Dutch Elm Disease: What an Arborist Should Know[1]

by D. Newbanks,[2] D. N. Roy,[3] and M. H. Zimmermann[4]

I. UNDERSTANDING THE TREE

In order to control Dutch elm disease, one must be aware of a few essential facts concerning the anatomy and function of elm wood. It is amazing how ineffective the most strenuous efforts can be if these facts are ignored.

First of all, elm is a ring-porous tree, like chestnut, oak, and ash (Fig. 1). This means that the bulk of the water is carried to the crown via the wide earlywood vessels of the xylem (wood) of the most recent growth ring (Huber, 1935). In other words, most of the water moves in a very thin layer of wood, immediately beneath the cambium. Wide and long vessels, like those of elm, are extremely efficient: those of a single growth

[1] Commercial sources appearing in this publication are for the purpose of providing specific information. Mention of a source does not constitute an endorsement or warranty of products available, nor does it signify approval of this product to the exclusion of other comparable products.

[2] Cabot Research Fellow, Harvard Forest, Petersham, Massachusetts 01366.

[3] Bullard Fellow of Harvard University, 1980–81. Permanent address: Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada M5S 1A1.

[4] Harvard Forest, Petersham, Massachusetts 01366.

ring can supply the entire crown with all the required water. However, they are so vulnerable that they only remain functional during one growing season. The tree must therefore produce a new set of vessels every year, before the leaves unfold (Zimmermann and Brown, 1971).

The second fact to remember is that water is usually pulled up into the tree. This means that when the water-conducting vessels of the wood are injured, xylem water does not leak out as it does, for example, from sugar maple stems in late winter. The opposite happens: air is sucked into the system, and air-blocked vessels cease to function. Normal physiological conditions of water conduction are such that even a minute injury — one not even visible under the microscope — can be sufficient to admit air and render the vessel useless (Zimmermann, 1978).

The water-conducting system of ring-porous trees is extremely vulnerable. This becomes obvious when we compare, for example, an elm with a maple tree. The vessels of elm are some 4 times wider and 30 times longer than those of sugar maple. We know that the conductivity of capillaries is proportional to the fourth power of their diameter (Zimmermann, 1978). From this we can calculate that maple, when compared to elm, needs about seven thousand times more vessels to carry the same amount of water to the crown. If one vessel is accidentally lost, due to an insect bite for example, the damage is seven thousand times more serious in elm than in maple. Moreover, in ring-porous trees the functioning vessels are located very near the surface and are in a vulnerable position. Spring is the most dangerous period. During the course of the summer, as the functioning vessels are gradually covered with latewood, vulnerability decreases. Young, vigorous trees are somewhat less likely to be damaged than old, slow-growing ones, because they produce more latewood.

II. UNDERSTANDING THE DISEASE

Dutch elm disease is caused by the fungus *Ceratocystis ulmi*. The disease is known to affect four of the seven North American elm species: American elm (*Ulmus americana*), rock elm (*U. alata*), red elm (*U. rubra*), and winged elm (*U. serotina*) (Campana & Stipes, 1981). The fungus comes in contact with the tree in two ways: it is either carried to the tree by insect vectors or is introduced into the tree via root grafts from diseased to healthy trees.

The beginning and development of Dutch elm disease symptoms is dependent upon two major factors: the time of year in which infection occurs and the site where it occurs. For reasons described above, spring and early summer infections, as well as large branch and multiple site infections, are generally more threatening to individual trees than are late season and small twig infections (Sinclair and Campana, 1978). With this in mind, we can generalize and say that the first symptoms consist of the drooping, curling, and yellowing of leaves on one or more of the smaller branches. These symptoms spread more or less rapidly throughout the tree's crown, leading to the death of the tree. Disruption of the water flow from the roots to the

