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Tree Decay in Our Urban Forests: What Can Be Done About It?

Walk along almost any city street in the world and you will eventually see some trees. Some appear fine. Most do not. Pollution, soil compaction, gas leakage, salt, diseases, and insects have all taken their toll. You will not look long before you see many wounds. Mechanical injuries and those resulting from improper pruning are everywhere. Such injuries are the major problems man has inflicted on trees, worldwide. But how can decay cause trees problems when decay is the breakdown of the dead, unresponsive, central core of trees—the heartwood? Here the confusion starts.

First a Quiz

How much do you know about trees, tree decay, and some commonly used tree care practices? Are the following statements true or false:

- Trees regenerate or restore injured and infected tissues.
- Trees heal infected and injured wood.
- Callus growth is associated with decay development.
- Heartwood is a dead, unresponsive tissue in all trees.
- Wound heartwood and pathological heartwood are types of heartwood.
- Given enough time, discolored wood will be the same as heartwood.
- When wounds expose heartwood and sapwood, heartwood will decay first.
- After wounding, the central portion of the heartwood core will decay first.
- Once "heartwood-rotting" fungi infect heartwood they will continue to attack the new heartwood as it forms.
- Hollows result when all the heartwood is digested.
- Frost causes "frost cracks."
- Wind causes "wind shakes."
- Minerals absorbed from the soil cause "mineral streaks."
- To stop the development of decay in water-filled cavities, holes should be bored to drain the water.
- Before a cavity is filled, thorough cleaning beyond the rot, deep into the surrounding healthy wood, should be done.
- When pruned, all branches should be cut as close as possible to the trunk.
- Pruning cuts should be painted with wound dressing to prevent decay.
- When a fresh mechanical wound is scribed or traced, the vertical ends should be pointed.
- When a tree is braced, triangular washers should be used on the ends of rods.
- Decay is a problem only on old trees; decay affects only dead heartwood, therefore decay does not affect tree vitality.
- Decay is not a disease.
- Because of the many microorganisms involved in the decay process, it is impossible to select decay-resistant trees.
- It is not possible to detect decay nondestructively in living trees.

And the list goes on and on. All these statements are false—and all are in textbooks, are being taught, or are in common practice. Indeed, we have some problems.

Time for Some Changes

The original concept of tree decay, developed mainly by Robert Hartig, has existed with little change for over a century. The same can be said for many tree care practices based on the decay concept and old gardening practices. In brief, the original decay concept states that wounds expose heartwood, Hymenomycetes infect the heartwood, and decay results. Heartwood is defined as the dead, unresponsive central core of trees.

Early researchers could not systematically dissect large trees with the equipment available to them. As a result, the early view of tree decay was from the crosscut sections of trees. Studies of fruit bodies were possible; studies of decay as viewed from small wood sections were possible; laboratory studies on dead wood were also possible; large-scale dissections were not possible.

Some of the first systematic dissections of trees were done by George H. Hepting during his studies in the Mississippi Delta in the 1930s. Hepting was the first to observe compartmentalization of decay in trees (3).

It was not until 1950 that the powerful one-man chain saw, capable of dissecting large trees, came on the market. In 1959, I started dissecting trees, not only by crosscuts but also with full-length longitudinal cuts to expose the wood associated with external wounds and branch stubs. From these observations and the results of studies by many other investigators, an expanded concept of decay emerged. Then the CODIT model was developed, and with the help of many other researchers, a new method was developed to detect decayed wood in living trees and utility poles.

As the quiz indicates, there are many myths and misconceptions about what a tree is and about how trees respond to injury and infection. Once we begin to clarify some of these basic points, it will become obvious what adjustments must be made in tree care practices to maintain healthy, safe, and beautiful trees in our urban forests.

What Is a Tree?

Trees are highly compartmented, shedding, perennial woody plants. Wood has four functions: storage, transport, protection, and support. Sapwood has all of these; heartwood maintains a strong protective and support function. The confusion between heartwood and wood altered as a result of injury and infection is at the center of a century of problems.

After a tree is wounded and infected, it responds—first in an electrical way, then in a chemical way, and, in the growing season, in an anatomical way. The wound-altered wood goes by so many confusing terms that it would be impossible to mention them all here.

