A Practitioner's Guide to Stem Girdling Roots of Trees

Impacts on Trees, Symptomology, and Prevention

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Trees may decline and prematurely die as a result of the stresses induced by stem girdling roots. Or, they may appear healthy and normal until they suddenly fail during a windstorm, breaking at or near the point where girdling roots have compressed and weakened the stems.

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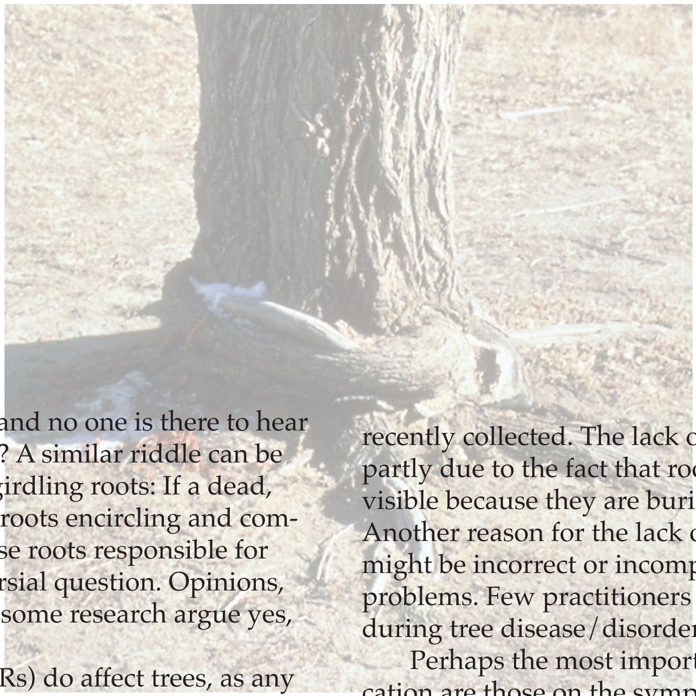


Introduction

If a tree falls in a forest and no one is there to hear it fall, does it make a sound? A similar riddle can be applied to trees with stem-girdling roots: If a dead, declining, or fallen tree has roots encircling and compressing the stem, were those roots responsible for the damage? It's a controversial question. Opinions, anecdotal information, and some research argue yes, no, and sometimes.

Stem girdling roots (SGRs) do affect trees, as any disorder would. SGRs, as opposed to root-girdling roots, encircle or run tangential to a tree's stem, eventually compressing the woody and nonwoody tissues of the stem. The degree to which trees are impacted varies with severity of encirclement, site (growing) conditions, weather, age, size, and, very likely, genetics. Urban trees are subjected to a continual barrage of natural and unnatural stresses—conditions that deviate from optimal. SGRs add another layer of stress, sometimes significantly.

Trees commonly fail for structural and physiological reasons. Physiologically, trees might slowly decline and die as a result of SGRs. Or, a tree might suddenly fail during a windstorm when stresses accumulate to the point of acute strain on the tree's structural system from stem compression and decay due to SGRs. This translates to economic and environmental losses: labor and materials to maintain trees; labor to remove and replace trees; cost of new trees; damage to personal and public property; and loss of carbon sequestration, shade, wildlife habitat, noise attenuation, and other benefits of trees. The degree to which SGRs affect urban forest health and condition is not known due to insufficient research and, very likely, to inaccurate diagnoses of tree disorders and losses.

The purpose of this publication is to present an objective perspective of SGRs. Most importantly, this publication reviews the symptomology, potential causes, treatments, and prevention of decline associated with SGRs. It is intended for field and diagnostic applications by arborists, landscape managers, growers, and urban forest health specialists.

Research on SGRs is limited, but more practitioners are becoming aware of the problem, and new information on the formation and effects of SGRs has been recently collected. The lack of information might be partly due to the fact that roots are not always clearly visible because they are buried under soil or mulch. Another reason for the lack of research on this subject might be incorrect or incomplete diagnoses of tree problems. Few practitioners investigate below ground during tree disease/disorder diagnostic efforts.

Perhaps the most important sections of this publication are those on the symptomology and prevention of SGRs. Although the extent is relatively uncertain, SGRs do cause damage and premature loss of trees or tree health. As with any other natural or unnatural stress, recognizing the problem and preventing future damage to urban trees are the practitioner's responsibilities and goals.

Historical Accounts and Current Research

Published accounts of SGRs first appeared in the 1930s. Van Wormer (1937, 1940) observed that many trees that were declining during droughts had roots that encircled the stems, while many healthy trees did not have girdling roots. He surmised that girdling roots "strangled" the trees. Van Wormer's account, however, was anecdotal. Scientific studies that quantified the impact and frequency of SGRs were first conducted approximately 40 years later by Tate (1980).

Interestingly, during the time span between Van Wormer's and Tate's published work, common tree care and tree pathology texts described SGR causes, tree health impacts, symptoms, and treatments (Pirone 1941 and all subsequent editions; Marshall 1942; Hallar 1959; Tattar 1978). It is not known whether these are first- or second-hand accounts. The authors presented no citations or original data to support their statements. It is plausible that Van Wormer (1937, 1940) formed at least a partial basis for the textbook statements, based on similarities in SGR descriptions. Pirone (1941) listed Van Wormer's papers in his suggested reading section, indicating he was familiar with them. In sum, many reasons for SGR formation and the subsequent impact on trees were given prior to Tate's work, but these were probably speculative and lacked scientific scrutiny.

Tate (1980, 1981) studied morphological characteristics of Norway maple trees with SGR in Ann Arbor, Michigan. He observed that trees with SGRs often lacked a normal root flare, had flattened stems, and had smaller leaves. However, he did not detect differences in survival, diameter, or crown density between trees with and without SGRs.

Hudler and Beale (1981) reported on the anatomical effects of girdling roots on stem wood and bark tissue. Roots that encircled the stem tissue caused deformation of xylem tissues, including fewer vessels with a smaller diameter; skewed rays; and compressed bark tissues. However, no research to date has been conducted that has investigated how or if these anatomical changes affect tree physiology.

