IMPROVED TRUNK INJECTION FOR CONTROL OF DUTCH ELM DISEASE

by William E. Phair[1] and George S. Ellmore

Abstract. Conventional preventative injections into healthy trees overlook the properties of elm's ring-porous wood. The new injector described here forces fungicide into the large earlywood vessels of the outermost growth ring. Only these vessels can conduct fungicide to the entire tree. Older vessels, tapped by conventional injectors actually reduced spread of injected fluids in the outer growth ring in our dye experiments. Of the 55 elms treated with Lignasan by our method for three years, none developed disease symptoms while 11 of the 15 control trees in the same area died.

Since its discovery in 1919, Dutch elm disease (DED) has become the most destructive condition to strike shade trees. It reached this country in 1930 (1). Loss of many elms has dramatically changed the landscape of US municipalities and campuses. In wild wetland forests, loss of once dominant elms altered the distribution of alder, dogwood, and other species, and re-establishment of the original forest profile may be suppressed (5).

The fungal pathogen of DED is transmitted to healthy trees either by bark beetles or by a natural root graft between two elms. The outer, youngest wood is infected. In elm and other ring-porous trees, virtually all of the crown's water supply moves through the youngest growth ring's earlywood vessels (8). Here the fungus can spread upward at 18 feet per hour in the transpiration stream (13). Thus, DED may kill the tree within a few weeks.

A current control measure against DED is to inject trees with soluble phosphate salts of benomyl (8). The method usually used for such injections, however, misses the high flow rates in current-year, earlywood vessels. Instead, fungicide is put into wood older than one year (9).

This paper describes a protocol to inject large quantities of fungicide into the tissue under attack by *Ceratocystis ulmi.* This method spreads the fungicide throughout the outer growth ring of the entire tree.

Procedure

Drilling the ports. Seventy-eight individuals of *Ulmus americana* (American Elm) in the town of Harvard, Massachusetts, were used in this study. Trunk diameter, four-and-one-half feet above soil level, averaged 26 inches, and ranged from 16 to 35 inches. Injection ports (Fig. 1) were drilled into the trunk at intervals four to six inches apart, around the tree. The series of ports was drilled as near as possible to ground level on the trunk. This ensured greatest lateral spread of injected fluid both in the root system and in the crown. The injection ports penetrated at most one quarter inch into young xylem. The shape of the port (Fig. 1) accommodated the shallow-pit injector by holding the injector body (Fig. 2) in the bark layers. A thin layer of bark separated the injector body from the cambium and the present year's xylem.

Installing injectors. Injectors, interconnected by high tensile strength plastic tubing, were hammered into injection ports. This was done by inserting the nail, point first, through injector body and into the injection port (Fig. 3). For each injector, the nail was hammered only until the injector achieved a snug fit within the injection port. Injectors were made of high impact polypropylene to withstand pounding. Those made of softer material, such as hard nylon, cracked. A tube clamp was placed at the end of the series of injectors (Fig. 3). After installation, the system had to be cleared of air.

Pressurized fluid. Fluid would not enter the tree if pressurized nitrogen reached the xylem before the injection fluid did. To prevent this, an air-check valve was placed in front of the series of

