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FORMATION OF GIRDLING ROOTS[1]

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Abstract. Root crowns of 60 Norway maples, 15 sugar maples, 15 red maples, 10 green ash, 10 honeylocust, and 10 littleleaf lindens were excavated 3-10 years after planting in order to study girdling roots. Girdling roots and potentially girdling roots were more common on maple species. The majority of the girdling roots were either small or new laterals initiated during the first year after transplanting. Lateral roots at perpendicular angles, close to the base of the trunk, are often naturally positioned to develop into girdling roots. Growth of the lateral roots, which is often slow while the root terminal is intact, is stimulated when the terminal is severed as the tree is dug from the nursery. Girdling roots were not related to planting depth. Only Norway maples frequently had severely girdling roots as mature trees. Mature sugar and red maples had few girdling roots.

Résumé. Le système racinaire de 60 érables de Norvège, 15 érables à sucre, 15 érables rouges, 10 frênes rouges, 10 chèvrefeuilles et 10 tilleuls à petites feuilles ont été excavés 3 à 10 ans après leurs plantation dans le but d'étudier les racines étouffantes. Les racines étouffantes et les racines étouffantes potentielles étaient plus communes chez les érables. La majorité des racines étouffantes étaient petites ou de nouvelles latérales initiées durant la première année après la transplantation. Les racines latérales à des angles perpendiculaires près de la base de tronc sont souvent naturellement positionnées pour se développer en racines étouffantes. La croissance des racines latérales, qui est souvent lente pendant que la racine terminale est intacte, est stimulée quand cette dernière est endommagée au moment où l'arbre est sorti de la péppinière. Les racines étouffantes n'étaient pas reliées à la profondeur de plantation. Seulement les érables de Norvège avaient fréquemment de manière grave des racines étouffantes à maturité. Les érables à sucre et rouges avaient peu de racines étouffantes à maturité.

A girdling root has been defined as "a root that grows around another root or stem, thus tending to strangle the plant" (1). Girdling roots are commonly found on Norway maples *(Acer platanoides)* in the urban landscape (8). Radial growth at the point of contact is distorted and reduced, particularly on stem tissue, but cambial death and grafting are uncommon (5). Xylem and phloem transport are greatly reduced in stems. Holmes (3) reported that girdling roots can constrict growth on a large percentage of the trunk circumference before crown symptoms develop. If present, canopy symptoms can include reduced growth, abnormal color, early fall coloration, and dieback of certain parts of the crown (2). By the time crown decline develops, the girdling roots are often at an advanced stage and little can be done for the trees.

Recommendations vary in regards to the value and practicality of removing girdling roots (2, 3, 8).

Circling roots of container-grown plants can clearly result in girdling roots after planting in the landscape, but girdling roots must also develop by some other mechanism since they are also common in conventionally grown stock. This study was undertaken to answer the following questions about trees planted as B & B stock: 1) how and why do girdling roots form?, 2) which species are most likely to form and be injured by girdling roots?, and 3) how can girdling roots be prevented or corrected?

Methods

Trees selected for the study were all parkway trees that were 5-6.25 cm (2-2.5 in.) in diameter at planting, and that had been in place for 3-10 years. Planting dates were verified by village records. Trees in this size and age range were chosen because preliminary data indicated that after more than ten years in the landscape, many

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trees had intertwined and overgrown girdling roots, making them unusable for study (Fig. 1). The six species chosen for the study include both species prone to girdling roots and species not usually associated with girdling roots. The species included and number of trees sampled were: Norway maple—60 trees; sugar maple *(Acer saccharum)*—15 trees; red maple *(Acer rubrum)*—15 trees; green ash *(Fraxinus pennsylvanica)*—10 trees; honeylocust *(Gleditsia tricanthos)*—10 trees; and littleleaf linden *(Tilia cordata)*—10 trees. Cultivars were seedling rootstock. Root crowns of naturally regenerated Norway and sugar maples (2 each) in the Morton Arboretum woodland were similarly inspected for girdling roots.