The frequency of SGRs in various tree species was reported by d'Ambrosio (1990) and Watson et al. (1990). SGRs were commonly found on maple species (i.e., red, silver, sugar, and Norway), green ash, and honeylocust. (See Appendix for scientific names of trees referred to in this publication.) Tree care practitioners throughout the United States and Canada also reported in a 1997 survey their observations of 56 tree species that had SGRs (Hauer and Johnson 1997). And in a 1997 randomized study of 100, 3- to 9-inch diameter breast height (d.b.h.) sugar maples, 41% of the trees had stems that were compressed from girdling roots (Johnson and Johnson 1997).

Removal of SGRs has been recommended to prevent and reduce the impact of stem compression on tree health, but little scientific research has been conducted that either refutes or supports this recommendation. Watson and Clark (1993) found that after SGRs were removed, roots often grew in directions that placed them in conflict with the tree stems, creating new and potential SGRs. However, their research was limited to Norway maple.

g. 1—During a windstorm, this littleleaf linden failed below ground at a compression point created by stem girdling roots.

Occurrence of SGRs

SGRs are not always at the soil surface and easily noticed. A respected pathologist was called upon to diagnose several Norway and sugar maple trees in Northfield, Minnesota, a few years ago. It was suspected that they were suffering from general decline and/or *Verticillium* wilt. Field symptoms for *Verticillium* wilt proved to be negative, and searches for above-ground signs and damage were fruitless. Root collar examinations revealed that the trees were severely affected by SGRs several inches beneath the ground level. Without root collar examinations, the primary cause of the trees' decline would not have been discovered.

Fewer than 50% of the practitioners who responded to a 1997 survey (Hauer and Johnson 1997) performed root collar examinations as part of their diagnostic procedures. In that same survey, girdling roots were observed 52% of the time root crown examinations were conducted. Most practitioners reasoned that these exam-inations were too time consuming and/or their clients were not willing to pay for them. When below-ground examinations are performed as part of the diagnostic process, however, the frequency of SGRs associated with tree decline and/or sudden failure is noteworthy. In a recent five-year study, more than 80% of declining sugar maples had SGRs, which were presumably associated with the decline in health or death of those trees (Johnson 1999).

In storm damage research conducted since 1997 by the University of Minnesota (n=600), 73% of linden species that failed completely in the storms broke at SGR compression points (Figure 1). For all species, 30% of trees that failed completely and were not located in

Fig. 2—This Norway maple had two SGRs that compressed almost 100% of the stem's circumference.

storm centers but at the edge, broke at SGR compression points (Johnson et al. 1999). ("Edges of storms" are areas outside the direct paths of straight-line windstorms or tornadoes.)

SGRs have been observed on a wide variety of tree species. In a practitioners' survey (Hauer and Johnson 1997), 56 tree species and genera, ranging from *Acer* to *Zelkova*, were identified as having been observed with SGRs (Appendix). The most commonly observed species were Norway, red, silver, and sugar maples and littleleaf lindens. SGRs also were observed frequently on Norway, red, and sugar maples by Watson et al. (1990), but not on littleleaf linden. D' Ambrosio (1990) observed SGRs frequently on Norway and sugar maples.

A note of caution: In a scientific study addressing SGR frequency, a population of trees would be sampled and a mean incidence of girdling within the population could be derived. However, root crown examinations are often conducted on trees that are exhibiting symptoms of decline or have failed during storms. Thus, frequency calculations derived only from a pool of symptomatic trees could underestimate or overestimate the incidence of trees with SGRs in any given population.

Symptomology

Signs and Symptoms

Signs and symptoms are terms used to describe physical evidence of the causal agent(s) (signs) and plant reactions to the presence of the causal agent

Fig. 3—Roots crossing roots are not documented to be a problem. They often are embedded or grafted together.

(symptoms). Signs are generally much less common than symptoms.

Roots that encircle or grow tangentially to the stem of a tree and cause bark and wood tissue compression are the sole signs of SGR problems (Figure 2). Roots crossing roots and causing compression are not known to be associated with plant health problems (Figure 3). Tree roots are commonly observed growing over other roots and root grafting frequently occurs (Figure 4). However, if root grafting doesn't occur and roots girdle

Fig. 4—These crossed roots have formed a graft union (arrow). Neither root is harmed.

Fig. 5—Left: Compare a leaf from a sugar maple without SGRs (foreground) with the scorched leaves of a sugar maple affected by SGRs. The two trees were planted at the same time, were the same size at planting, and stand 20 feet apart.

Fig. 6—Below: More than 50% of the leaves on this sugar maple with SGRs had greater than 50% of the leaf surface exhibiting scorch symptoms.

roots, the potential effect on the total tree transport system is presumed to be minimal.

The symptoms associated with the presence of problem-causing SGRs are many and often inconclusive, in that many are common and characteristic of several different causal agents. For instance:

(Figure 5) Leaf tip and margin scorching is a common, visible symptom of physiological stresses caused by SGRs. However, this might also indicate a soil water extreme (droughty or flooded), root death from a variety of causes, bacterial- and fungal-induced leaf scorch, cambial death from cold temperatures, herbicide drift, or nutrient disorders.

(Figure 6) Severe (greater than 50% of individual leaf surfaces) and chronic leaf scorch is commonly associated not only with SGR problems, but also with drought, flooding, vascular wilt diseases, drying winds, and deicing salt accumulations in the soil.

(Figure 7) A less obvious, more insidious symptom associated with SGR problems is stunting of the foliage, annual twig growth rate, and d.b.h. However, root damage/loss, nutrient imbalances, chronic drought, and poor soil water percolation often yield the same symptoms.

(Figure 8) As stress from SGRs continues, excessive and/or localized (one-sided) twig and/or branch dieback following normal winters often becomes more common. However, this could also indicate that the tree was less cold hardy than others (either genetically or due to reduced vitality for any number of reasons), or that an unusual spring weather pattern occurred (alternating warm and cold after dormancy was broken).

(Figure 9) Trees, in particular deciduous trees, normally flare or expand near the ground. Trees suffering acute stem compression from SGRs often lack trunk flares, appearing more like utility poles. However, many conifers normally lack obvious trunk flares. Also, excessive and unnatural depths of soil over root systems will disguise trunk flares.