In the early stages, wound-altered wood, which may contain pioneer microorganisms, has a stronger protective function than the contiguous wood, whether the contiguous wood is sapwood or heartwood. Under some conditions that we do not understand, this wood will maintain its highly protective capacity for long periods. Under other conditions, the wound-altered wood becomes less protective than the contiguous wood. Wound-altered wood can be either more protective or less protective. Wound-altered wood is a wood in transition. Many microorganisms, bacteria, nondecay-causing fungi, and decay-causing fungi may all inhabit the wound-altered wood (4).

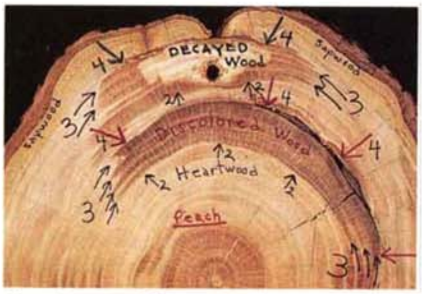


Fig. 1. In the CODIT model, 1s (not shown here) represent resistance to vertical spread of infection after injury, 2s show resistance to inward spread, 3s show resistance to lateral spread, and 4s show the separation between wood present at the time of infection and new wood.

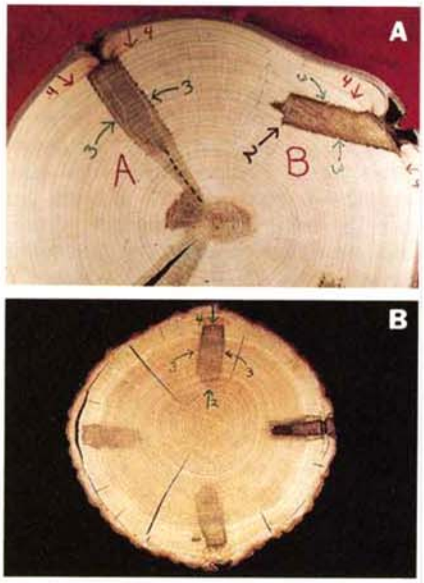


Fig. 2. (A) Discolored wood associated with drill wounds in red maple, which does not have heartwood. In wound A, the drill tip ended so close to the already discolored center that the wood between the drill tip and the center (dotted line) died and discolored; 2s of the CODIT model did not hold. In wound B, 2s resisted inward spread, mainly because of a large amount of living cells; 3s resisted lateral spread; and 4s separated wood present at wounding from new wood. Barrier zones (4s) continued beyond the wounds. (B) Patterns of discolored wood associated with drill wounds are the same in oak, which has heartwood.

Compartmentalization and CODIT

Trees survive after injury and infection by compartmentalizing injured and infected wood. Trees are generating, not regenerating, systems. Trees generate tissues in new positions every growing period. When branches or woody roots begin to die from injuries and infections, the tree begins to shed them. When trunk wood or wood in large branches and roots is injured or infected, the tree cannot shed it. The microorganisms may spread so rapidly that the branch, root, or entire tree is killed. Or the tree recognizes the infection and interacts with the microorganisms. The tree begins to compartmentalize the infected wood. The technical parts of compartmentalization are very complex, and we still only have a slight understanding of the mechanisms (10).

To make the compartmentalization process more understandable, we have developed a model called CODIT, an acronym for Compartmentalization Of Decay In Trees (5) (Fig. 1). CODIT is a model and should not be identified too closely with actual biochemical and anatomical features. The model has two parts. Part one is represented by three walls: Wall 1 resists—not stops—vertical spread, wall 2 resists inward spread, and wall 3 resists lateral spread. Walls 1, 2, and 3 are in the tree ready to go before injury and infection. After injury and infection, part two starts when the tree forms wall 4. This wall separates wood present at the time of injury from new wood. Wall 4 is a representation of the barrier zone that forms in response to injury and infection (11) (Fig. 2). The zone contains a large amount of axial parenchyma and, in conifers, many resin ducts. It is a nonconducting tissue and forms in roots as well as in trunks. It also forms in response to vascular pathogens, such as *Ceratocystis ulmi*, and to root-rotting pathogens, such as *Fomes annosus* and *Armillaria mellea* (8).

Some trees of a species can activate walls 1, 2, and 3 so rapidly and hold them so effectively that when infection takes place, the volume it occupies is small. Other trees of the same species may respond very weakly with walls 1, 2, and 3. Then the infection damages a large volume of wood. The CODIT model has made it possible to select trees that have a high resistance to the spread of decay-causing microorganisms. We can now begin selecting, and soon breeding, trees resistant to the spread of decay (2).

