TREE HEALTH[1]

by Alex L. Shigo

Abstract. A nontechnical discussion for the arborist on what a tree is and how it responds after injury and infection. The more we know about trees, the more we can help them help themselves after injury and infection.

Tree care, arboriculture, tree pathology, phytopathology, plant disease, tree insects, and tree diseases are common terms used in our work to control tree problems, and to help trees stay healthy, safe, and attractive. Tree problems have been controlled many times by using sprays, injections, and other methods. This is fine! Yet, some tree problems persist in spite of our many control attempts. Dutch elm disease, chestnut blight, declines and diebacks, and root rots are only a few of the continuous problems. Maybe we have spent too much time and effort on the second part of the terms given in the first sentence. Maybe it is time to give the first word in the terms more attention. Maybe it is time to approach some of our tree problems from the view of the tree. We should not stop our other efforts, but we should look more at the tree and see what it is and how it functions to survive under all types of stress and strain. How can we help trees help themselves? Trees have been helping themselves for over 200 million years. With half a chance, I believe they will continue to survive. My point is, let's give them that half a chance.

Some Tree Basics

It is time to reexamine our patient, the tree. Most people who work with trees know all or most of the points I will give, but it is necessary sometimes to review and see how some of the sound, old information connects with some of the new information. Connections are the keys to understanding.

In this article, I will discuss some very important points without using technical terms. I will give some basic points and then discuss how a tree defends itself.

Trees are highly compartmented plants. They are built up in compartments, and when they breakdown — disease — they do so compartment by compartment.

Trees survive after injury and infection by walling off the injured and infected wood to as small a volume as possible. Some individual trees do this rapidly and effectively. They can live in a healthy state while having hundreds or even thousands of infections walled off in pockets throughout the tree. Other individual trees of a species do not wall off rapidly and effectively, and the force of the infecting microorganisms quickly leads to very large volumes of injured wood. Such a tree will not live very long.

Research by geneticists shows that some individuals in a species are tough, while others are weak when it comes to walling off infections. When the walling off force of a tree is strong, the tree wins. However, when the infection force of the microorganisms is stronger than the counterforce of the tree, the tree loses. Walling off or compartmentalization is not an absolute process that always assures that the tree will win.

Sometimes the tree and microorganisms exert an equal force and a see-saw interaction begins.

Trees use and wall off leaves and needles, reproductive parts, and fine absorbing roots. Trees keep wood and inner bark. Wood is a highly ordered arrangement of living, dying, and dead cells with walls of cellulose and lignin mostly. The three major functions of wood are to: transport, store, and support. Wood also has a protection system. Sapwood has all of these. Heartwood has a greatly diminished to nonexistent mineral transport and nutrient storage function, but a very high protective system and a mechanical tree support function.

Inner bark or phloem is primarily a transport tissue. Tree food manufactured in the leaves and needles is moved downward. Energy reserves are

[1]Presented at the annual conference of the International Society of Arboriculture in Louisville, Kentucky in August 1982.

also stored in the inner bark. Beyond the inner bark is the protective bark which has three types of tissues: a bark cambium, cork that forms to the outer side of the bark cambium, and layers of outer bark cells that form to the inner side of the bark cambium.

Healing and Compartmentalization

When wood is injured or infected, it responds to limit the spread of infection. The tree responds to the infected wood and not to the specific microorganism. Wood responds to each attack only once! By contrast, when animals or humans are injured and infected, they respond by replacing cells in the same position; the same tissue can respond again if it is injured at another time. For example, look at your hand and think of all the cuts and bruises you received during your lifetime. Some serious cuts may have left scars, but most have healed and left no trace of the injured tissue. The same spot on your hand may have been the site of many cuts. Animals and humans can repeat the healing response; trees cannot. Mature trees have hundreds or even thousands of injuries and infections walled off in pockets in the wood. The tree can do something that animals cannot do — trees grow a completely new tree over themselves every growing season.