(Figure 10) As tree vitality and root systems decline, trees often lose their stability and begin to lean. However, leaning might also be due to wind, root cutting, or perched water tables.

Fig. 7—The sugar maple leaves on and to the left of the normal leaf in the center are stunted in comparison.

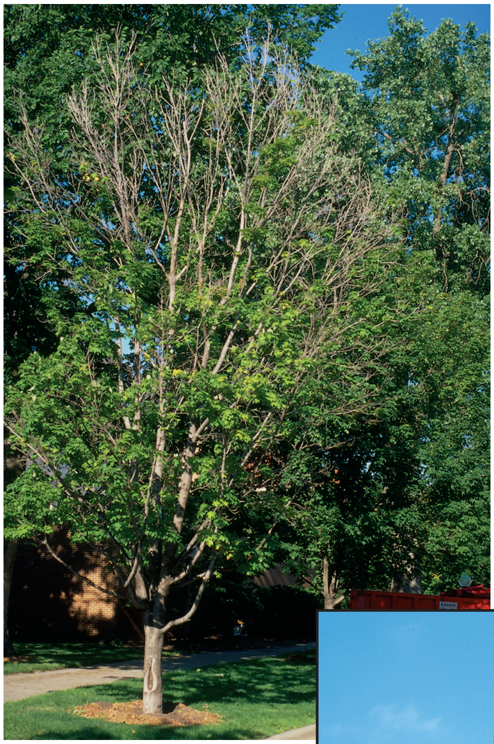


Fig. 8—This sugar maple's health was severely impacted by exten-sive SGRs. The tree suffered significant dieback and cambial death following a normal winter.

Fig. 9—Most trees exhibit a characteristic flaring of the stem near the ground line, such as this healthy oak.

Fig. 10—Only three trees in this large, commercial landscape exhibited an abnormal lean. All had 85% or more of their stem circumferences compressed by SGRs.

Fig. 11—This hackberry failed during a thunderstorm with high winds. It broke several inches below ground where almost 100% of the stem circumference was compressed by SGRs. (Note arrows pointing to girdling root.)

Fig. 12—Left, above: In 1994, this sugar maple exhibited significant stunt and dieback following a normal winter. There were 12 inches of soil over the main order roots and the stem circumference was significantly (> 50%) compressed by SGRs.

Fig. 13—Right, above: The same sugar maple from a different angle in 1996. It failed to leaf out in the spring and had extensive cambial death, two years after the first decline symptoms became obvious.

(Figure 11) An alarmingly high number of trees lost during windstorms break off at compression points in their stems caused by SGRs, often several inches below ground. Above the point of breakage, the stem looks like a pinched balloon. This might be confused with breaks at points of graft incompatibility or areas girdled and compressed by synthetic materials (e.g., wires, synthetic ropes).

Manifestation of Symptoms

Symptoms of physiological stress from SGRs rarely show up immediately and rapidly (Figures 12 and 13). Most commonly, several years pass before stem compression becomes extensive enough to become symptomatic. In studies at the University of Minnesota, above-ground symptoms became obvious 12 to 20 years after planting (Johnson 1999).

SGRs are most likely primary stressors (like extended drought or defoliation) rather than primary "killers" (like vascular wilt diseases or lightning). Primary stressors greatly weaken a tree's ability to grow and function normally, combat destructive agents such as disease pathogens or insect pests, and recover from damage. Tree vitality eventually becomes so reduced that other, relatively minor, stresses result in major, long-term damage to the tree (Figure 14). In other words, SGRs contribute to tree health decline and premature death. If all other stresses—for instance, drought, deicing salt accumulations, and defoliation from diseases or insects—are kept to a minimum or avoided, it is entirely possible that many trees can live many years with the stresses SGRs inflict on them.

There are instances when the effects of SGRs can be dramatic and acute (e.g., tree failure during severe weather, especially loading from snow, ice, or winds). A tree is only as strong and stable as its weakest point, and compressed stem areas are commonly weak points. High winds and loading from snow and ice often result in breaks at the point of stem compression.

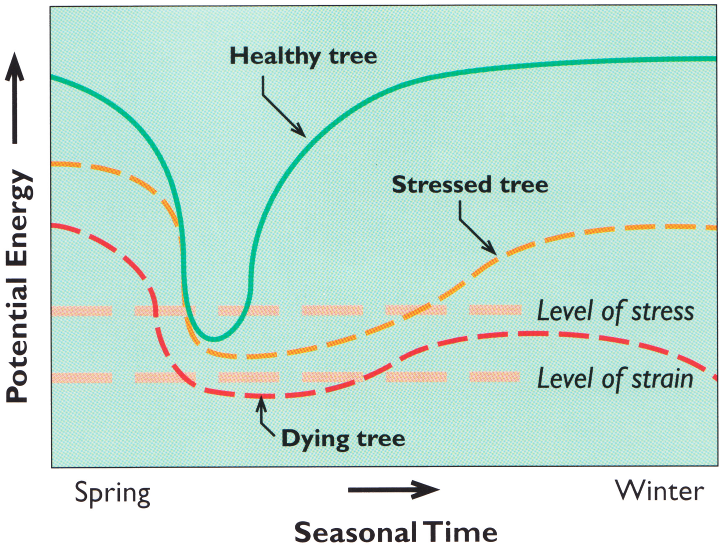


Fig. 14—This modification of the Askenasy Potential Energy Curve shows how common disturbances can cause trees to progress from stages of stress to irreversible conditions of strain.

Formation of SGRs

Relatively little research has been conducted on the formation of SGRs and the frequency of their occurrence. In a survey by Hauer and Johnson (1997), practicing professionals suggested the formation of SGRs was related to confined rooting areas (boulevards, sidewalk tree pits), but Tate (1981) found no statistical relationship between boulevard planting sites and SGR incidence in Norway maple. Johnson and Borst (1999) also did not find a relationship between SGRs and boulevard width.

Roots are often forced into an encircling growth pattern when trees are grown in containers (Figure 15). If these trees are sub-

Fig. 15—This container-grown sugar maple formed encircling, woody roots as a result of the length of time it had been growing in this container. The first main order roots were 6 inches below the surface.