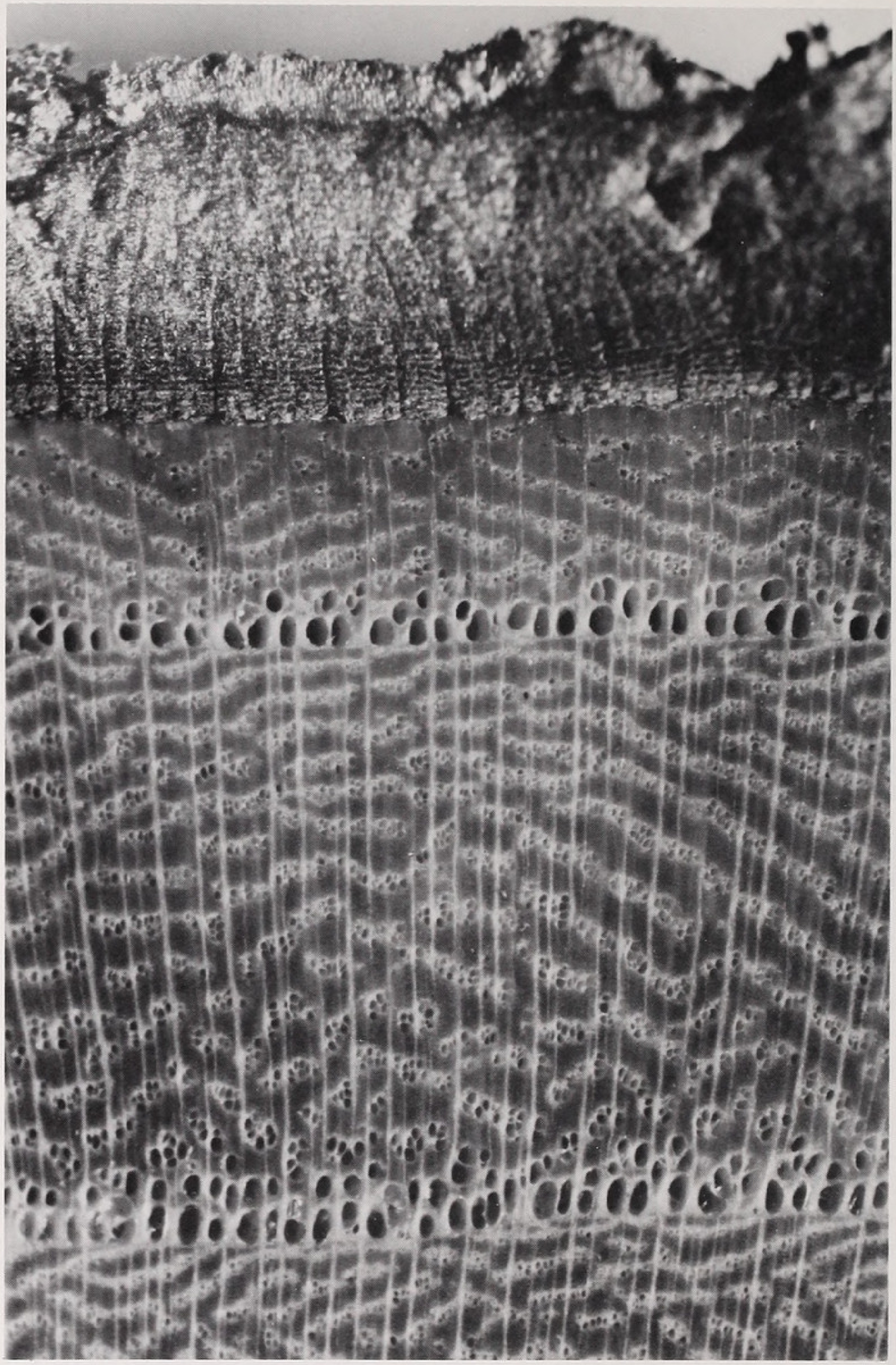


Figure 1. A transversely cut stem of a young, vigorous American elm (Ulmus americana), *showing two (and part of a third) growth rings, the cambium, and the bark. The bulk of the water moving from roots to crown is transported through the large earlywood vessels of the most recent growth ring. The large vessels of previous rings do not function any more; in fact, the photograph shows tyloses in some of them.*

crown of the tree is believed to be the primary cause of symptom development and the death of the tree.

The elm bark beetles, both the lesser European (*Scolytus multistriatus*) and the American (*Hylurgopinus rufipes*), are the primary vectors of the Dutch elm disease fungus in North America. They carry the spores of the fungus from tree to tree, which accounts for the rapid spread of the disease throughout the countryside. The bark beetles are attracted by weakened and dying trees. They bore into the inner bark, where they breed and lay their eggs. The larvae hatch, feed, mature, and emerge from the tunnel galleries, carrying microscopic spores of the fungus that stick to their bodies. They may briefly feed on healthy elms, but then return to weakened trees to breed and complete their life cycle (Sinclair & Campana, 1978).

