Dysfunctional Root Systems and Brief Landscape Lives: Stem Girdling Roots and the Browning of Our Landscapes

Gary Johnson

Consider this comparison of potential life spans for trees (Burns and Honkola 1990; USDA 1998)

Quercus macrocarpa **(bur oak), in upland site**	**250+ years**
Acer saccharinum **(silver maple), in riparian site**	**125+ years**
Acer negundo **(boxelder), in lowland site**	**100+ years**
Pinus banksiana **(Jack pine), in field site**	**80+ years**
Betula papyrifera **(paper birch), in northern lowland forest**	**65+ years**
Tree planted in urban core street site	**less than 10 years**

That's a sobering thought—a tree with a normal life span of 65 to 250 years may live less than 10 years when planted in any American city's downtown landscape. Admittedly, that figure represents tree placement in the worst of our urban landscape sites: sidewalk cut-outs. These inhospitable planting sites are also known as tree coffins, tree burial mounds, or urban tree disposal units to frustrated urban foresters. When the mortality rate of downtown trees is compared to tree losses from Dutch elm disease, oak wilt, sudden oak death, and gypsy moth, it doesn't take too long to realize that there's an epidemic of urban tree loss going on and it's largely under the radar (Figure 1).

Another oft-quoted number is that the average urban residential tree lives for 30 to 35 years (Moll 1989). That life span is three times as long as a sidewalk tree, yet only half as long as a paper birch in its natural environment. Growing conditions in residential landscapes may not be quite as bad as sidewalk sites, but there are many natural and unnatural pressures on the trees that lead to briefer landscape lives. Residential landscape soils can be as stressful as downtown sites: poorly drained, outrageously alkaline, subjected to blends of every pesticide known to modern society, and compacted to such a degree that lawns may seem like nothing more than green concrete.

With few exceptions (perhaps tornadoes and a few diseases), there are no "angels of death" that descend and quickly kill trees in landscapes. More commonly, a multitude of predisposing stresses that occur in our highly altered urban landscapes combine to weaken trees over the years. Often, inciting events such as floods or hailstorms and/or contributing agents such as target cankers or wood boring insects complete the job for the majority of tree losses. Meanwhile, plant health care professionals attempt to determine the true causes of decline and death, and often the diagnoses are incomplete or incorrect because of the multiple offenders involved with the problem.

Predisposing Factors and Tree Decline

When trees are chronically stressed (long-term drought, repeated defoliation, etc.), their normal reserves of chemical energy—primarily as complex carbohydrates—are slowly depleted. Each year as stressed trees come out of dormancy, they emerge in a weakened state due to this energy depletion and find it increas-

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Figure 1. Trees in urban sidewalk sites are subjected to very unhealthy environments and live less than 10 years on average.

ingly difficult to releaf, grow, and deal with the harsh realities of urban landscapes on a normal basis. It takes a tremendous amount of chemical energy to push out new leaves and shoots, recover from accidental wounds on the stems, or produce flowers and fruit.

As the tree's energy reserves continue to decline—and thereby affect the tree's ability to capture and store new energy through photosynthesis—the entire system is affected and the decline spiral to premature death begins. So decline in a sense refers to the tree's ability to deal with life's normal stresses. A tree in decline may die suddenly because of an event such as a cold winter with no snow cover, a short-term summer drought, or a defoliation from insects or hail. The other trees in the landscape tolerate the damage and survive, but the predisposed trees—those in decline—are unable to recover from the damage.

Dysfunctional Root Systems as Predisposing Agents

Despite the fact that roots are seldom seen, dysfunctional root systems are too often the predisposing agents connected to tree health decline, and ultimately the reason why many urban landscape trees experience such brief lives. If the root system—approximately 50% of a tree's biomass—is not operating normally, the entire system will be abnormal. Abnormal is not always harmful, as seen in bonsai plants and trees growing on slopes. In bonsai plants, a restricted root system causes compacted growth in the rest of the plant system, but the system itself may be healthy and completely functional under most circumstances. In the case of a tree growing on a slope, the tree is anchored with a skewed and asymmetrical root system, but its overall health is not compromised even though the root system could certainly be considered abnormal.