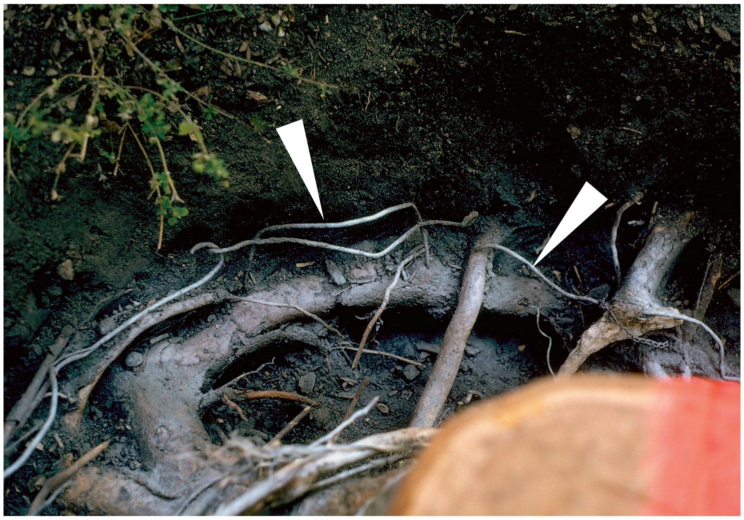


Fig. 16—Left: The secondary roots that formed after transplanting were directed in an encircling pattern by the wire basket (see arrows) that was left intact at planting time—14 years earlier.

Fig. 17—Below: When roots hit an obstruction such as a road or curb, they typically redirect their growth to follow that obstruction.

sequently planted in the landscape several inches lower, encircling roots can eventually enlarge and become SGRs. Even wire baskets can later induce girdling (Figure 16). However, the frequency of this is unknown.

When tree roots hit obstructions such as curbs and compacted soils and gravel, growth is redirected. If roots are redirected toward the stem, they might eventually contact and compress stem tissue. More commonly, however, roots will follow the obstruction (Figure 17). Watson et al. (1990) concluded in their study of maples, honeylocust, green ash, and littleleaf linden that root pruning during transplanting encouraged the production of new roots, often in directions that eventually conflicted with stem tissues. In many cases, SGRs were already present (though not stem compressing) in the soil balls of transplanted trees, or formed within two years of transplanting. They observed no relationship between depth of soil over the roots and increased incidence of SGRs. However, two recent studies (Johnson and Johnson 1997; Johnson and Borst 1999) observed a relationship between SGRs in green ash, maple, and lindens and planting depths. The mechanism that leads to SGRs in deeply planted trees, however, is unknown.

Although there is anecdotal evidence that excess soil depths over primary roots might stimulate secondary and tertiary roots that eventually become SGRs (Johnson 1999), no published research supports that speculation. However, if in fact roots are produced within two years of

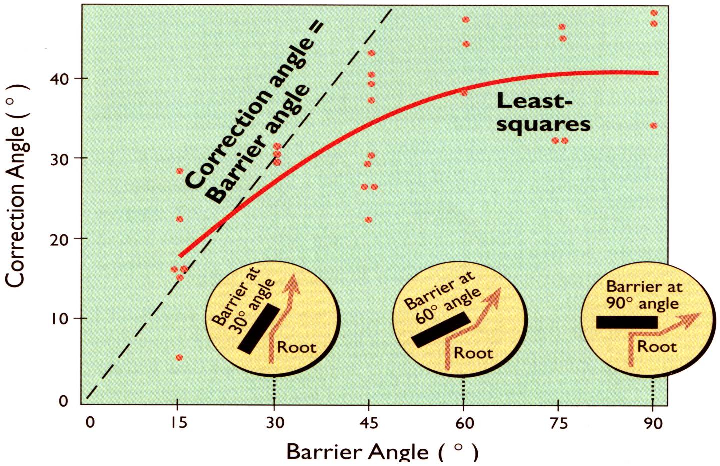


Fig. 18—When roots hit a barrier, their tendency to grow in the original plane after passing the barrier decreases as the barrier angle increases. Equation for least-squares is $Y = 5.44 + 0.858X - 0.005X^2$. Adapted from Wilson (1967).

Fig. 19—The first main order roots were buried by 9 inches of soil in this balled-in-burlap tree.

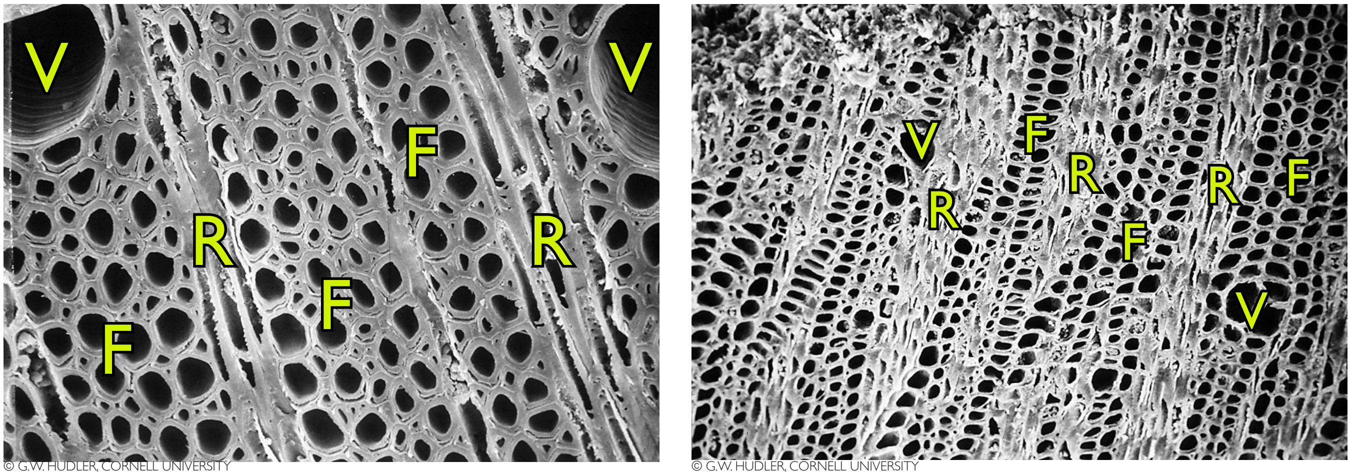
planting and are positioned to eventually conflict with and compress stem tissues, excess soil depths over root collars would certainly disguise the developing problem. If stem tissues were not buried, SGRs would be obvious and correctable at an early stage.