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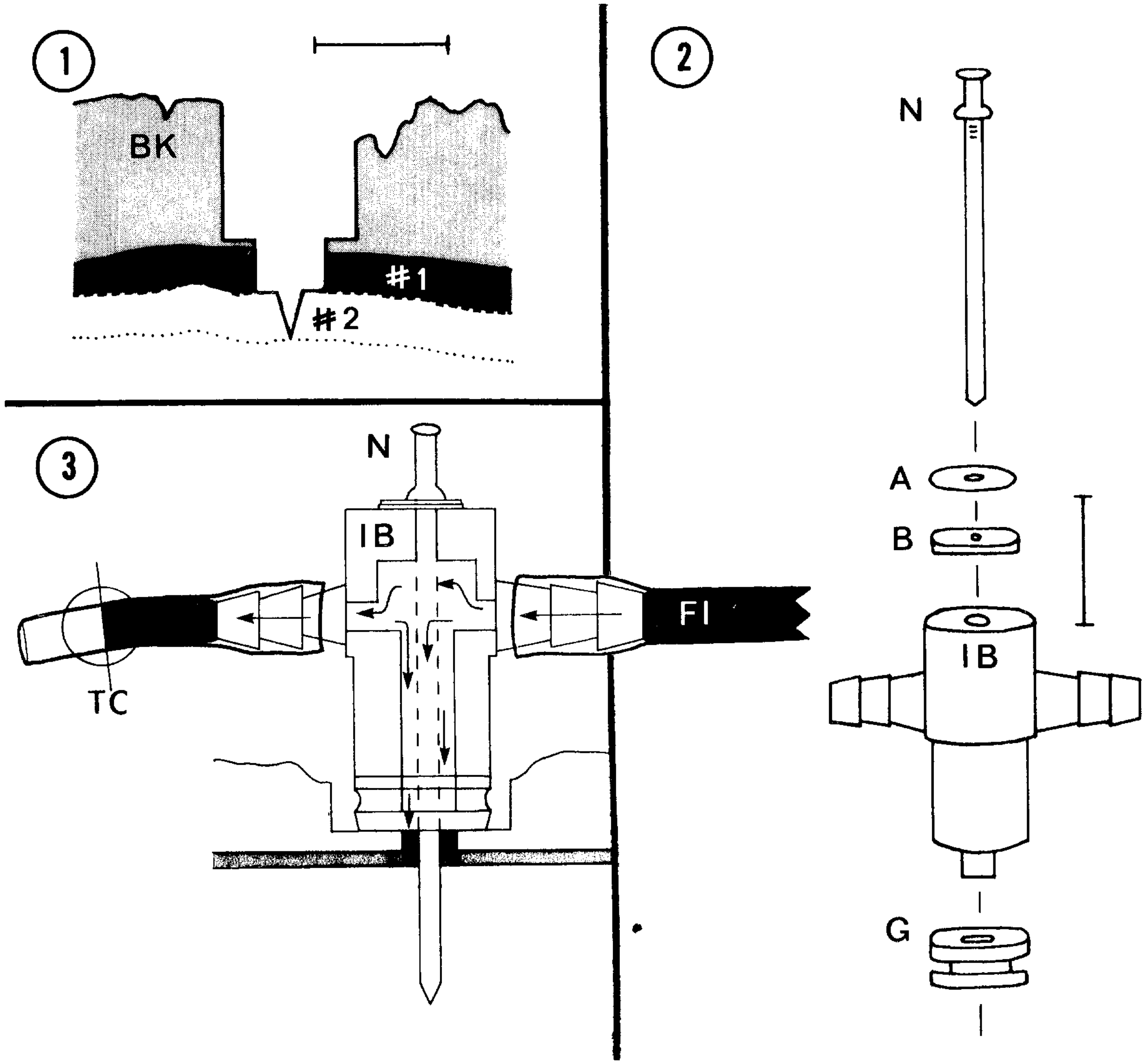
1. Current address P.O. Box 97, Harvard, MA 01451



Figures 1-3. Shallow-pit trunk injection. Fig. 1. Injection port drilled into elm trunk (cross section). A sanitized spade bit on a powered drill is used to produce ports which penetrate heavy bark (BK) to reach the present year's growth ring (#1). Previous year's growth ring designated as #2. Fig. 2. Exploded view of shallow-pit injector. Axis of injector body (IB) is held perpendicular to tree trunk axis by a double-headed nail (N). Seal between nail and injector body is maintained by steel washer (A) and rubber washer (B). A rubber grommet (G) is inserted between injector body and tree tissue. Fig. 3. Injector (longitudinal section) fastened to tree trunk, using double-headed nail (N). Fluid (Fl) is propelled through tubing, into channel within injector body (IB). Fluid moves along the nail, through rubber grommet, to be discharged into the injection port. Fluid is thus exposed mainly to inner bark and the present year's growth ring. Injectors are fastened in series across the tree trunk. Air in the line is vented by opening tube clamp (TC) at end of the line of injectors. Arrows denote fluid flow. Scale bars = 1 inch.

injectors. The sequence of components in the injector system ran as follows: tank of compressed nitrogen — source tank of injection fluid — air-check valve — series of injectors — tube clamp. Air was expelled from the system by opening the tube clamp and pressurizing the source tank with 5-10 psi. Fluid was forced through the system, displacing air past the open tube clamp. After the air was discharged, the tube clamp was closed (Fig. 3).