Spring and early summer infections of American elms by the Dutch elm disease fungus are usually fatal to the tree. Death often occurs within the same growing season for smaller elms and within two growing seasons for larger trees. Occasionally a tree may die slowly, a branch at a time, over several years. The vulnerability of the large springwood vessels to injury is one of the primary reasons for the high susceptibility of the elms during the early season. The probability of vessel wounding by bark beetle feeding or by direct penetration of the fungus is greater during the spring because the ring of large springwood vessels is just beneath the bark.

Transpiration pulls water into the crown of the tree. The water in the xylem vessels is therefore normally under tension. When vessels are wounded by a feeding beetle, air is immediately sucked in as water recedes to both vessel ends. The microscopic spores of the fungus, which have been introduced into the beetle feeding site, may be sucked into the wounded vessel and carried up and down to the ends of the vessel along with the inrushing air. In large branches many vessels are as long as 15 feet, some may be considerably longer. In smaller branches and twigs they may be only several inches in length (Zimmermann, unpublished). In either case, the fungus can be introduced into the tree far beyond the point where a beetle is feeding.

Fungal spores germinate within the bark-beetle feeding tunnels, grow through the wood, and penetrate the vessels by dissolving the walls enzymatically. Such direct penetration may result in the vessel becoming air filled, as in the case of bark-beetle wounding, or the fungus may be able to enter the vessel without introducing air. In either case, once the fungus has established itself in the large springwood vessels, it is able to spread rapidly throughout the tree using the vessels as its pathways. During the later stages of infection, when the tree is weakened and dying, sticky spores are produced by the fungus inside the tunnels containing the newly hatching beetle larvae. The spores are carried on the bodies of the newly emerging beetles as they fly to new feeding sites on healthy elms.

There are several theories as to what actually causes the interruption of water flow through the vessels. Introduction of air into the vessels, as the fungus penetrates from the bark-beetle feeding sites and grows from vessel to vessel, has been suggested (Zimmermann and McDonough, 1978). Physical plugging of the vessels by the fungus and by gums produced by the fungus, as well as outgrowths of neighboring cells (tyloses), have all been shown to play a role (Dimond, 1970). Toxic substances produced by the fungus may also interfere with water movement in a more indirect way (Van Alfen and Turner, 1975). It is a complicated picture, and it is quite probable that all the above-mentioned factors are involved to varying degrees. Regardless of the relative importance of these factors, it remains that the large size of the springwood vessels and their vulnerable location just beneath the bark during the early growing season are two of the primary reasons for the susceptibility of American elms to Dutch elm disease.

III. CONTROL OF THE DISEASE

Successful Dutch elm disease control or management programs employ a combination of pruning, sanitation, insecticide spraying, and therapeutic injection as control measures. Such control programs have been quite successful in reducing the tree mortality due to disease.

1. Pruning and sanitation

Traditionally, control of Dutch elm disease has involved pruning and sanitation. Pruning simply involves the removal of diseased branches. One difficulty with this is that vessels are very long in elm. When infection occurs by the mechanism explained above, air enters an injured vessel and water retreats — in both directions. This can carry spores both up and down from the place of injury, and the fungus can be present considerable distances below a dead branch. It is therefore important that the pruned sections be long enough to eliminate the entire length of air-blocked vessels. As very few vessel-length measurements have been made so far with elm, the best guide is information from the Extension Service or the arborist's own experience.

Sanitation involves the removal of dead elm trees (i.e. cutting and burning) as early as possible so as to deny the bark beetles easy access to food and breeding ground. Pruning and sanitation can be quite effective, but it must be done promptly and consistently.

2. Chemical control

a. Spraying

The target of spraying is the adult bark beetle. Use of insecticidal spray in early spring has been a common practice. The most commonly used insecticide, until about 15 years ago, was DDT. This is banned now because of the strong environmental concern of the public. It has been replaced by a less effective but biodegradable product called Methoxychlor. Another recently marketed insecticide in use is Dursban 4E (Dow Chemical Co.). These insecticides are effective only for a short period of time; repeated spraying may be necessary.