Compartmentalization is an effective and essential survival process, but it can also be self-defeating and destructive when it goes too far or too fast. In compartmentalization, a tree gives up a small portion of itself to save the larger whole. Every time tissues that normally function for storage and transport are walled off, the vitality of the tree is reduced. Energy is required for compartmentalization. As demands for protection through compartmentalization increase, the amount of tissue present to supply the energy decreases. When the tree has

Fig. 3. (A) A pruning cut should be made on the outer side of the branch-bark ridge that separates the branch from the main stem (black line), not behind the ridge (red line); a stub should not be left. (B) When a cut is made behind the branch-bark ridge (pencil point), the trunk is wounded, and infection develops rapidly into the trunk.

enough energy and enough time between injuries and infections to wall off and to generate tissues, the tree will continue to live in a healthy state (8).

Survival of a tree depends on energy, and the energy reserves are held in the living cells. Storage of energy-releasing materials is a major function of sapwood. As wounds decrease the volume of wood that can be used for storage, the tree becomes more susceptible to infection by other microorganisms. A tree can live for long periods on a minimum of energy reserves as long as it is not injured or infected again and there is no call for added energy.

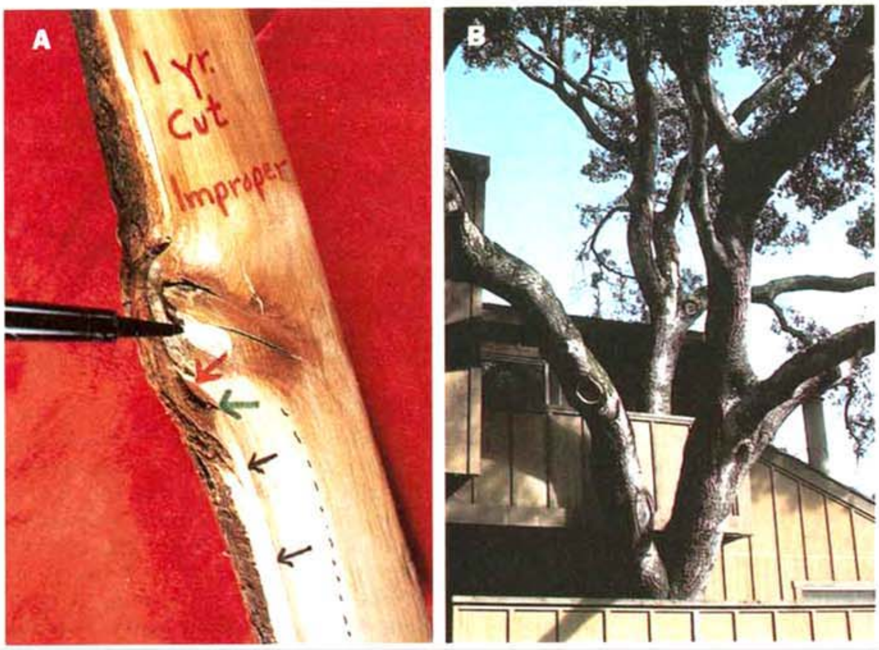


Fig. 4. (A) Pointer indicates decay developing 1 year after a small dead branch was cut flush with the trunk of a cherry tree. Red arrow shows limit of cut, green arrow shows limit of dieback after cut, black arrows show discolored sapwood on inner side of wall 4, and dotted line represents the sapwood-heartwood boundary before the cut. Sapwood above and below the cut died and discolored. (B) This live oak has many columns of decayed wood associated with large flush cuts made for aesthetic reasons (the tree died).

Decay caused by wounds can reduce the vitality of trees and open the way for other microorganisms, such as those associated with cankers and root rots. But how can this be so if "heartrot" affects only the dead, unresponsive heartwood? This point keeps coming up and must be clarified because it is at the heart of over a century of confusion about trees and tree decay.

Wound the heartwood and it compartmentalizes (7). Is this a characteristic of an unresponsive tissue? The so-called heartwood-rotting fungi *do not, cannot* infect heartwood in a living tree that has not been first altered by wounding or by the death of branches. A common sight on oak, pine, or locust, all of which have a large heartwood core, is a hollow. Why do not the so-called heartwood-rotting fungi continue to attack the surrounding heartwood? They do not do it even when hundreds of growth rings surround the hollow. The diameter of the hollow is the diameter of the tree at the time of wounding. A hollow forms when walls 1, 2, and 3 all fall to the microorganisms. Experiments on living trees show this.