Trees are generating organisms, and animals are regenerating organisms. Animals repair, replace, restore, regenerate, and repeat the wound response in the same position. Trees wall off injured and infected tissues and then continue generating new tissues always in a new spatial position.

Compartmentalization is a boundary-setting process to resist, not stop, spread of infections.

The tree must confine the infection in the growth rings present at the time of wounding, and it must stop the infection from spreading into the new growth rings or trees that form after the infection.

How the tree does these two things is not clearly understood. We do know that if they do not confine and stop infection, they die. Healing in an animal does not work always. Sometimes the infection spreads so fast that the animal dies. The same happens with trees. Compartmentalization is the tree's defense system, but sometimes it does not function perfectly. Compartmentalization is only half of the action. The other half is the force of the microorganisms. Remember, trees have two tasks: keep injury small and to keep infection from spreading into the new trees or new growth rings.

How can a tree protect its central core of heartwood after injury and infection? Can heartwood respond? Isn't heartwood a dead, nonresponsive, tissue? It may be dead according to our definition of dead, but it is surely a responsive tissue. Our problem is that we think and relate in terms and thoughts that we know for ourselves. We relate to healing. Trees do not heal because they cannot restore injured and infected tissues. Restoration means to replace or repair in the same position. After wood is injured or infected, the tree sets boundaries around the infection and then produces new cells in a new position.

Tree Wound Response

The tree's response to injury is very different from that of an animal. The tree's response is similar to that of a mousetrap. When a wandering mouse triggers the mousetrap, the trap goes off in a predictable way, and usually the mouse will be killed. Should this be called a response of the mousetrap? Or should we say that the trap had to be set off by a living thing. It took our energy to set it. Maybe this is the way that heartwood works to wall off infected wood. Heartwood is always cambium first. So, the living force of the cambium is transferred in some way to the sapwood, and as sapwood ages, there may be a chemical equivalent of the setting of millions of mousetraps. Aging is the regulated change over time as an organism or its part fulfill the program set by the genetic code, as affected by environment. Could it be that one of the programmed parts of the tree's genetic code for wood is a "setting" mechanism? The "traps" may go off when the tissues are injured or when free oxygen reaches the triggering mechanism. We know for sure that the traps go off only once. They are never reset.

This type of defense mechanism has many advantages for a long-lived, massive organism like a tree which cannot move. Or it could be the other way around. Perhaps the tree became a long-lived, massive organism because it developed such a defense system.

Good News, Bad News, and Energy

The good news of the defense system is tainted with some bad news. The bad news is that a tree can compartmentalize itself to death. If it keeps walling off and walling off, soon nothing will be left. Indeed, this can happen. For a tree to maintain itself, it also must look after growing processes and reproduction; this takes energy. Trees trap energy from the sun. Trees use energy for reproduction and maintenance. A tree is committed by its master plan or genetic code to produce a new tree or growth ring every growing season or it dies. A high amount of energy must be present to produce this new tree. Reproduction is still another matter, which also takes a great amount of energy. Most trees solve this problem by spacing their heavy seed years. The exception to this rule is the American elm, which produces a heavy seed crop every year, and it takes the added risk of doing this before it produces its leaves. Other trees such as oaks and pines produce mature seeds at the end of the growing season. Maintenance and reproduction take energy. The tree also must have energy reserves to get the new tree started every growing season. The reserves are usually held in the living cells in the form of starch. Some trees also store fat or oil.

Energy must be stored, and it must have some place to be stored which brings us back to sapwood. A major function of sapwood is storage. When the tree begins to wall off sapwood that normally would be used for storage, it could be risky business. The risk is diminished if after infection the tree quickly generates enough new tissue to maintain the storage volumes. And there is less risk if the tree has no call for additional energy for defense. But, if the tree is injured, it must call for energy; it must be stored. If it is not available, the defense machinery may not work so well.