Little information is available in the literature on how much insecticide is present on the tree after spraying. Recent work using insecticidal spray (Dursban 4E [0.5%]), applied with a mist blower and a hydraulic sprayer, has shown that coverage of the tree was not uniform. Insecticide concentration in some areas was well below the effective dose necessary to kill the beetles (Roy, unpublished). Specific insecticides should be tested independently.

b. Injection

The target of injection into the tree is usually the fungus. The ideal chemical to control Dutch elm disease should be highly toxic to the fungus but harmless to the tree; it should be water soluble to allow for systemic distribution within the tree and yet be environmentally safe. Numerous chemicals have been tested throughout the years with little success until recently. A major breakthrough was the discovery of the fungicidal activity of a class of synthetic organic compounds called carbamates.

Benomyl (methyl 1-[butylcarbamoyl] benzimidazol-1-yl carbamate) (Delp and Klopping, 1968) and a chemically related compound, thiabendazole, 2-(4-thiazolyl) benzimidazole, have shown the greatest promise in the control of Dutch elm disease (Biehn and Dimond, 1971; Smalley, 1971, 1978).

There are numerous difficulties associated with the chemical injection and distribution in trees. How some of these problems relate to chemical effectiveness and tree physiology will be discussed using the active fungitoxic compound of Benomyl, MBC, and its phosphate salt (MBCP), as an example. It should be kept in mind that MBC-containing compounds have proven most promising, and that the problems discussed are common to a greater or lesser extent in all Dutch elm disease control chemicals.

Benomyl reacts with water and is slowly converted to a more stable, water-soluble, and weakly basic compound called MBC (methyl benzimidazole-2-yl carbamate) (Clemons and Sisler, 1969). Insolubility of MBC in water (8–10 ppm at pH 5–6) was a problem because uptake and distribution in the xylem of the tree after injection is only possible if the substance is water soluble. This was achieved by the production of acid salts of MBC with inorganic acids (Kondo et al., 1973). Phosphate salts appeared to be particularly suitable, because they are both soluble in water and fungitoxic. Upon breakdown, phosphate acts as a nutrient for the tree. The phosphate salt is marketed under various names: MBCP, Lignasan P, Lignasan BLP (DuPont trade name), carbendazim phosphate (British Standards Institute), and others. They all have the same active ingredient and concentration (0.7% or 7000 ppm). The fungicide is stable, has a very low phytotoxicity, and is not toxic to the environment.

Fungicides may be injected into the trunk, the roots, or the root flare. The best distribution has been reported for root injection of dilute solutions under low pressure. Information on concentration, volume, tree diameter and the period of injection is available in the literature (e.g. Kondo, 1972). For larger trees, the root flare area should be injected in addition to roots for proper coverage. If the root system is not accessible, such as under urban conditions, then the tree might be injected in the root flare area only. Trunk injection is considered the least effective option.

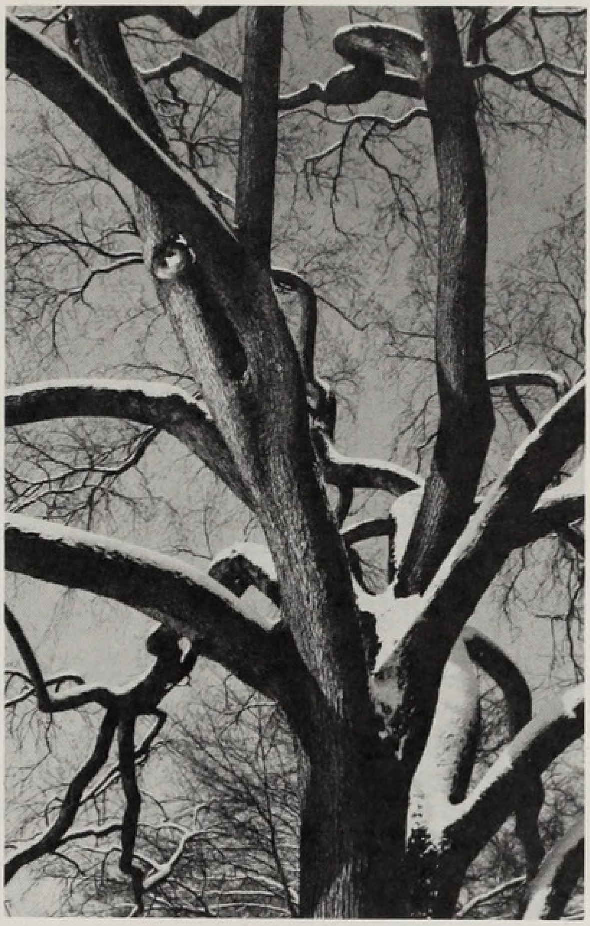
Injection and distribution of the fungicide is a very complex problem that has received some systematic attention (e.g. Day, 1980). First of all, xylem water is normally under tension. As soon as the xylem is injured, air is drawn into vessels, and if liquid is not applied quickly, the air pockets will prevent sufficient uptake. This problem can be overcome by applying positive pressure that decreases the size of the air pockets. But forcing fungicide into old, non-functioning vessels might be useless and wasteful. One method that has reasonable potential, but has only been used in the laboratory for fundamental research, is vacuum infiltration. Air can be removed from the wood with a vacuum pump (small, hand-operated pumps are inexpensive). Once the air pockets are removed from the functioning vessels, liquid is taken up by the xylem without applied outside pressure.