Pruning—Beneficial or Destructive?

The CODIT model has helped us to reexamine many tree care procedures. The most important is pruning. Proper pruning is the best thing that can be done *for* a tree; improper pruning is the worst thing that can be done *to* a tree.

For centuries the recommended pruning method has been to cut branches flush with the trunk and then coat the cut with some dressing. Now we know that branches—living, dying, or dead—should be cut as close as possible to the branch collar at the branch base, but the collar should not be injured or removed (6). Every branch has a branch-bark ridge that separates the branch from the main stem. The cut should be on the outer side of the ridge; if the cut is made on the inner side, a trunk wound will result that provides easy entry for microorganisms (Fig. 3). A flush cut will remove the protective chemical layer that is in the branch collar. And there is more. When a flush cut is made, the trunk is injured and it responds by forming a barrier zone,


Fig. 5. So-called frost cracks start from wounds, especially on small trees. The large internal crack forms as the callus ridges close the wound. The secondary cracks (pencil point) form at the ends of the wound. Stress could cause the tree to split out along the three internal cracks.


Fig. 6. Four wounds from the same tree show that dressings do not prevent discolored and decayed wood from developing.

which is highly protective but very weak structurally (Fig. 4). When other pressures or strains are put on the trunk, the tissues along the barrier zone may split to form a circumferential crack called a ring shake.

There are two types of vertical cracks: those that start from the outside and move inward and those that start from old wounds and move outward. The first type are usually shallow and confined to the bark, causing little injury. They still start where some wound, branch stub, or other type of interruption occurred on the trunk. Dead roots also are common starting points for seams.

The second type of crack is very injurious. The large seams moving outward from wounds are often called frost cracks. Frost does not start these; wounds do (1). After wounding, especially on small, rapidly growing trees, wall 4 forms. In addition to this, the callus begins to close the wounds. When the callus ridges meet, a seam forms that could break out later when pressure is applied (Fig. 5). Also, small secondary cracks form where the callus begins to form.

Wound Dressings

There are many types of wound dressings. The common treatment for wounds has been to cover them with shellac or some asphalt or bituminous material. Why paint or dress a tree wound? The rationale has been to block out microorganisms; or to keep moisture in; or to keep moisture out; or to apply chemicals in the dressing that will kill the wood-inhabiting microorganisms. Anyone who knows anything about microorganisms and their size knows the wound cannot be shielded from them. The moisture-in or moisture-out rationale is also unrealistic because dressings coat the surface of the wound. Experiments in which trees were dissected and microorganisms isolated revealed that treated wounds did no better than untreated ones (9) (Fig. 6). To be worthwhile, a dressing would have to do better than the controls to justify the time it takes to treat the wounds and the cost of the dressing.

In the past, callus formation or "wound healing" was taken as a measure of success of the dressing. Many materials stimulate callus formation, but callus formation is not associated with prevention of decay. Decay goes on in the wood present at the time of wounding; callus forms *after* wounding. Callus formation is associated with current growth rate: A fast-growing tree will form large callus ridges. In theory, decay would stop if the wound closed rapidly and completely. But this happens rarely. Even when wounds close rapidly, microorganisms still have time to infect the injured wood. An almost-closed wound gives most wood-inhabiting microorganisms the best environment for their growth. Many fungi, such as the canker rots, even form wedges of fungus material that keep the wounds slightly open. The constant death of other branches keeps wood open to infections. We do know that some trees can wall off the injured and infected wood to small volumes. We should be more concerned with selecting and planting decay-resistant trees than with trying to treat trees like humans.

Injections

There are other reasons why we must have strongly compartmentalizing trees in the city. The recent interest in injections is one reason. Injections properly done can help trees; injection improperly done can harm trees. All types of chemicals are being injected, infused, or implanted into trees with little regard for the injury caused by the treatment. If the tree may die, then the risk of added wounding is justified. But when many deep, large holes are bored into healthy trees year after year, and all types of chemicals are introduced, trouble will begin. *A tree can survive after many severe wounds as long as the tree has energy and time to wall off the injured and infected tissues and more time to generate tissues of the type injured in a new position.* But when severe wounds occur faster than the walling-off process and faster than the generation of tissues, then the storage and transport capacity of the wood begins to decrease. When this happens, many weakly parasitic or opportunistic microorganisms quickly infect. Thus even if the wounds and chemicals of injections and implants cause injury, the tree will recover, given enough time. But if wounds are repeated year after year, the tree will be in trouble (Fig. 7).