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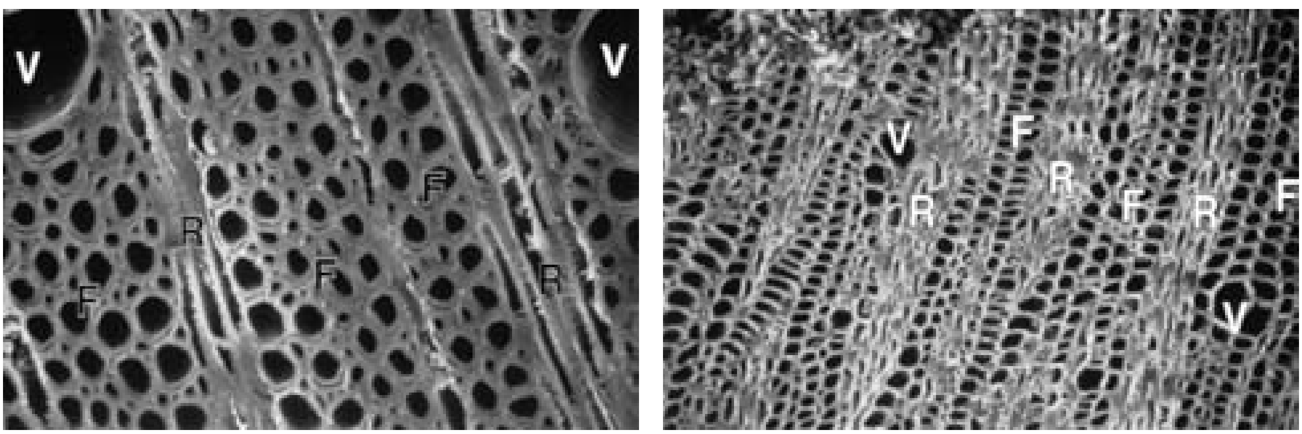
Figure 2. With part of a stem girdling root removed, the compression to the tree's trunk is evident.

But abnormal root systems that do affect the overall health or stability of the tree are considered dysfunctional. For example, when a container-grown tree with a severely pot-bound root system is planted, its rhizosphere does not occupy a large enough area to capture sufficient water and nutrients needed to support a normal sized tree without supplemental help. Dysfunctional root systems are also common on newly transplanted bare-root and balled-and-burlapped plants; these plants often lose 75% or more of their root systems during the harvest operation, resulting in transplant shock which may go on for several years until the root system regrows. And then there are stem girdling roots (SGRs), which create a root system so dysfunctional that it can end up killing the entire tree.

Stem Girdling Roots as Predisposing Agents

Stem girdling roots are those roots that grow either partially or completely against the tree's stem and compress (girdle) the stem tissues (Figure 2). Xylem and phloem tissues in the stem become much narrower at the point of compression, impeding normal water movement and sap flow (Figure 3). This restriction affects energy reserves by directly and indirectly affecting photosynthesis. Trees become stressed and more vulnerable to secondary problems. For this reason, SGRs are considered to be primary predisposing agents in landscape tree decline and death.

Some of the first symptoms of SGR-impacted tree health include leaf scorch or leaf wilting on a tree when no other plants in the area are showing the same symptoms. There may be adequate moisture in the soil, but the tree's ability to move water throughout the system is thwarted by the areas of compression, i.e. the greatly reduced diameter of vessel elements. Soon, this water stress evolves into early leaf coloration and leaf drop in the summer, late leaf-out in the spring, and chlorosis or other



G. W. HUDLER, CORNELL UNIVERSITY

Figure 3. Transverse views of normal Norway maple stem wood showing a healthy growth pattern (left), and malformed stem wood compressed by a stem girdling root (right). Water and nutrient transport in trees is negatively affected when tissue is malformed by compression. V = vessel element, R = ray, F = fiber tracheid. Both views are at the same scale.

nutrient deficiency symptoms. If the stem compression becomes more severe, affecting 50% or more of the stem circumference, so do the symptoms. Trees will tend to suffer more damage during the winter seasons, in particular true frost cracks, cambial death, and dieback. In the latter stages of decline due to SGRs, trees usually suffer from severe stunting (very small leaves, annual twig growth of 1 to 2 inches or less) and significant defensive dieback. With so little vascular capacity left, affected trees may succumb completely from even a short-term summer drought (Figure 4).