The first 36 Norway maples were excavated in the fall of 1987. From these trees, it became evident that future efforts should concentrate on trees that had been planted 4-6 years previously. The remaining 84 trees were all in this more restricted age range and were excavated in the summer of 1988. Soil was carefully excavated from the root flare area to beyond the perimeter of the original root ball, typically 30-45 cm (12-18 in.) from the trunk. When the roots were exposed, the number of girdling roots, branching hierarchy of each root (primary, secondary, etc.), and depth of planting were recorded. Girdling roots were removed where it was judged that such removal would not cause a substantial reduction in the total root system. After removal, the approximate age of each root was determined by smoothing a cross-section and counting the number of annual rings [the number of annual rings does not always correspond exactly to the chronological age on roots (6). Photos were taken before and after root removal to document the work and to aid in follow-up studies.

Typical crown decline symptoms associated with girdling roots are usually not observed in mature sugar and red maples in the landscape, as they are in Norway maples. To determine if girdling roots are present but not causing crown symptoms on mature red and sugar maples, root crowns of five, 21-28 year old parkway trees of each species were excavated.

The natural branching angle of each species was measured to determine if this factor played a role in the development of girdling roots. Species with perpendicular lateral root branches might be more prone to developing girdling roots than species with more acute branching angles. Small roots were used because they are easily obtained in large numbers, the angles established in the early stages of woody growth will persist indefinitely, and there is little chance that anomalies have been hidden by woody growth. Freshly collected roots 1-3 mm in diameter were floated in a thin layer of water to maintain their natural shape. The image was magnified 10 times with a standard overhead projector, and the angle between the lateral branch and the proximal portion of the main root was measured with a protractor from tracings.

Statistical procedures were performed using the SOLO Statistical System Version 2.0. Analysis of variance (ANOVA) was used to study the differences between species. Separation of means was by the Neuman-Keuls procedure with a significance at 5 percent (0.05).

Results

Norway maple had an average of 4.4 girdling roots per tree and sugar maple had a similar number (Table 1). Red maple had significantly more—nearly twice as many. Honeylocust, green ash and little-leaf linden had less than half as many girdling roots as any of the maples. Though the two-fold or greater differences seem large, they were not always statistically significant because of the small number of girdling roots on some

Figure 1. Typical girdling root formation on an older Norway maple.

species. Lindens had so few girdling roots that they could not be analyzed further.

When the age of the roots was expressed in relation to the year the tree was transplanted into the landscape, a strong relationship between transplanting and girdling root formation became apparent for all three maple species (Figure 2). The year when the greatest number of girdling roots were initiated was just prior to transplanting for Norway and red maples, the two species with the largest samples. The peak for sugar maple was at the year of transplanting. Girdling root initiation on the other three species also seemed to occur at, or just before, planting, but there were too few samples to allow for reliable analysis. At least two-thirds of the girdling roots were initiated within two years of transplanting, and for four of the five species, at least half of the girdling roots existed at the time of transplanting (Table 2).

A small percentage of the girdling roots were primary roots, originating from the base of the trunk (Table 3). It is unlikely that one of these primary roots would curve sharply and reverse direction unless it was distorted during planting as bareroot stock in the nursery or was not a true primary root. Several years of woody growth can often make it difficult to distinguish when the true terminal root has died and a lateral has become dominant. In four of the five species, the greatest percentage of the girdling roots were lateral branches of the primary roots (secondary roots). A substantial number of girdling roots were tertiary roots (lateral branches of lateral branch roots).

Roots that were actually girdling and causing damage were distinguished from potentially girdling roots, the latter being a root not yet causing actual damage, but positioned as to be a problem in the future as the diameter of the roots and trunk increase. It is an artificial distinction, based only on stage of development, but was used to help ascertain the best time to attempt to remove girdling roots and correct the problem. Table 4 shows that 4-6 years after planting, there are about equal numbers of girdling and potentially girdling roots, supporting field observations that no serious damage had yet developed. As mentioned above, few girdling roots are formed after this time.

Though it has never been formally studied, it is often contended that trees planted too deeply

Table 1. Average number of girdling roots per tree for the six species tested.

Species	Girdling roots per tree*
Norway maple	4.4 b
Red maple	8.9 a
Sugar maple	4.0 b
Honeylocust	1.7 bc
Green ash	2.0 bc
Littleleaf linden	0.6 c

*Values with the same letters are not significantly different (5% level) using one-way analysis of variance with separation of means using the Newman-Keuls procedure.