Fig. 20—Note the random direction of the secondary and tertiary root growth. The white band on the tree stem was the soil line, 13.5 inches above the main order roots.

Wilson's (1967) research on how roots grow around barriers might shed light on root growth of deeply planted trees (Figure 18). Roots growing in their normal horizontal plane were forced to grow around barriers. Those deflected at angles of 30 degrees or less returned to their original plane of growth upon growing past the barrier. As the barrier angle increased beyond 30 degrees, the angle of correction (adjustment back to the original plane) was less than the deflection angle. For example, a root deflected by 30 degrees that grew beyond the barrier and returned to the original plane had a 30-degree angle of correction. Roots deflected between 60 and 90 degrees would have an angle of correction of approximately 40 degrees.

Tree roots grow in areas favorable to growth. Deeply planted tree roots might grow toward the surface to areas conducive to growth. If the roots that grow to the surface respond as did those studied by Wilson (1967), it would be expected that some roots will grow toward the stem. Roots that grow toward or tangential to the stem could become SGRs. Redirection of tree roots toward the stem from deeply planted trees has been observed in Minnesota by Johnson (1999) and in Wisconsin by Miller (1999).

Root collars and developed branch roots can be excessively buried by a variety of situations and practices. Trees might be transplanted with excessive soil over the root collar and contained within the burlapped soil ball (Figure 19). Six to nine inches of soil over the root collar flare of transplanted or containerized trees is not uncommon. Trees might be planted in the landscape at a depth greater than they were grown in the field or container (Figure 20). A 1997 survey by Johnson and Johnson, and a 1999 survey by Johnson and Borst observed a range of less than 1 inch to more than 10 inches of soil over the root collars of 3- to 9-inch d.b.h. sugar maples, green ash, and lindens. Construction and surface regrading can add extra soil to the rooting surface of newly or recently planted trees. Applications of mulch against the stems of young trees also can hide developing stem girdling problems.



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a. **b.**

Fig. 21—Transverse views of normal Norway maple stem wood:
a) normal stem wood showing a healthy growth pattern; b) malformed stem wood.
V = vessel element, R = ray, F = fiber tracheid. Both views same scale.

Physiological and Structural Effects of SGRs

SGRs affect trees through stem compression, resulting in (1) physiological effects, (2) structural defects, and (3) adaptive growth. These responses, like xylem anatomy defects and changes in tree water relations, might go unnoticed, then become suddenly apparent when trees fail and expose a severely discolored and decayed stem, or by the tree's attempt to repair itself through adaptive growth, expressed as a bulge of stem tissue on the top of the SGR.

The presumed physiological cause of tree decline with SGRs is that the compression of stem tissues causes anatomical changes in wood and bark tissues, which in turn affect normal physiological processes. Anatomical changes have been documented, but the relationship with physiological processes has not been empirically measured.

When a root comes in contact with a tree stem, woody and bark tissues are compressed as the root and stem enlarge. Hudler and Beale (1981) found that in girdled woody stem tissue in a Norway maple, the numbers of vessel elements declined, vessel cross-sectional area was reduced by a factor in excess of 10, rays were skewed, and pits in rays were few (Figure 21). Bark tissue was compressed by a factor of 25. Cursory observation of phloem tissue suggested there was as much, or more, damage than there was to the xylem.

The transport of sap in trees is likely affected by compression from SGRs. Hudler and Beale (1981) suggested that stem compression causes tree decline by reducing stem conductivity and radial communication between tissues. Vessels and tracheids are cells that transport water in woody tissues of roots and shoots. Water transport occurs along a pathway from the soil to the atmosphere in response to a water potential gradient. Among the resistances to water transport found along the pathway is the diameter of the water transport cells. The smaller the diameter of the cell, the greater the resistance to water transport. In other words, greater pressure is required to pull water through a small-diameter water-conducting cell than through a larger-diameter one.

Hagen-Poiseuille Law

$$Jv = \left(\frac{\pi r^4}{8n}\right) * \left(\frac{\Delta P}{\Delta x}\right)$$

where: Jv = flux of a liquid
π = 3.14
r = radius of a cylinder
n = viscosity of liquid
ΔP = change in pressure
Δx = change in distance

The Hagen-Poiseuille Law models liquid transport through circular tubes with rigid walls and laminar flow. The model can be used to estimate the impact of smaller diameter vessel elements and tracheids as a result of stem compression.

Using the above equation, the pressure gradient needed for similar water flow through vessel elements or tracheids under normal and compressed conditions can be approximated. Using data from Hudler and Beale (1981), a 10-fold difference in pressure required for water transport is estimated—0.007 MPa/meter (0.07 bars/meter) for normal vessel elements and 0.08 MPa/meter for altered vessel elements. Hence, a 10-meter-tall Norway maple would require 0.8 MPa of pressure to overcome resistance associated with the smaller-diameter vessel elements. As soil moisture is depleted, this resistance would plausibly influence tree water deficits earlier in trees with SGRs than in those lacking them. The percentage of total xylem-conducting area altered by girdling roots is an integral component influencing increased water deficits.

Damage to phloem tissue is another area in which SGRs can impact tree vitality. Phloem tissue is involved in the translocation of sugars, growth regulators and hormones, minerals, nitrogen compounds, and other substances within the tree. Damage to phloem tissue impedes translocation between branches and roots. A reduction of transport of photosynthesis products to the root system can result in root system decline and death and hasten overall tree decline and death.

No direct physiological measurements have been collected that quantify the effects of SGRs on tree health. Indirect indicators suggest negative physiological effects to varying degrees that influence tree survival, diameter growth, leaf size, leaf color, tissue structure, crown density, foliage dieback, crow(n height, tree vitality, and tree condition (structural integrity). These might or might not affect a tree's longevity or overall appearance.

Structural defects arise when stem compression results in tissue death. Compartmentalization of decay limits the vertical, radial, and tangential spread to healthy tissue. Decay organisms work to invade the dead area and, if successful, weaken the wood. Tree failure will occur when the strength of the wood holding the tree upright is less than the force acting upon the stem to topple it.