Though often a slow-acting cause of death, SGRs can also cause tree death that is a bit more sudden and dramatic. The compressed areas of tree stems are structurally weak points and far too often are the points of failure during windstorms (Figure 5). For example, in severe windstorms that occurred in Minnesota in 1998, 73% of the lindens (*Tilia* spp.) that were lost in urban landscapes failed at compression points from SGRs, and most broke several inches below ground. This is a different type of predisposition but equally damaging to a tree's ability to grow, survive, and add to the quality of life.

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Figure 4. The middle littleleaf linden was in the last stages of decline from stem girdling roots at the time of this photograph. One year later it was dead.

Figure 5. Stem compression from SGRs located 4 or more inches below ground was the most common cause of urban tree failure in windstorms in Minnesota from 1995 to 2005.

More (Soil) is Not Always Better

Early SGR studies conducted by the University of Minnesota were in response to unexplained tree decline in urban areas. From 1994 through 1996, 220 declining and dying trees were diagnosed. In 81% of the cases, stem girdling roots were the only causal agents isolated. This figure closely paralleled data collected from a national survey of tree care professionals (Johnson and Hauer 2000). More specifically, these trees had been planted in the previous 12 to 20 years and had significant stem compression (greater than 50% of the stem circumference) from SGRs. In all cases, these SGRs were well below ground (from 4 to 14 inches)—out of sight, out of mind (Figure 6).

In landscape surveys conducted by the University of Minnesota Department of Forest Resources (1997 to 2004), five species of trees were investigated in three different communities. All trees were growing in public spaces: boulevards, schools, government centers, parks. Species surveyed included hackberry (*Celtis occidentalis*), littleleaf linden (*Tilia cordata*), sugar maple (*Acer saccharum*), 'Shademaster' honey locust (*Gleditsia triacanthos* 'Shademaster'), and green ash (*Fraxinus pennsylvanica*). Trees were randomly selected, evaluated for health and condition, and then examined for depth of soil over the main order roots and the presence of stem encircling roots (potentially conflicting roots within 6 inches of the stem) or stem girdling roots. The results were a bit depressing. Only 4% of the lindens, 8% of the ash, 10% of the maples, 15% of the honey locust, and 40% of the hackberries had their stems completely above ground. The rest of the sampled trees had from 1 to 12 inches of soil over the first main order roots and against the stems.

Non-destructive root collar examinations were performed on a total of 1,380 trees. The intent of these examinations was to determine the frequency of SERs (stem encircling roots—those potentially conflicting roots within six inches of the stem) and SGRs associated with different depths of soil (up to 12 inches) over the first main order roots. The excavations demonstrated that the deeper tree stems were buried in the soil or mulch, the more likely it was for them to have multiple layers of stem encircling and stem girdling roots. The increased presence of these problem roots showed up in trees beginning with as little as one inch of excess soil against the stem. In a nutshell, the more soil or pre-soil (organic mulches that will break down) that is piled over the root systems and against the stems, the more likely it is that trees will decline or fail due to multiple conflicts with SGRs (Figure 7).

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Figure 6. This SGR, located approximately 4 inches below ground, runs tangential to the tree trunk and is compressing 30% of the stem circumference.

Figure 7. As shown on this littleleaf linden, more layers of SGRs develop as the stem is buried deeper. Greater than 40% of the stem circumference of this tree was compressed by several layers of SGRs.

How SGRs Form

Observations from the 1,380 root collar examinations conducted during the species surveys and a separate nine-year planting depth study have led to the conclusion that stem girdling roots form in one of two ways: first, new roots regenerating from deeply buried main order roots, and second, from stem adventitious roots. When main order roots are buried too deeply, new woody roots that originate from them or any part of the buried root system tend to grow closer to the surface. It is speculated that this action is in response to a more desirable soil oxygen and moisture balance. As the roots reach the soil surface, an unpredictable percentage of them grow tangential to the tree stem or in some cases encircle the stem. For the next number of years (12 to 20, from our observations), the roots and stems expand in diameter, resulting in the ultimate confrontation between roots and stems.

