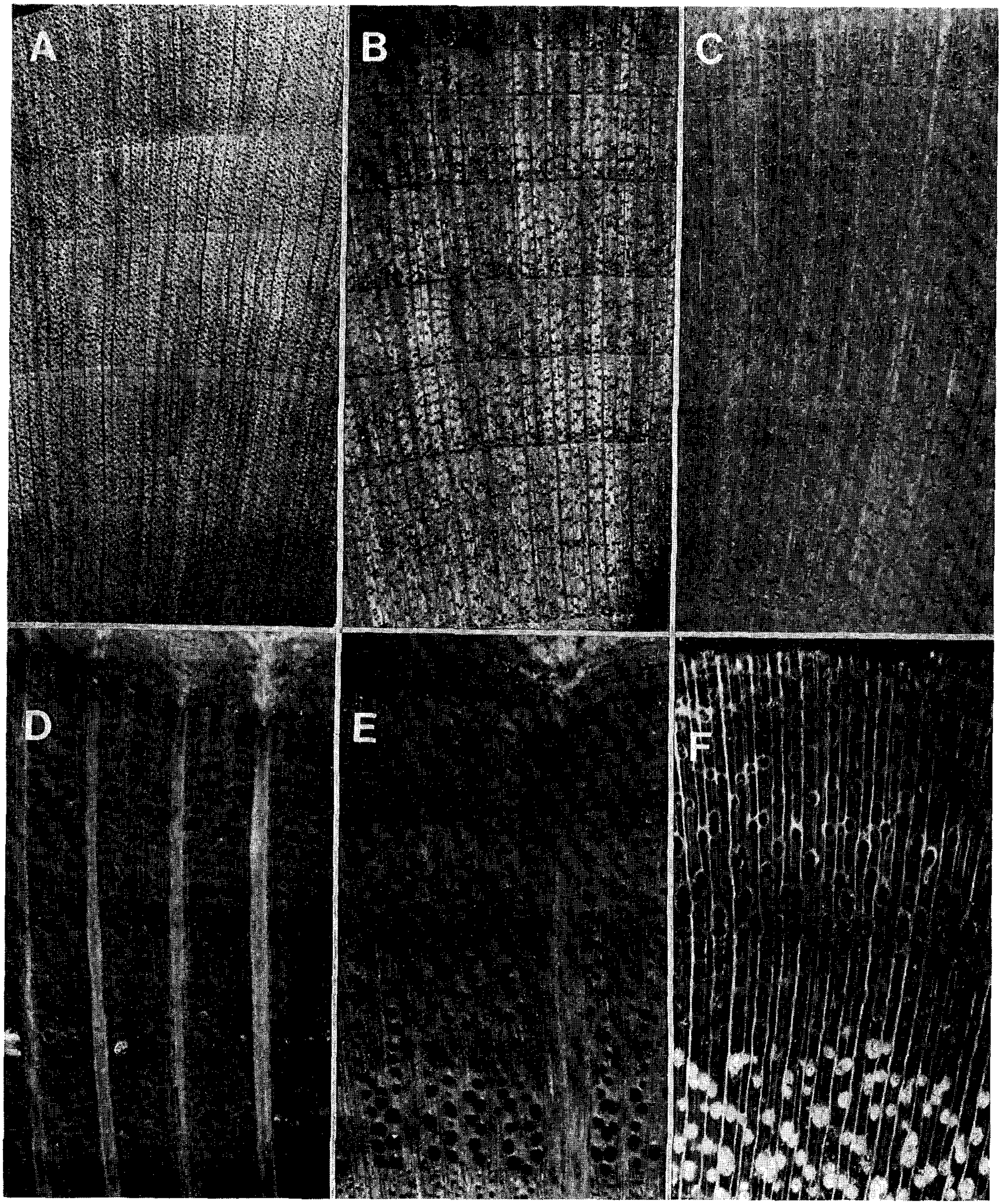

Figure 1. Transverse sections of outermost wood of 4 tree species, all 9.2X. A) Cockspur hawthorn stem, characterized by great numbers of small vessels. B,C) Black cherry stem and root, respectively, showing apparent greater porosity of stem wood. D, E) White oak stem and root, respectively, showing small numbers of large vessels and greater porosity of root wood than stem wood. F) Black locust root showing naturally occluded vessels in wood 1-2 years old.

hawthorn or maple, may be poor for black locust because only the outermost sheath of wood in locust has open vessels (Fig. 1F), and these may be blocked by the shank of the spile. For tree species in which most water conduction is in the wood of the current season, techniques which promote movement of solution into the youngest xylem are preferable. Inappropriate technique may have been the reason for negligible uptake by ash, butternut and hickory.

Similarly, although positive pressure generally enhances the injection rate in comparison to that at atmospheric pressure, this neither assures superior distribution of solutions in trees nor applies at all to pines and related gymnosperms. The wood of pines is so constructed that pressure injection merely causes valve-like structures to block the normal routes of water movement among xylem tracheids. Thus, our pine trees also accepted negligible water.

Injectabiity of other species. We also injected one or more trees of several species related to those in the main study: bitternut hickory, black walnut, burr oak, Douglas-fir, English hawthorn, European white elm, and red maple. The injection rate into each of these species was similar to that of its relative in the main study.

The take-home message. An injection technique which works well for one tree species may be OK for related species but wholly inappropriate for unrelated ones. For a given technique, differences in injection rates among tree species are related to anatomical characteristics of the wood. These can be learned either by consulting standard wood technology references or by inspection. Given this general basis for explaining variation in injectability of trees, arborists and researchers should be able to compare notes and interpret varying results better than has heretofore been the case, predict the injectability of additional species, and thus move in an orderly way from empirical research to practical injection of many tree species. Much useful information could be collated from research reports and especially from the unpublished field records of researchers and tree-injecting arborists.

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