Trees respond to wounds through addition of new wood (Mattheck and Kubler 1995) in order to optimize themselves against external loading factors. A bulge is common evidence of such adaptive growth. Examples include addition of stem tissue near a cavity and growth around a foreign object (e.g., rock, fence post, or rope). Trees respond to SGRs by attempting to embed the root within the stem (Figure 22). In an SGR, however, both the foreign object (the root) and the stem tissue trying to embed the root are growing. The success of trees embedding roots within their stem tissue is unknown. However, the failure rate of trees successfully embedding SGRs must be great due to the abundance of SGR cases in which trees topple during a loading event.

Fig. 22—Note the bulge in the stem over the girdling roots (arrow), which is stem wood embedding the roots.

Fig. 23— A normal littleleaf linden's root system, showing the larger, main order roots radiating out from the stem/root interface (root collar).

Root Collar Examinations

Normal vs. Abnormal Root Systems

Root collar examinations are used to determine if root system abnormalities are impacting a tree. To determine if a root system abnormality exists, one needs to compare against a normal root system. Field observation, along with a review of species-specific root system profiles, will help provide the practitioner with an understanding of a normal root system. An easy way to observe normal root systems is to take a walk in the woods. But in general terms, what is a normal or ideal root system?

Normal root systems are often described as having main (first order) laterals that radiate from all sides of the stem/root interface (Figure 23). The number of main laterals ranges from a few to more than a dozen.

Trees in forests with a greater number of main laterals than other trees tend to become dominant survivors in a competitive forest community (Kormanik 1986). The root diameter of main order laterals decreases rapidly through the zone of rapid taper into ropelike roots with approximate diameters of 0.5 to 3 inches. Root spread is usually well beyond the drip line, commonly to about three times the branch spread (Gilman 1997).

Most main-order laterals originate from the root collar and parallel the soil surface at depths of a few inches to a foot or more. Many tree species also produce oblique roots, which grow at a sharp angle into the soil and stabilize trees. Sinker roots grow downward from lateral roots on approximately 75% of tree species, function in support and absorption, and usually are located within 6 to 10 feet of the stem.

From main-order laterals arise secondary and tertiary woody and nonwoody roots, which magnify the absorption of water and nutrients. These roots proliferate in zones of favorable moisture and nutrition. Most exist within the top foot of the soil surface.

Stem diameter normally increases from the top downward. Root flares and/or stem tapers are common (except in some conifers) due to a growth pattern in which growth is greater on the top of the root than the bottom (Figure 24). When trees are planted deep or soil fill is placed over the root system, this characteristic pattern might not be visible.

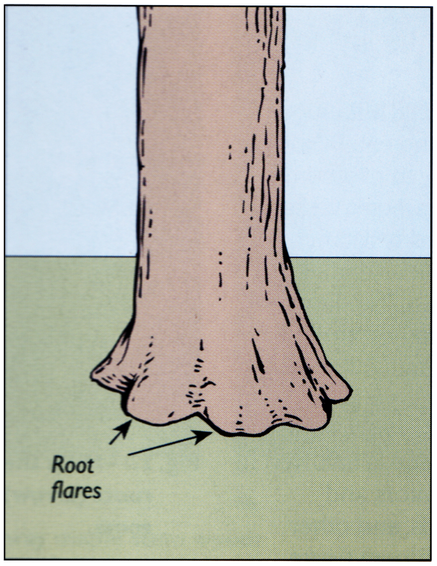

Fig. 24—Root flares develop due to the growth pattern of roots where the top of the root (proximal end) grows more than the bottom of the root (distal end).

In landscape trees, abnormal root systems often develop through cultural practices (Figure 25). Nursery production methods such as the use of containers that induce encircling roots, propagation that encourages stem-origin adventitious roots, or tillage practices such as "hilling-up" plowing to control weeds can create abnormal root systems, as can planting practices such as deep planting, narrow planting holes, and confined planting locations such as small planters. Tree vitality and longevity is not always harmed by production and planting methods. In some forest plantations developed from seedlings with abnormal root systems, seedlings successfully developed into mature trees because of adventitious root development and fusion of the abnormal root system into a central mass (Van Eerden and Kinghorn 1978). In

Fig. 25—Abnormal root systems such as these often develop through propagation and or cultural practices.

Fig. 26—Many root collar examinations, especially on smaller trees, may be performed with simple gardening tools.

landscape trees a clear picture is also lacking, but the development of a new root system can overcome an existing abnormal root system (Gilman 1997). Regardless of the rules and exceptions, an examination of the root system and its relationship to stem condition is a vital aspect of tree health evaluation, problem diagnosis, and assessment of root system condition.

Performing the Examination

A root collar examination typically takes from fewer than 20 minutes for smaller trees and less invasive examinations, to more than two hours for larger trees or more extensive operations. Equipment can range from simple and basic—trowels, knives, pruners, stiff brushes, saws, and shovels—to elaborate and specialized—tile probes, portable generators, air excavation (Smiley 1999b), wet/dry vacuums, wood gouges, chisels, and water (Figures 26 and 27).

Fig. 27—Larger, more extensive and nondestructive examinations justify the use of wet/dry vacuums and portable generators. These tools greatly reduce the amount of time required to remove soil from the examination area.

Most diagnostic examinations need not be extensive. Begin by probing into the soil near the trunk flare with a 3/8-inch-diameter tile probe or stiff wire (coat hanger gauge) to detect the depth of branch and encircling roots and to determine the soil area around the tree stem you need to remove (Figure 28). For the average size landscape tree (9 to15 inches d.b.h.) with roots 6 to 10 inches from the surface, a 12- to18-inch-wide examination area is usually sufficient. If primary branch roots are deeper than that,

Fig. 28—Probing the soil area near the root flare can help determine the extent (depth and width) of the examination and if it's warranted.

Fig. 29—The examination area for this 7.5-inch d.b.h. sugar maple was 11 inches deep and 30 inches wide. Total time involved with a vacuum was approximately 30 minutes.

you will need to widen the examination area as the examination progresses (Figure 29).