But, what about heartwood? Why protect heartwood if it does not store energy? True, but if heartwood is decayed completely, the tree does not have a support system. A tree dies either a biological or mechanical death. When microorganisms disrupt the normal physiology of the tree, biological death of the entire tree or a part may occur. When the cambium is killed by some aggressive microorganism, that part of the tree will die. If all the living cells in the sapwood and phloem are killed, the tree will die. These are examples of biological death.

Mechanical death happens when the tree breaks off at the trunk or when it is cut off. When decay proceeds to the point where the tree breaks off, mechanical death occurs.

Heartwood Compartmentalization

Trees must defend themselves against both biological and mechanical death. Heartwood must support the weight of the increasing mass of the tree. In its evolutionary period, the tree developed some ways to protect the heartwood, or there would be no trees as we know them today.

We keep returning to the heartwood and trying to understand its defense system. If you drill a hole through an oak tree and a year later make a cross cut an inch above the hole, the diameter of the drill bit will be the diameter of the discolored band. Heartwood discolors when wounded. If the tree is girdled after it is drilled, the discolored wood above and below the hole will spread out. If decay sets in, it usually starts at the sapwood heartwood boundary, and not in the center of the heartwood. Yet, in wood products, the center or older heartwood will decay faster than younger heartwood; but in the living tree, the youngest heartwood will decay before the older heartwood. If this is so, why do so many trees have a central core of decayed wood? Many of the central decay columns are associated with old branch stubs that have a connection with the tree center, or the decay columns are associated with wounds inflicted when the tree was very young.

Every tree begins as sapwood, then some form heartwood, and others do not. What do you call the central column of wood in a heartwood forming tree when the wood was altered as a result of severe injuries when it was still sapwood? The sapwood will discolor and have the appearance of heartwood, yet the wood never was changed by the normal heartwood forming process. This type of wood is common in some species of eucalyptus and in oak and walnut.

When wounded, wood reacts only once. Heartwood maintains the capacity to react after it is wounded. Our studies on discolored heartwood in oak show that the discolored heartwood has many characteristics similar to discolored wood in maples, which have no core of dark heartwood. Is it the living force of a cell that initiated the discoloration process? Maybe, but what about heartwood, and what about the discoloration of fiber cells that have no cellular contents?

The major problem is that we keep trying to understand the tree's defense system from the reference point of an animal's defense. It will not work. We keep trying to explain the tree's defense system on the basis of an animal's defense system, and worse yet, on the basis of our own human response system.

The Need for Fuel — Energy

Trees trap energy from the sun in a molecule of sugar formed from carbon dioxide in the air and water. It is the tree's food. Food is something that will burn to run something (fertilizer is not plant food). Trees use energy for maintenance and reproduction. A tree maintains itself by building a new tree every growing season and by having a triggered defense system. The defense system is either dynamic — living force, or passive — no living force. It is easy to understand a dynamic response because a living cell does something. But what is a passive response? The mousetrap analogy mentioned above may be the answer.

When energy reserves diminish, defense systems probably get first chance at the energy. Energy is required to protect against biological death as well as mechanical death. If trees can produce a new tree every year and keep energy reserves at an adequate level, trees should live forever. But they don't! Why does a tree die?

Decisions, Decisions

Trees have some difficult problems. The bigger they grow, the more energy it takes for their maintenance and reproduction. The bigger they get, the better target they become for wounding agents that want some of their energy. So, bigger is not the answer to tree survival. Yet, a tree is bound or obligated by its genetic code to produce a new tree every year, which means "sliding" a new tree over all the others. This means that the tree must get bigger, and if it does get bigger, it will fall into the trap of more wounds, more infection, and the need for more and more energy.