Stem adventitious roots are also sources of SGRs. When a buried stem begins forming adventitious roots, many or most of those roots grow away from the stem in a radial fashion. As with new roots growing from main order roots, an unpredictable percentage of these adventitious roots do not grow radially but instead grow tangential to the stem or encircling the stem. The interface area between soil and stem appears to be a highly desirable area for stem root growth, perhaps because it provides an ideal balance of soil oxygen and moisture and is also the path of least resistance for root proliferation. The exact reasons for these root growth responses are still speculative, but it is clear that when tree stems are buried by a media that supports root growth, SGRs are highly likely to occur.

It's worth noting that stem girdling roots are a problem primarily with younger trees. As trees mature, their growth slows down dramatically, including the growth of trunk diameter and encircling roots. Because of this reduced growth—and the fact that there is often a relatively thick outer bark—stems of mature trees that then become buried by soil or organic matter are much less likely to develop stem girdling root problems. SGRs can still develop, but if they do they are less likely to result in the decline and death of the tree.

How to Cause Stem Girdling Roots

If you want to cause the formation of SGRs, bury the tree stem with a medium that supports root growth. Here are some common ways SGRs occur:

- Excess soil is piled over the first main order roots during the growing and harvesting of balled-and-burlapped trees.
- Excess growing medium buries stems when container-grown trees are up-potted.
- Decayable organic mulch is piled high around tree stems in nurseries and landscape sites.
- Soil is piled against tree stems during construction regrading in landscapes.
- Trees are planted in a new landscape *before* final grading is completed.

There are so many different ways that stems can be buried—accidentally or with good intentions—that it is difficult to pinpoint the main source of the problem. One seemingly common cause is the act of burying trees rather than planting trees. Unfortunately, too many people still have the notion that trees are like fenceposts and need to be buried deep for stability. Not so.

In 2002, we conducted a planting depth study in collaboration with a large wholesale nursery. Bare-root birch (*Betula* spp.), ash (*Fraxinus* spp.), and crabapple (*Malus*) were potted up in number-ten containers at four different depths: 0, 2, 4, or 6 inches of soil over the first main order roots. On a weekly basis, each of the 240 trees was inspected for lean or windthrow from the containers. At the end of the four month study, all trees were well-rooted in the containers and the results of the study showed that all trees, regardless of depth, leaned at the same frequency and to the same degree. Planting tree stems deeper had absolutely no positive effect on tree stability. If newly planted trees are unstable, they may need temporary support from a guying or staking system, not entombment.

Nine Years of Burial

In 2000, a long-term planting depth study was installed at the University of Minnesota's Urban Forestry and Horticulture Institute's research fields. Three hundred and sixty trees equally represented by two species (sugar maple [*Acer saccharum*] and littleleaf linden [*Tilia cordata*]) were planted at three depths: 0, 5, or 10 inches of soil over the first main order roots. All trees were planted in a complete, randomized block design in a .75 acre plot as unbranched, 2 to 3 feet tall liners. At three year intervals, one-third of the trees were harvested and had their root systems excavated with a supersonic air tool. Each year, mortality rates, growth rates (stem caliper), number of suckers produced, and percentage of dieback was recorded. In 2009, the final third of the original experiment will be harvested, but some interesting trends and

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Figure 8. Bury the stem of littleleaf linden just 5 inches deep and a profusion of suckers will develop. These suckers eventually become SGSs (stem girdling suckers) as they grow in caliper and compress the tree's stem.

significant data have already been revealed from the first two harvests, including:

- Planting sugar maples 5 to 10 inches too deep is an effective way to kill them. The mortality rates for the 0, 5, and 10 inch depths as of 2006 were 30, 40, and 65%, respectively.
- There was a significant positive relationship between placing 5 to 10 inches of soil against the stems and the frequency of SGRs on *Tilia cordata* in both the 2003 and 2006 harvests. *Acer saccharum* showed a trend in the same direction.
- *Tilia cordata* with stems buried in 5 inches of soil will produce masses of stem suckers, making the tree look more like a shrub.