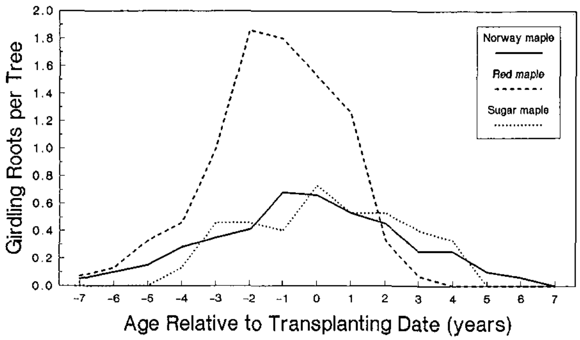

Figure 2. Norway, red and sugar maple girdling root age relative to transplanting.

Table 2. Girdling root initiation relative to transplanting year

% Girdling roots formed	Norway maple	Sugar maple	Red maple	Green ash	Honey-locust
Before transplanting	61	37	64	50	50
Year of transplanting	13	18	19	20	41
After transplanting	26	45	17	30	9
Transplanting +/− 2 yr.	67	67	77	75	88

Table 3. Classification of girdling roots

Root Type (%)	Norway maple	Sugar maple	Red maple	Green ash	Honey-locust
First order (1°)	28	8	6	25	17
Second order (2°)	50	48	56	30	72
Third order (3°)	20	36	32	45	11
Fourth order (4°)	2	8	6	0	0

Table 4. Roots of trees 4-6 years after planting.

Root type (%)	Norway maple*	Sugar maple	Red maple	Green ash	Honey-locust
Girdling roots	43	46	60	50	66
Potentially girdling	57	54	40	50	34

*Some trees 6-10 years after planting also included in data have more girdling roots. In this study, there was no relationship between planting depth and girdling roots (Table 5). The data also point out how often trees are planted too deeply in the landscape.

There were no significant differences in root branching angles among the six species studied, though the Norway maple lateral root branches were slightly more perpendicular.

Discussion

The data presented here can be used to describe how girdling roots may be formed. Normally, all the primary roots radiate out from the base of the tree. When the tree is dug in the nursery, or perhaps root pruned a year or two earlier, many roots are cut and several new roots are formed at or near each cut end (Figure 3). These new terminal roots are not likely to become girdling roots because they grow in the same general direction as the original root and can even curve to follow the same direction as the original root (4).

Lateral (secondary) roots existing at the time the primary root is cut, are usually nearly perpendicular to the primary root (Table 6). When the primary roots are cut, lateral roots were stimulated to grow more rapidly (4). Small lateral roots are most often stimulated (unpublished data). As long as the terminal apex of the main root remains intact, most laterals would probably continue to grow slowly, remain small and usually persist only a few years. When the main root is cut during transplanting, these otherwise insignificant, short-lived laterals apparently become large, vigorous

Table 5. Frequency of girdling roots in relation to planting depth for all maple species. The first root of trees planted at 'at grade' was within 2.5 cm (1 inch) of the soil surface.

Root flare relative to grade [cm (inches)]	*Number of trees*	*Average number of girdling roots/tree*
+2.5(1)	1	4
at grade	21	5
-2.5(1)	2	3
-5.0(2)	13	5
-7.5(3)	2	9
-10.0(4)	7	5
-12.5(5)	1	4
-15.0(6)	4	5
-17.5(7)	1	1
-20.0(8)	2	2