To solve these problems, a tree sets some hard rules. When branches and roots stop supplying the energy demands of the tree, the tree walls them off. To avoid being walled off, the branches lower their energy demands by walling off some of the not-so-productive twigs that supported only a few not-so-productive leaves or needles. So, the walling off game starts. Tree parts either meet the standards of the system or they are walled off. This works very well for the total tree system, but not so well for the twigs and branches and roots. A genetic code for energy requirements must be built into the tree. By maintaining a set energy level, some walling off is assured. The weak succumb to maintain the strong. But, the strong of today may be the weak of tomorrow. Nobody is really safe in the walling off game. It does assure a reasonably long life for the system.

Meanwhile, wounds and infections increase as time passes and as tree size increases. The walling off starts, and as twigs and branches, and roots are walled off and die, the ever-present clean up crew — microorganisms — digest the remains. This presents a new problem for the tree. How can the tree stop the clean up crew from continuing into the trunk? The tree has no control over the digestion of the dead branch or root because the part was walled off. The microorganisms may or may not stop at the walled off boundary as set by the tree. Most of the time they do, and the branch eventually falls because of storm, ice, or snow damage and other factors. It is not cast off by the tree. The soil microorganisms decay the root in place.

Stress, strain, vigor, and vitality are conditions connected with energy. Trees are born with the genetic capacity to generate cells, the capacity to grow. Vitality is their ability to grow whether on a rock, in a swamp, in a desert, in rich soils, in poor soils, and so on. Vigor is the tree's built-in genetic capacity to resist stress. Stress is any force — living or nonliving — outside the tree's own system that blocks, shunts, or exerts a drain — directly or indirectly — on the tree's energy reserves. When stress results in an energy drain, or blockage that permanently affects some tree process or part, then the process or part has been strained. Trees are injured when stress results in strain. Trees survive after stress so long as the process or tree part affected is not permanently altered. In animals, strain may be met with a restoring process, healing. But with trees, this does not happen. When any part of a tree is strained, it is walled off. The tree survives so long as it continues to supply the tree's needs for maintenance and reproduction.

Another way to view this complicated set of conditions is to think of the genetic code as a set of coil springs. How well the springs are made is the vigor component. Stress is the pull on the springs. If a spring is pulled — stress — and then returns to its starting position, there is no injury or loss of power in the spring. But, if the spring is pulled so far that it does not return to its starting position, then it has been strained. When the spring is so strained that it can no longer act as a spring, then the processes or parts that depend on that spring die. Trees get a new set of springs every growing season.

Thresholds and Death

This complicated group of events presents a very rough idea of what a tree must do to survive. Any number of things can go wrong, and this is common. But, above all, the tree by the law of its genetic code must produce a new tree — a new growth ring — every growing season. When wounds, infections, and energy drains from reproduction all start to take their toll, the entire system may begin to wane. The highly compartmented tree then falls victim to weaker and weaker pathogens that take more and more tree space and energy. The tree begins to wall off larger and larger portions of itself. When the amount of energy required to produce a new growth ring is not available, then that part of the tree dies. The threshold is met. There is no return. A tree without energy is similar to a starving animal. When an animal loses the ability to digest food, no amount of additional food will return the animal to a normal condition. Life may continue for awhile, but the end is definite. The same condition occurs with trees. What do these concepts mean, and can they help the tree professional in any way? I believe very strongly that they can. I believe it has been the missing ingredient in many tree practices, and in many decisions made trying to help trees. The more you understand what a tree is and how it must struggle to survive, the more you will be able to help it. Many times, the best thing to do is to leave the tree alone.

So What?

The tree care industry seldom gets credit or profit for examining trees and then stating that the best thing is to leave them alone for a while. I spend money gladly when after a medical exam I hear the doctor say all is well, keep doing whatever you are doing! Why can't we have such a system for maintaining healthy trees?

An understanding of trees also will avoid treatments that do more harm than good: deep drill holes for injections, harsh flush cuts, cavities cleaned beyond the barrier zone, heavy amounts of wound dressings, drain tubes for water in decay pockets, harsh scribing far beyond the limits of injury, dead-ended hardware in decayed wood, and the list goes on and on. All of the above treatments are too common. Yes, injections, pruning, scribing, cavity-filling, and cabling and bracing can be very beneficial when done properly. It is not the treatment that is harmful, it is the way the treatment is done. The improper treatments indicate a complete lack of understanding about trees.