Proper injections require skill. For the safest injections, holes should be made as small and as shallow as possible at the base of the tree, never in the roots. The holes should not be plugged or painted. After injection, everything possible should be done to maintain or increase the vitality of the tree.

Adjustments in Other Practices

The responsibility of the professional arborist is not only to help trees stay attractive and healthy but to do so in such a way that the tree is not a hazard to property and people. One way to do this is to use cables, rods, or other types of hardware to brace branches and trunks. All bracing procedures involve some wounding; there is a trade-off where some wounding is better than a hazard tree.

When holes are bored through stems that have decayed wood, wall 4 will be broken. Decay will spread rapidly into the wood along the hole. Because of this, it is best to use large washers on the ends of the rods. The washers should be seated, when possible, on the wood—not in the wood or on the bark. The washers should be rounded or oval; washers with sharp points cut into the bark and make it difficult for the tree to wall off the wound. Cambium will die back around sharp-pointed washers. When lag screws are used, they should be placed only in sound wood. If the screw penetrates decayed wood, the decay will spread outward around the screw, decreasing its holding power.

Open ends of lag screws should not be turned so tightly into the bark that the cambium is wounded; dead area will result. Often, the wood that forms after the hardware is put into a tree gives most of the holding power to the bracing (Fig. 8). A wall 4 may form in the growth ring that develops after the hardware is inserted. This is good because it limits the development of decay, but it may be bad because the wood may later crack along wall 4, which is a strongly protective but structurally weak tissue.

When fresh wounds are traced or scribed, the dead and dying bark should be cut back to healthy wood. There is no need to scribe in the shape of an ellipse. The scribe should be as shallow as possible into the wood, and the margins or perimeter should be rounded. When the scribe has pointed ends, the cambium beyond the pointed ends may die back and callus will not form there. If the cambium remains alive directly above and below the wound, callus will form at these positions as well as from the sides.

When a cavity is being filled, only the decayed wood that comes out easily should be removed. The hard rim of tissue—wall 4—that surrounds the decayed wood must not be broken; if wall 4 is broken from the inside, the decay will spread rapidly into the newly exposed wood. Cavities can be filled with any type of material except abrasives. The filling may give the callus ridges a place to seat, thus stopping the inroll of callus. There are no data to show that fillings add strength to the trunk, but the hardware used in the cavity may add strength.

Holes should not be drilled to drain water from a cavity. The holes will break wall 4 and open new wood to infection. Tubes may be used to drain the liquid from wetwood areas. This, again, is a trade-off. The tube will break wall 4 and the wetwood column will develop out to the bark. A new wall 4 will form as a result of the new wound. But wetwood is not decayed wood further development of the wetwood will not decrease the strength of the tree.

Construction jobs near trees result not only in wounds to trunks and roots but also in changes in soil grade that can cause trees problems. Tree owners should

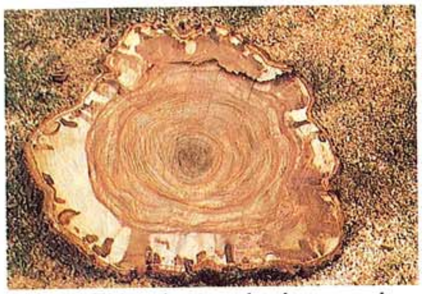


Fig. 7. This elm received many deep injections and died from Dutch elm disease.

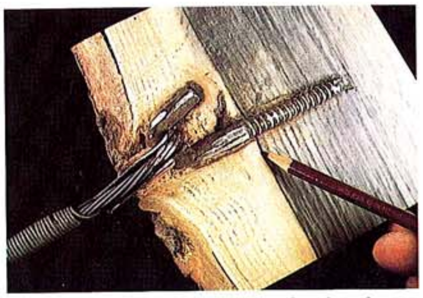


Fig. 8. The wood that forms after hardware is put into a tree does most of the holding. The pencil points to a crack that developed along the growth ring that formed after the screw was inserted. When a screw touches decayed wood, new decay will develop rapidly in the wood around the screw.