If sod surrounds the trunk, strip it away to a depth of approximately 2 inches. If the tree is mulched, carefully remove the mulch and any plastic or fabric ground cover beneath the mulch. Loosen the soil gently in the examination area with a trowel, hand cultivator, or knife and remove with a trowel or wet/dry vacuum. Do not use spades or shovels unless absolutely certain that no roots exist in the excavated soil. Gradually loosen and remove deeper layers of soil until the stem/root conflict or the root collar flare is exposed (Figure 30).

You can also use compressed air or water to expose tree roots. Air is blown at the soil through a tool called an Air Spade® to expose the roots. Water under low to high pressure has been used for more than 50 years to expose roots.

Choose a method based on availability of equipment, available time, and your objectives. Shallow examinations of smaller trees do not warrant elaborate equipment, such as vacuums and generators. However, with larger trees and examination areas, vacuums and portable generators are much more efficient and safe. Vacuuming loosened or water-saturated soil is less destructive to roots, reduces the chances of cutting through utility cables, and offers a clearer view of the root/stem conflict area.

Fig. 30—A small trowel and vacuum may be used to loosen and remove soil during a nondestructive examination.

Fig. 31—This J-root (arrow) could easily be removed prior to planting, which would eliminate its potential for stem conflict.

Fig. 32—Vertical slices through a pot-bound root system encourages more radial root development.

Prevention and Treatment of SGRs

A survey of practicing tree care professionals (Hauer and Johnson 1997) revealed that 88% of the respondents treated trees with SGRs. The two most common treatments were removal of SGRs and treatments to increase tree vitality (e.g., fertilization, irrigation, aeration).

Although the practice of removing offending roots has been recommended in countless publications for decades, there is nothing beyond anecdotal evidence that supports this treatment.

The most effective “treatment” is prevention.

Preventing SGRs

Prevention begins at planting. Watson et al. (1990) speculated that SGRs formed just before or at the time of transplanting with the species they investigated. This speculation has been confirmed with a larger number of species in field studies at the University of Minnesota (Johnson 1999). Therefore, time spent inspecting for and correcting developing SGR problems at planting time is time well-invested and considerably less than that required for a root collar examination after the tree has been in the landscape for several years.

Fig. 33—An alternative to slicing and removing roots is simply straightening them out prior to planting in a sufficiently wide planting hole.

For bare-rooted nursery stock, closely examine the root system and remove encircling roots or “J” roots that could eventually compress stem tissues (Figure 31). Consider rejecting trees with moderately to severely deformed root systems.

For containerized trees, inspect the root systems for encircling woody roots and depth to the root collar flare. If woody roots are encircled, straighten or prune them prior to planting (Figures 32 and 33). If the root collar flare is buried more than 1 to 2 inches, remove the excess growing medium to expose the flare areas prior to planting.

Inspect balled-and-burlaped or tree-spaded trees

Fig. 34—Buried with 12 inches of soil during a construction project 15 years prior to this examination, this white oak had formed two SGRs.

for soil depth over the root collar flare using a wire probe. If there is more than 1 to 2 inches of soil over the flare/branch root area, plant the tree higher than normal in the landscape, remove the excess soil prior to back-filling the planting hole, and inspect the stem for developing encircling roots or SGRs. Consider rejecting trees that are deeply buried within the root ball. Use the height of the root ball versus the depth within the root ball to the lateral roots as a guide. The more deeply buried the root system, the fewer roots available for tree establishment.

If the root collar flare and stem are above the soil surface, developing SGRs will be easily detectable and treatable long before they cause physiological stress to the tree. Therefore, prevention of SGRs must include planting trees so that the root collar flare is at or only slightly below the soil or mulch surface.

Treating Trees With SGRs

Removal is the most common treatment of encircling roots or SGRs that have caused minimal stem compression. Roots may be removed with wood gouges, saws, or pruners during the examination process (Figures 34 and 35).

Fig. 35—Both SGRs were removed with a mallet and wood chisel. The excavated area was then lightly (2+ inches) mulched.

When SGRs have caused extensive stem compression and are fully or partially embedded in the stem, modify the removal treatment to avoid damage to the stem. Embedded and severely compressing SGRs are often left in place when they cannot be safely removed; there is some belief that SGRs reduce the typically short life span of urban trees by only a few years, and the potential damage associated with SGR removal is not justified (Watson et al. 1990; Tate 1981). A compromise is to prevent the SGR from growing and further compressing stem tissues by severing it at the edges of the stem. Remove the remaining root to a distance where it no longer poses a threat to the stem and allow the severed SGR to decay with time. Annual examination of the stem to assess for decay is recommended.

The season during which SGRs are removed might influence the success of the treatment. Smiley (1999a) found that summer removal resulted in better diameter growth over two years than did fall removal or a combination of summer and fall removal for red maple

Fig. 36—After this littleleaf linden was examined, the encircling and girdling roots were removed, as well as the twine. The sod was then removed farther out and the area lightly mulched. This tree continues to be periodically monitored, but should live a long and healthy life.

trees under an irrigation system.

Regardless of treatment, do not backfill the examination area. Lightly mulch the exposed roots but not the root collar flare or stem area (Figure 36). Subsequent examinations will not require the time-consuming removal of soil.

Treat the tree to improve vitality or at least reduce environmental stresses during the recovery period if SGRs are removed, or as long-term maintenance if SGRs are prolific and imbedded. Maintain optimum soil water through irrigation and surface mulches. Surface mulch as much of the rooting area as possible, but do not pile mulch against the tree stem or completely bury the exposed root collar examination area. Mulch also helps to remove competition for water and nutrients from turf grass.

Control infectious diseases and insect pests, especially those that defoliate canopies or induce stem cankers. Nutrients may be added if soil and/or a foliar analysis indicates a deficiency.

There are instances where the treatment options include removal. If stem compression from SGRs is severe and extensive (greater than one-third to one-half of the stem circumference), tree stability might be the main issue. Consider removing SGR-affected landscape trees that pose a high risk of failure and are near immobile targets (e.g., sidewalks, buildings, streets). In other instances, planting new trees near SGR-affected trees in anticipation of their death would be appropriate.

Glossary

Adaptive growth. The elaborate shaping of individual tree designs well-adapted to external loading conditions in order to optimize against external loading factors.