The chemical nature of fungicides may pose problems with regard to distribution. For example, the structure of MBCP is such that it is strongly adsorbed to the vessel walls and thus becomes immobile. In contrast, acid dyes move easily into the entire crown. Acid dye injections are therefore not good indicators for the effectiveness of an injection method; distribution of injected MBCP is often quite erratic when checked with chemical analysis of twig samples taken from the crown (Roy et al., 1980). Another important factor is the pH of the injected solution. For example, MBC is very active at low pH (very acid), but this is injurious to plant tissue. If the pH is raised (the solution made less acid), MBC precipitates out of solution. In addition, the pH is also slightly raised along the translocation path, and MBC may precipitate along the vessels. The problem of solubility may be solved by using a slight excess of phosphoric acid, but too much acid damages the wood. For these reasons, many compromises must be made to optimize injection procedures (Kondo, 1972).

There have been justifiable concerns about injection wounds (Shigo, 1977). Drilling into the wood destroys some of the conducting tissue, in addition, the holes can serve as points of entry for other micro organisms. From this point of view, root injections are also best because roots are easily regenerated (Lyford, 1980).

It has been reported that the effectiveness of chemical therapy is good for one growing season when it is done by root flare or trunk injection, and for almost two growing seasons if injection has been made into the roots. This is probably due to poor radial movement of MBCP. Once new vessels have formed in the stem, there is no MBCP

The branch structure of an American elm in the Public Gardens, Boston, Massachusetts. Photo by P. Del Tredici.



available to them. In the roots, however, vessels often function for a number of years and precipitated MBC can be very slowly dissolved a year or so later. For a reliable therapeutic program, injection should be done annually, once the tree has been injected.

3. Outlook

To overcome the limitations associated with MBCP, a host of other fungicides have been marketed that are chemically related to Benomyl. Thiobendazole (Mertect, Arbotect, ME II6), Fuberidazole, Mecarbinzid, Thiophenate methyl, M2B21914 and NF 48 are being tested.

In the belief that the insecticide will translocate to the crown area and protect the tree from insects, attempts were made to control beetles feeding on elms by systemic insecticide injection. Bidrin (Trade name of Shell Co.) was extensively field tested using trunk injectors but was found to be highly phytotoxic; in addition distribution was very poor. Recent reports indicate the same type of effect using well-known systemic and reportedly non-phytotoxic insecticides (Aldecarb, Diazinon, Dimethoate, Meta-Systox R, Phosphamidon) as well as mixtures of MBCP and these insecticides. When injected into the root system or the root flare of elms, these mixtures were found to be extremely phytotoxic (Roy et al., 1980).

Certain chemicals can be used to control the movement and population of elm bark beetles. These include sex attractants, repellants, confusants, and antifeedants (Strobel & Lanier, 1981). They are generally very expensive and depend to a large extent on climatic conditions such as wind direction and rainfall.

At present, injection treatment of elms is quite expensive and only affordable in the case of high-value elms. It is possible to achieve reasonably good levels of protection using injection of therapeutic chemicals into the roots or root flare under diligently controlled conditions as a part of a comprehensive tree care program that includes sanitation, insecticidal spray, and fertilizer.