As pressurized fluid moved through the system it slowly filled the injection ports within the tree trunk. Air originally in the ports was forced out through the dry cork layers of the bark (Figures 1 and 3). Once the ports filled with fluid these cork layers themselves became wet and swelled, creating a pressure seal. The entire system, including lines and ports, filled with fluid within two minutes. Any leaks at injector ports were then stopped by further hammering upon the nail of the injector.

With injectors seated firmly in place, pressure can be increased to 30 psi. Any new leaks can be stopped by again hammering upon the double-headed nail of the injector. By further securing injectors with clamps, up to 50 psi can be used to force fluid into the tree. The limiting factor in clamped injector systems appears to be the strength of the one-quarter-inch tubing between injectors. Pressure tolerance was increased by using tubing **diameter**1/16 inch *smaller* than the T-barb diameter of the injector body. Thus, one-quarter-inch plastic tubing was forced over a wider (5/16 inch) T-barb, making the connection tight enough to tolerate 30 psi.

After injection. As the source tank of injection fluid emptied, the fluid level on the air-check valve dropped, allowing the float within it to block the outlet to the injector series. Thus, flow of air into the system was sealed off. The system was depressurized by turning off the compressed nitrogen, venting fluid source tank to atmosphere, and opening tube clamp at end of injector series. Injectors were removed from trees by use of a claw hammer supported by a wood block.

To evaluate effectiveness of injectors, trees were injected with the red tracer dye, Rhodamine B (0.25% aqueous solution). Wood from injected trees was sampled in order to determine the extent to which injected dye had spread throughout the tree. To compare shallow-pit injection with other methods, single trees were injected simultaneously. One half of the trunk circumference was injected by shallow-pit method, while the other half was treated using deeper injections (10,11). Deeper, "conventional" injections were made with devices sold by the Elm Research Institute (ERI), Harrisville, New Hampshire. Both halves were injected with Rhodamine B. Three days after injection, wood samples were taken from root, trunk and crown areas.

Results

Superior coverage. Under all conditions tested, the shallow-pit injection method delivered more fluid throughout the outer growth ring of the tree than did conventional methods (6,9). When a trunk was injected using both shallow-pit and deeper injections, only the side injected by the shallow-pit method showed any marked dye migration in the outer growth ring. Extended wood sampling revealed lateral, as well as vertical, spread of the dye. For every ten feet of vertical coverage, the dye migrated one inch laterally. Dye delivered by shallow-pit injection reached into the crown, more than 50 feet away from injection ports. On the other hand, our conventional injections failed to transmit the fluid within the outer growth ring even six feet from injection sites.

Environmental conditions. Several factors regulate the rate at which injected fluids enter elm. Dry soil, warm temperature, and air movement each promote uptake of injection fluid by trees. In the three years of this study, injections were made under varied circumstances. Acceptable rates of uptake (see below) were achieved on non-rainy days, with a 3 mph breeze and temperatures above 70°F. Highest rates occurred on warm windy days. In addition, there was a distinct seasonality to fluid uptake. Material injected between June 1 and July 1 entered trees at an average of six gallons/hour. Injections made earlier than late May or during late July or August produced only 10% of that uptake rate.

Tree size. In the course of this study, 63 trees have been injected. After our work with dye, we chose the shallow-pit method to inject fungicide into DED-susceptible elms. DuPont fungicide, "Lignasan P," was injected (Fig. 4) at a volume of one half gallon/inch-diameter. Average trunk diameter of the study population was 26 inches; such a tree required 13 gallons of fungicide. There was no correlation (r is statistically insignificant) between tree diameter and the rate at which fluid could be injected into the tree (Fig. 4). Trunk diameter had no consistent effect on the rate of injected fluid uptake by trees. Using the shallow-pit technique, an average of six gallons of fluid could be forced into a tree every hour regardless of tree size. Injections therefore took one to three hours to complete for our experimental trees ranging in diameter from 12 to 36 inches.