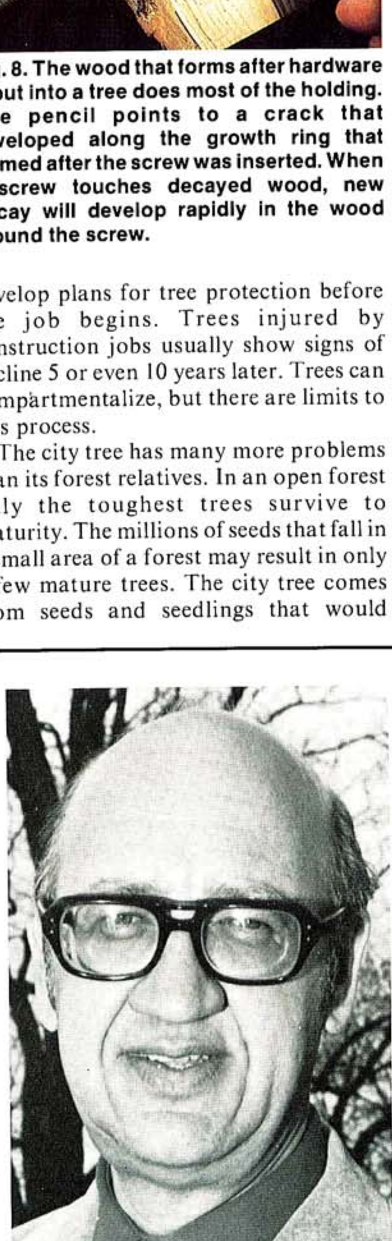
develop plans for tree protection before the job begins. Trees injured by construction jobs usually show signs of decline 5 or even 10 years later. Trees can compartmentalize, but there are limits to this process.

The city tree has many more problems than its forest relatives. In an open forest only the toughest trees survive to maturity. The millions of seeds that fall in a small area of a forest may result in only a few mature trees. The city tree comes from seeds and seedlings that would probably never survive in a forest. They are weaklings. This is why we must start selecting and planting strongly compartmentalizing trees in our cities. It can be done now. Genetic studies have been done on several tree species; they suggest that the capacity to compartmentalize effectively may be under strong genetic control.

Hazard Trees

Trees with decayed trunks, roots, and branches are hazards to property and people. External indicators of decayed wood are often present, such as fruit bodies, cavities, cracks, and fluxing material. But trees may contain a large amount of decayed wood without having obvious external indicators. This is most common with root rots. It is possible now to use a pulsed electric current to detect decay in trunks and roots. A special wire probe attached to a pulsed current meter is inserted into a small hole made by a battery-powered drill. As the tip of the probe goes inward, the electrical resistance of the wood is measured in ohms on the meter. Sudden decreases in resistance indicate changes in the wood.

The same electrical device can be used to determine the relative vitality of trees. Needle probes attached to the meter are inserted into the cambial zone. The electrical resistance of the cambial zone is shown in ohms on the meter. The lower the resistance, the higher the vitality. To use the method, many trees of the same species must be measured first and a mean reading determined. Trees of that species with electrical resistance readings below the mean are more vital than trees with electrical resistance readings above the mean. This information can be very helpful when a tree is a suspect hazard. The professional arborist needs all the information possible when a decision must be made on the fate of a tree.



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Dr. Shigo is the leader of a USDA Forest Service Pioneering Project on discoloration and decay in living trees. He is also an adjunct professor of plant pathology at the University of New Hampshire and a lecturer at the University of Maine. He joined the Forest Service in 1959 after completing his Ph.D. in plant pathology at West Virginia University. All his research has been on wound response in trees, and he has packaged portions to reach many audiences worldwide.

What Now?

How can this information help our trees, especially those in an urban environment? Help will come in two ways. First, we must take PROPER care of the tree now growing. Second, we must use the new information now available as we plant new trees.

Maintenance programs must be developed to make certain that trees receive proper care long after they are planted. Tree care takes time and money, and the best possible procedures should be used to get the most for our time and money.

Proper pruning is still the best thing we can do for our trees. Dead and dying wood should be removed before a hazard tree harms property or people. We must make more people AWARE of what a tree is and how it survives. Wounds must be prevented. Research results must get into use. We must start selecting, then start planting, decay-resistant trees. Indeed, there is much that can be done to help our trees stay safe, healthy, and beautiful.

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