Sucker formation on *Tilia cordata* doesn't just ruin the tree's appearance, it can also cause premature failure. Stem girdling suckers (SGSs) are suckers that form prolifically and, when they enlarge in diameter, can girdle the stem vertically and horizontally (Figure 8).

How Often do Trees Die from SGRs?

This question is likely unanswerable. When trees suddenly fail and die during a windstorm, diagnosing the problem below ground is not often considered. Weather alone is often blamed for the deaths, and the trees are hastily removed and replaced.

Research we conducted from 1995 through 2005 on tree failure in windstorms exposed a broader picture of the effects SGRs have on landscape trees. During this period over 1,500 "tree autopsies" were conducted on trees that had failed during wind-loading events in Minnesota. These trees were not those from the centers of severe wind-loading events such as straight-line winds or tornados. Rather, they were victims of thunderstorms or those at the edges of severe wind events.

From that data, the destruction and economic losses from premature tree failures due to SGRs were determined, and it was startling. The most common tree size category for boulevard tree failures was the 6 to 10 inch DBH (diameter at breast height, 4.5 feet above ground) range. Of those trees, 50% snapped off at compression points from SGRs at a depth of 4 or more inches below ground. The Achilles' heel was a compression root that couldn't even be seen because the stem was buried so deeply. The data also indicated that littleleaf lindens (*Tilia cordata*) were grossly affected by SGRs. Littleleaf linden ranked as the third most common species for total failure (the tree went down completely) during those years, and 73% of those trees snapped off at below-ground SGRs, almost the exact percentage of littleleaf linden that failed during the previously mentioned 1998 storms. After 11 years of data collection, the presence of SGRs and, more specifically, stem compression from SGRs that amounted to 50% or more of the stem circumference, emerged as the number one reason why urban trees failed in windstorms.

What to Do, What to Do?

Prevention is the easiest and most effective way to eliminate the SGR problem in landscapes. Whether you are an urban forester, commercial landscaper, or home gardener, follow these steps to prevent or manage stem girdling roots:

- Don't plant container or balled-and-burlapped trees that are already buried too deeply. Assume there is too much soil over the first main order roots and remove that excess soil before planting a newly purchased tree (Figure 9).
- Plant trees, don't bury them. If stems aren't buried, it's not likely that SGRs will become a problem. They can still occur on correctly planted trees, but much less frequently than on buried trees.

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Figure 9. Most containerized trees will have 2 to 6 inches of excess soil over the first main order roots and against the stem. Use a pruning saw to remove this excess soil before planting. Of 500 trees subjected to this treatment at the University of Minnesota's research nursery, there has been a 0.7% mortality rate in 2.5 years.

PHOTO BY DAVE HANSON

Figure 10. The fastest and most non-destructive method for conducting a root collar exam is with a supersonic air tool that blows the soil away without harming the roots. This root collar exam was accomplished in approximately fifteen minutes.

- Don't pile mulch against stems. Organic mulch is basically pre-soil. Piling on mulch will result in a buried stem and a wonderful environment for SGRs to develop.
- When suspicious, investigate. Root collar exams are not all that difficult to perform (Figure 10). If you have a trowel and a wet-dry vacuum, you can perform a non-destructive root collar exam. If you find offending roots during the exam, remove them. Also, remove all that extra soil. If you do nothing, it will only get worse.
- If greater than 50% of the stem's circumference is severely compressed, it is probably best and safest to remove the tree and start over.

Treatments for affected trees are uncertain. If SERs (stem encircling roots) can be removed before compression begins, that's an excellent and effective treatment. If the SERs have become SGRs and if, during the course of removing SGRs, the stem is wounded, the long-term potential for recovery is uncertain. The study of stem girdling roots is a relatively young science and long-term data on treatment options and efficacy are not there. If 50% or more of the tree's trunk is severely compressed by the SGRs, and if the symptoms included dieback and severe stunt, the tree is probably beyond salvation. If that same tree is ten feet from a house or utility line, then the risk of leaving the tree is unacceptable. Buy a new tree. Remove the excess soil over the root system. Plant it with the trunk fully exposed. Mulch the roots, not the trunk. These steps will put your new tree well on the way to a long, healthy life.

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Gary Johnson is a professor in the Department of Forest Resources at the University of Minnesota.