Survival of injected trees. For three years, injections of Lignasan P (400 ppm) were made annually, using the shallow-pit method, in 55 trees. Their mortality was compared to that of an untreated control group of 15 trees in the same vicinity. Dutch elm disease did not appear in any of the 55 trees annually treated using shallow-pit injection. In contrast, the control group suffered a mortality rate of 23% per year; after three years, 11 of the 15 control trees had died.

Discussion

Conventional injection techniques deposit most fluid into wood layers up to two inches deep in the tree. However, in ring-porous trees such as *Ulmus*, nearly all water transport occurs in the present year's growth ring, especially in the large diameter vessels formed in the spring and early summer (8). Wood of past years carried little water. Conventional injections deposit material uselessly in older, non-conducting wood. On the other hand, injection ports of the shallow-pit method penetrate only the present year's growth ring (Figures 1 and 3), releasing fungicide into the very vessels which currently conduct substances to the crown (12). The superior coverage offered by the shallow-pit method is evident in our dye experiments; dye was transported more than 50 feet from the injection site, while it failed to appear even six feet from a conventional injection site.

Tracer dye. We predicted that if shallow-pit injections were more effective than conventional two-inch deep injections at delivering fluid to water conducting cells, then dye solution should spread farther in the trees if injected with shallow-pit, than when deep-injected. Based on this assumption, our shallow-pit technique was dramatically more effective than deep-injection because dye was carried much farther throughout the outer growth of the tree. This encouraging result, of course, does not prove that *fungicide* will spread throughout the tree when injected in shallow pits. According to Newbanks et al. (8), the active component of Lignasan P (and certain other fungicides) may bind to vessel walls instead of migrating through the vessels toward the crown and root system. Chemical analysis of twig, leaf, and root samples is needed to determine the concentration of fungicide in areas distant from injection sites.

Survivorship. The 100% survival is indirect evidence that fungicide did spread throughout the 55 trees we injected by our shallow-pit method. Decimation by DED of untreated elms adjacent to treated ones attests to the presence of the pathogen in our study area. If the fungicide is less mobile in the outer growth ring than is the tracer dye, we would expect distant branches and roots to contain no fungicide. This would be likely to result in infection either by insect vectors or by root grafts to diseased trees. The fact that no infections have occurred despite insect presence suggests that preventative doses of fungicide do reach branches and roots when large trees (Figure 4) are injected by shallow-pit.

The route taken by fungicide may be a combina-

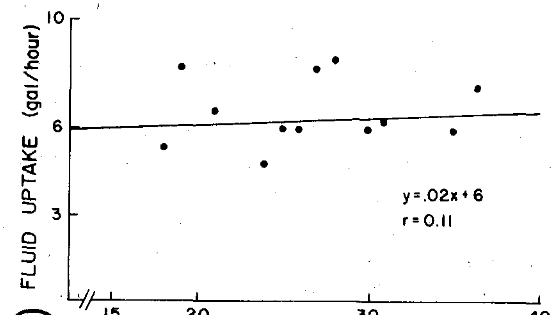


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Figure 4. Rate (gallons/hour) of fluid uptake after injection at 30 psi into elm trunks of different diameter. Trunk diameter had no consistent effect upon uptake of injected fluid.

tion of vessel lumen and walls. Migration through walls may bypass xylem embolisms (air bubbles). Fungicide could spread from functioning vessels into walls of non-functioning ones, providing protection against fungal spread even from previously infected (embolized) tissue (7).

Seasonality. In elm and in other ring-porous trees, vessel function changes with time. When first formed by the cambium, vessels are a series of smaller cells, each with end walls which resist water flow (3). In elm, this stage occurs as buds are breaking, about April 25 to May 7 in Massachusetts. Soon after, end walls dissolve away, forming water conducting tubes (vessels) up to 15 feet long (8, 14). It is only *after* end walls have disappeared that the young vessel conducts large amounts of water rapidly. This stage is reached here by early June (9). Late May and early June are critical because shallow-pit injections made at this time will take advantage of rapid flow within active young vessels in the earlywood.

At our study site, the first week in June is the optimal time for injection. This date is usually one to three weeks after leaves unfold, and it affords best entry and spread of injection fluid in the tree. Rates of fluid uptake by the tree dropped to less than 15% of optimal level (Fig. 4) when injections were attempted a month earlier or later. Newbanks et al. (8) suggest that elm vessels are produced every year *before* leaves unfold but they do not specify when end walls dissolve enough to allow vessels to conduct water most efficiently. Campana (pers. comm.) believes that vessels of elms in Maine open up by June 15, but one should expect more southerly locations to promote earlier vessel activity. Thus, elms in such areas should perhaps be injected as early as late May.