Indeed, it is time to extend the art form of tree care to some science. When you know how a branch forms and how a tree walls off, it will be clear how to cut it properly. When you know how cavities form, you will not break the barrier zone that surrounds the decayed wood.

Time for Some Adjustments

This information on trees also will help those who plant trees. Many trees are committed to an early death at the time of planting, because of root injuries and a host of things that should not happen. It may take several years before dying is noticed, but they were committed to an early death at the time of planting. The best, or worst, example of this can be seen in many plantings 3 to 5 years old. By the time the dying is noticed, there is no way to reverse the situation. What can be done? First, some "teeth" must be put into planting contracts. Second, the information can be used to help with diseases such as chestnut blight and Dutch elm disease. With chestnut blight, research shows that some trees do respond to wall off the chestnut blight fungus. Some trees do it successfully for several years, and others do not. Some trees produce wedges of wood into the bark to wall off the fungus. We can now focus on this walling off in our search for resistant trees.

With Dutch elm disase, the tree information may be the important missing link. I have studied the problem, not from the traditional view of the fungus and insects, but rather from the view of the tree. I believe Dutch elm disease can be greatly reduced if we help the elms help themselves. American elms are unique trees because they produce a heavy seed crop every year, and they do this before leaves are formed. All the energy for the seeds, leaves, earlywood, and early phloem must come from energy reserves of the preceding year. This presents no problem for an elm that has a good site, plenty of energy reserves, and healthy leaves. But, when the tree has limited energy reserves and wilted leaves, then it is in trouble.

Elms wall off the fungus very effectively the first few times the tree is infected. But, after each walling off period, the volume of cells that would normally hold energy reserves is reduced. Elm does require a heavy load of energy reserves to produce its seeds. As more and more wood tissues are walled off, energy reserves begin to diminish. Even so, the tree still could survive so long as the new leaves had a few weeks to reload the energy bank. But, when the wilting toxin shuts down the food factories, the tree has little or no energy to run its defense system.

Our research shows that starch was depleted in dying trees, and starch was abundant in healthy trees. So it seems that the trees die when energy reserves are so decreased that the infections cannot be walled off from the cambium. The fungus then spreads to the inner bark and completes its life cycle by reproducing.

Dutch elm disease is a classic example for the points made here on how a tree is constructed and how it struggles for survival after injury.

Many trees receive wounds every year, and they do not die; so why should we concern ourselves about holes for injections. Yes, trees can and do wall off injuries. But, when the tree is attacked repeatedly, and the amount of wood being walled off is greater than the amount being generated, the tree is in trouble. Our studies on peach trees demonstrated this. Repeated wounds caused so much walling off that the volume of healthy sapwood capable of holding energy reserves began to decrease. When this happened, many weakly parasitic root-infecting fungi began to attack. The diagnosis was root rot; prognosis was death of the trees.

The wounds were the real killers that caused the trees to die. Too often we look only at the end point and do not realize the factors that caused the death of the tree. I cannot emphasize this point enough. A similar story is unfolding now in the sugar maple industry. A new tool, the mechanical tapper, has made it easy to put many holes in a tree. Some trees look like sieves. Again, root rots and insects come; they, not the holes are blamed for the death of the tree. I believe that the wounds start the death process, and the microorganisms that are opportunists come along and serve the death notice.

A similar story is beginning to emerge with deep injection holes. Yes, injections can be beneficial, but large deep holes are not needed. The current growth ring does most of the transport. Why go deeper?

It is time to give the tree more attention. If you learn what a tree is and how it works, you wil be able to help trees help themselves stay healthy.

Research Work Unit Leader
Northeastern Forest Experiment Station
Forestry Sciences Laboratory
P.O. Box 640, Durham, N.H.