Scientists may come up with a spray-on fungicide with the effectiveness of MBC. This would necessarily involve transport of the chemical through the phloem to ensure distribution. Spraying would eliminate the wounding problem. On the other hand, injection is relatively pollution free, whereas spraying might create environmental problems. Another recent development is the use of a fungitoxic bacterium (Stroble & Lanier, 1981).

In conclusion, we can say that although much progress has been made, we are still far from being able to protect our precious elm trees effectively. It is hoped that the development of more suitable chemicals, and a better understanding of how the tree functions, will bring improvement in the future.

Acknowledgments

We thank Terry A. Tattar and Francis W. Holmes for reviewing the manuscript.

IV. REFERENCE LIST

Biehn, W. L. & Dimond, A. E. 1971. Prophylactic action of Benomyl against Dutch elm disease. *Plant Dis. Rep.* 55: 179–182.

Campana, R. J. & Stipes, R. J., eds. 1981. Compendium of elm diseases. *Amer. Phytopathological Soc.* Compendia Series.

Clemons, G. P. & Sisler, H. D. 1969. Formation of a fungitoxic derivative from Benlate. *Phytopathology* 59: 705–706.

Day, S. J. 1980. The influence of sapstream continuity and pressure on distribution of systemic chemicals in American elms (*Ulmus americana* L.). MS thesis, University of Maine at Orono.

Delp, C. J. & Klopping, H. L. 1968. Performance attributes of a new fungicide and mite ovicide candidate. *Plant Dis. Rep.* 52: 95–99.

Dimond, A. E. 1970. Biophysics and biochemistry of the vascular wilt syndrome. *Ann. Rev. Phytopathol.* 8: 301–322.

Huber, B. 1935. Die physiologische Bedeutung der Ring- und Zerstreutporigkeit. (The physiological significance of diffuse and ringporousness). *Ber. Deutsch. Bot. Ges.* 53: 711–719. (Photocopies of English translation available from: National Translations Center, 35 West 33rd St., Chicago, IL 60616).

Kondo, E. S. 1972. A method for introducing water soluble chemicals into mature elms. *Can. For. Serv. Info. Rep.* 0–x–171.

Kondo, E. S., Roy, D. N. & Jorgensen, E. 1973. Salts of methyl-2-benzimidazole carbamate (MBC) and assessment of their potential in Dutch elm disease control. *Can. J. For. Res.* 3: 548–555.

Lyford, W. H. 1980. Development of the root system of northern red oak (*Quercus rubra* L.). *Harvard Forest Paper* No. 21.

Roy, D. N., Purdy, J. R. & Ayyamperumal, P. 1980. Distribution of methyl benzimidazole-2-yl carbamate phosphate in elm: effects of chemical properties and formulation variables. *Can. J. For. Res.* 10: 143–151.

Shigo, A. L. 1977. Discolored and decayed wood associated with injection wounds in elm. *J. Arboriculture* 3: 230.

Sinclair, W. A. & Campana, R. J., eds. 1978. Dutch elm disease perspective after 60 years. *Northeast Regional Research Publ. Search Agricult.* Vol. 8. No. 5.

Smalley, E. B. 1971. Prevention of Dutch elm disease in large nursery elms by soil treatment with Benomyl. *Phytopathology* 61: 1351–1354.

Smalley, E. B. 1978. Systemic chemical treatments of trees for protection and therapy. *In*: Dutch elm disease, perspective after 60 years. W. A. Sinclair & Campana, R. J., eds. *Northeast Regional Research Publ. Search Agricult.* Vol. 8, No. 5.

Strobel, G. A. & Lanier, G. N. 1981. Dutch elm disease. *Scientific American* 245(2): 56–66.

Van Alfen, N. K. & Turner, N. C. 1975. Influence of a *Ceratocystis* toxin on water relations of elm (*Ulmus americana*). *Plant Physiol.* 55: 312–316.

Zimmermann, M. H. 1978. Structural requirements for optimal water conduction in tree stems. Pp. 517–532 in: Tropical Trees as Living Systems. Tomlinson, P. B. & Zimmermann, M. H., eds., Cambridge Univ. Press.

Zimmermann, M. H. & Brown, C. L. 1971. Trees: Structure and Function. New York-Heidelberg-Berlin: Springer-Verlag.

Zimmermann, M. H. & McDonough, J. 1978. Dysfunction in the flow of food. Pp. 117–137 *in:* Plant Disease — An Advanced Treatise. Vol. 3. New York: Academic Press.