Mechanism of spread. Detailed studies by R.J. Campana and others have shown that the pathogen enters the trees' vessels, usually from an injection point in the crown (2, 9). Infections occur when beetles bearing sticky fungus spores wound twig crotches or large branches and trunk by boring into them. The first xylem the beetles, hence spores, encounter is just inside of the vascular cambium. Only the present year's growth ring is first infected with spores. Spore spread within the xylem stream is most rapid in early June due to access to large earlywood vessels. Infections occurring earlier or later will only have access to last year's latewood, or this year's latewood. In elm, latewood conducts little water, hence provides little current to carry the fungus (7, 8).

Water is pulled up the tree by transpiration from leaves. As spores enter the ascending water column, they are swept upward with the water flow (9). However, downward movement of the fungus also occurs, though much more slowly (9, 12). How spores move, apparently against the transpiration stream, is not known for certain. A recent suggestion by Zimmerman (12) is that as fungi break in, the water column embolizes. Some spores would go up and others down as the water column, formerly under tension, breaks at the point where fungus disrupted the vessel wall.

Summary

For prevention of Dutch elm disease, shallow-pit injection is superior to other methods because it selectively injects the fungicide into the tissue layer attacked by the fungus. Not only is the vulnerable earlywood protected, but also it is *used* to carry the fungicide rapidly throughout the tree. Propelling fluid with 30 psi (over two bars) ensures that fungicide will spread both upward and downward, despite embolisms formed while drilling the ports (Fig. 1). On the other hand, Holmes showed that conventional injections, commonly two inches deep, place much of the fluid into nonconducting xylem (4), wasting time and materials, and leaving the tree less protected.

Testimony as to the effectiveness of shallow-pit injection at present rests with the 100% survival of the 55 large elms we treated over the past three years. Confirmation depends on widespread use of our device by other researchers and by arborists. We found that annual injections in June protected against infections for the duration of the year, as well as infections during spring of the following year. By delivering more fluid through the large earlywood vessels of ring-porous species, shallow-pit injection may well prove useful in treating other vascular diseases of elm as well as diseases in other ring-porous trees such as oak.

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Department of Biology
Tufts University
Medford, MA 02155

ABSTRACTS

BLOOMFIELD, H. 1983. **Is DED dead?** Am. Forests 89(4): 21-24, 50-51.

The elm research community has identified over 20 resistant elms, some of which are listed below. The first three are considered to be the most commonly recognized. *Ulmus carpinifolia* X *pumila* "Urban," *U. glabra* X *U. carpinifolia* X *U. wallichiana, U. laevis, U. americana* L. (NPS 3), *U. americana* "Iowa State," *U. americana* "Delaware II," *U. japonica* "jacan," *U. japonica* X *pumila* "Sapporo Autumn Gold," *U. japonica* X *pumila* "44-25," *U. japonica* X *pumila, U. hollandica* "Groeneveld 494," *U. davidiana, U. Wilsoniana* X *japonica* (NPS 5), *U.* X *hollandica vegeta* "Huntington," *U. hollandica* Mill (NPS8), and Unnamed (NPS 36).

HIELD, H. and S. HEMSTREET. 1983. **Growth control of Chinese elm with inhibitor sprays.** California Agriculture 37(9 & 10): 10.

The Chinese elm *(Ulmus parvifolia)* is widely used in street plantings and requires pruning to accommodate street and sidewalk traffic. We conducted a study in which dikegulac, maleic hydrazide, and chlorflurenol were applied once annually for six years. In a second trial, mefluidide was applied and was observed for one year. Treatments with dikegulac or MH resulted in persistent growth control with good tree appearance. Chlorflurenol at 0.015 percent gave a similar response. Tree height, trunk diameter, top weight, root weight, and flowering were reduced for the treated trees. Mefluidide showed no growth control at 0.2 percent but significant reduction at the 0.4 percent level. Where spray drift is not a hazard, any of the four chemicals appears to offer an effective means of controlling growth of Chinese elm.