Adventitious root. A root in an unusual position, such as on a stem.

Anatomy. The structure (traditionally internal) of a plant.

Deeply planted. Excessive soil over the root collar flare.

Encircling root. A root that encircles the stem of a tree, either contacting the stem or positioned to contact the stem tissues within a reasonable amount of time.

Etiology. The science of the causes or origins of disease, together with the relations of the causal factor(s) to the host; the study of the causal factor, its nature, and its relations with the host.

Girdling root (sign). Physical evidence that a root is directly impacting another root or stem. The physical evidence would be compression of woody tissues of another root or stem by encircling roots that have contacted the stem or root.

Girdling root syndrome. The etiology of the effects of (stem) girdling roots on the vitality and condition of trees.

Morphology. The (outward) physical structure of a plant (e.g., characteristics of the root system, branch attachment, foliage).

Multiple stress factors. Situations in which more than one soil, environmental, biological, or cultural factor is negatively impacting the vitality and/or condition of trees (e.g., droughty conditions compounded by deicing salt spray, compacted soil, and defoliation by an insect pest).

Physiology. The study of the activities- and processes of living organisms (e.g., water movement, nutrient transport, respiration).

Pot bound. The impacted and encircling root system that often develops when a tree has been grown in a container that is too small for normal and uninterrupted root expansion; also referred to as root bound.

Premature fall color and leaf drop. A relative, symptomatic condition, associated with a decline in tree vitality, in which leaves change color and drop earlier than would be expected based on observations of other trees of the same species and other species at the same and other sites.

Root collar or root crown. The area of a tree where tissues differentiate into stem and root. Normally, this area appears swollen or tapered, and is located near or at soil level.

Root collar examination. The removal of soil, mulch, or other materials to sufficiently examine the entire root collar area, potential root aberrations, and/or root and stem conflicts (e.g., SGRs).

Root flare. The enlarged area where stem tissues begin to differentiate into main order, lateral root tissues.

Root graft. The phenomenon in which roots become grafted together, resulting in functional tissue connections.

Secondary and tertiary pests. Animals (usually insects) that attack and further damage stressed trees.

Sign. Physical evidence of a disease/disorder/damage causal agent (e.g., conks, spores, infesting insects).

Stem compression. A reduction in the normal diameter expansion of stems due to the presence of a physical barrier, such as SGRs.

Stem-girdling root syndrome. The accumulation of stress factors and symptoms associated with the compression of stem tissues from girdling roots.

Strain. An irreversible condition beyond stress in which plant mortality occurs.

Stress. A reversible disruption of the normal physiologic activities of a tree.

Stunt. An abnormal reduction in the growth rate and/or size of various morphological features of a tree (e.g., leaf size, stem caliper, root system, annual twig growth).

Symptom. A plant's visible reaction to the presence of a biotic or abiotic causal agent.

Symptomology. The study of plant disorders and the symptoms associated with those disorders, as well as the characteristic progression from one symptom to another over time.

Vigor. An organism's genetic capacity for survival or growth.

Vitality. A dynamic condition that distinguishes the living from the nonliving; used as a metric to conceptualize the relative health of a tree in response to its site condition.

Appendix. Tree Species Observed by Practitioners to Have SGRs.

Tree Species	Scientific Name
Acacia sp.	*Acacia* sp.
Aleppo Pine	*Pinus halepensis*
Arizona Ash	*Fraxinus velutina*
Austrian Pine	*Pinus nigra*
Black Gum Tupelo	*Nyssa sylvatica*
Bradford Pear	*Pyrus calleryana* Bradford
Bur Oak	*Quercus macrocarpa*
Callery Pear	*Pyrus calleryana*
Canary Island Pine	*Pinus canariensis*
Cherry sp.	*Prunus* sp.
Chilean Mesquite	*Prosopis chilensis*
Coral Tree	*Erythrina* sp.
Crabapple sp.	*Malus* sp.
Dogwood sp.	*Cornus* sp.
Elm sp.	*Ulmus* sp.
Eucalyptus	*Eucalyptus* sp.
Ficus sp.	*Ficus* sp.
Fruitless Mulberry	*Morus alba*
Ginkgo	*Ginkgo biloba*
Goldenchain Tree	*Laburnum x watereri*
Green Ash	*Fraxinus pennsylvanica*
Hackberry	*Celtis occidentalis*
Hemlock	*Tsuga canadensis*
Holly sp.	*Ilex* sp.
Honeylocust	*Gleditsia triacanthos*
Juniper sp.	*Juniperus* sp.
Kukui	*Aleurites moluccane*
Littleleaf Linden	*Tilia cordata*
Live Oak	*Quercus virginiana*
Mesquite sp.	*Prosopis* sp.
Monterey Pine	*Pinus radiata*
Norfolk Island Pine	*Araucaria heterophylla*
Norway Maple	*Acer platanoides*
Norway Spruce	*Picea abies*
Pin Oak	*Quercus palustris*
Ponderosa Pine	*Pinus ponderosa*
Poplar/Cottonwood	*Populus* sp.
Red Elm	*Ulmus rubra*
Red Maple	*Acer rubrum*
Red Oak	*Quercus rubra*
Russian Olive	*Elaeagnus angustifolia*
Sawtooth Oak	*Quercus acutissima*
Schefflera	*Schefflera* sp.
Scotch Pine	*Pinus sylvestris*
Shamel Ash	*Fraxinus uhdei*
Shumard Oak	*Quercus shumardii*
Siberian Elm	*Ulmus pumila*
Silver Maple	*Acer saccharinum*
Spruce sp.	*Picea* sp.
Stone Pine	*Pinus pinea*
Sugar Maple	*Acer saccharum*
Sugarberry	*Celtis laevigata*
Sweetgum	*Liquidambar styraciflua*
White Oak	*Quercus alba*
White Pine	*Pinus strobus*
Zelkova	*Zelkova* sp.

Sources: d'Ambrosio (1990), Hauer and Johnson (1997), Johnson (1999), Johnson and Borst (1999), Johnson and Johnson (1997), Tate (1980), Van Wormer (1937), Van Wormer (1940), Watson et al. (1990)

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