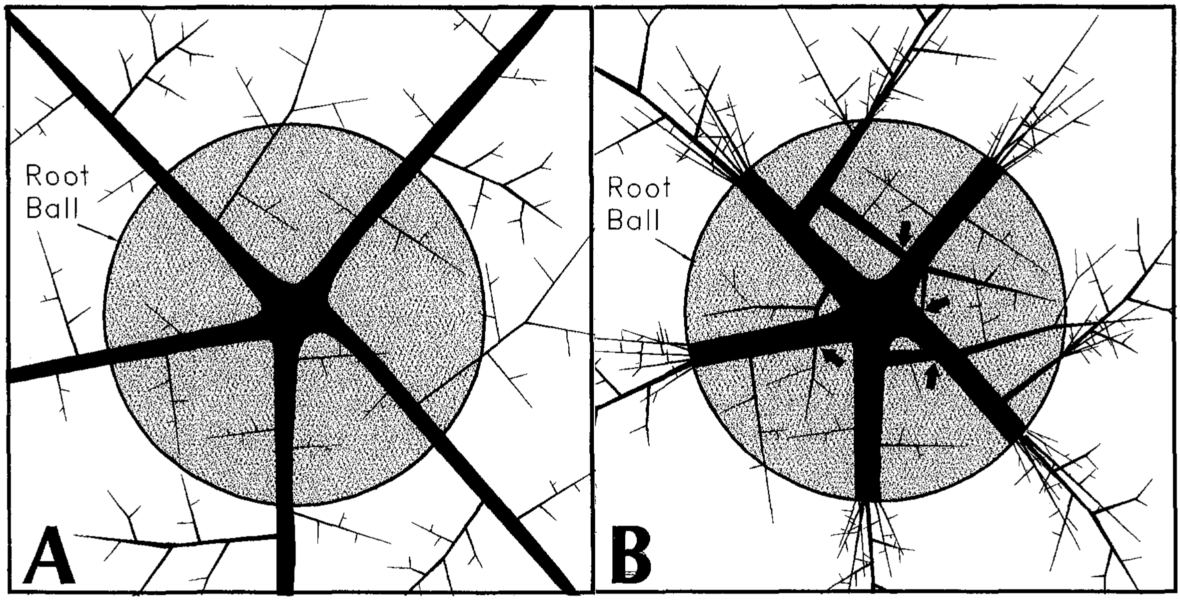

Figure 3. Probably mechanism of girdling root formation. (A) The major roots of a tree normally radiate out from the trunk. These roots and some of their lateral roots, are severed during transplanting. (B) After transplanting, new roots that are initiated from the cut ends and follow the same direction as the original. Growth of existing and new lateral roots is stimulated and these can become girdling roots (arrows).

roots growing in an inappropriate direction as girdling roots.

This pattern of lateral root stimulation/release can be observed in many species, regardless of their tendency to form girdling roots. Figure 4 shows a clear example of lateral root stimulation resulting from severing a primary root of Colorado spruce. The primary root was four years old, 2 cm in diameter, and increasing in size rapidly when it was cut during transplanting. The lateral root originated in the second growth ring, making it 3 years old at the time of transplanting, but was only 1 mm in diameter, indicating very slow growth.

Transplanting temporarily reduces vigor of the tree, as can be seen in the smaller growth rings of the severed primary root, but growth rings of the lateral root show a marked increase in size immediately after transplanting. This small, slow growing, lateral root was unintentionally transformed into a vigorously growing root by transplanting. It is nearly perpendicular to the original root, and only a few inches from the trunk. As it continues to increase in diameter along with the trunk, it is likely to become a girdling root.

New lateral roots may also form some distance behind the cut end at similar perpendicular angles as existing laterals (4). Girdling roots formed after transplanting are probably these new lateral roots (approximately 2 per tree average). Stimulation of existing lateral roots and formation of a few new lateral roots together can account for the fact that most of the girdling roots are formed just before or at the time of transplanting. This would also explain why girdling roots are not a problem in the forest, since the trees have not been transplanted. The forest trees checked in this study had no girdling roots.

Thus, 4-6 years after transplanting is probably the optimum time to remove girdling roots to prevent future problems. The process took approximately 2-3 hours per tree, and might well be considered a good investment in the future. Most of the time was spent removing the soil. Equipment does exist that could remove the soil in minutes instead of hours, without harming roots, but was not available for use in this study. Caution is advised when removing girdling roots as a routine practice until more is known about stress related to root removal and new root initiation from the pruning

Table 6. Mean branching angle of fine root lateral branches. Angles were measured between the lateral root and the proximal portion of the main root.

Species	*Branching angle**
Norway maple	102.0
Red maple	112.0
Sugar maple	120.0
Honeylocust	110.1
Green ash	110.5
Littleleaf linden	110.2

*No significant differences (5% level) using one-way analysis of variance with separation of means using the Newman-Keuls procedure.

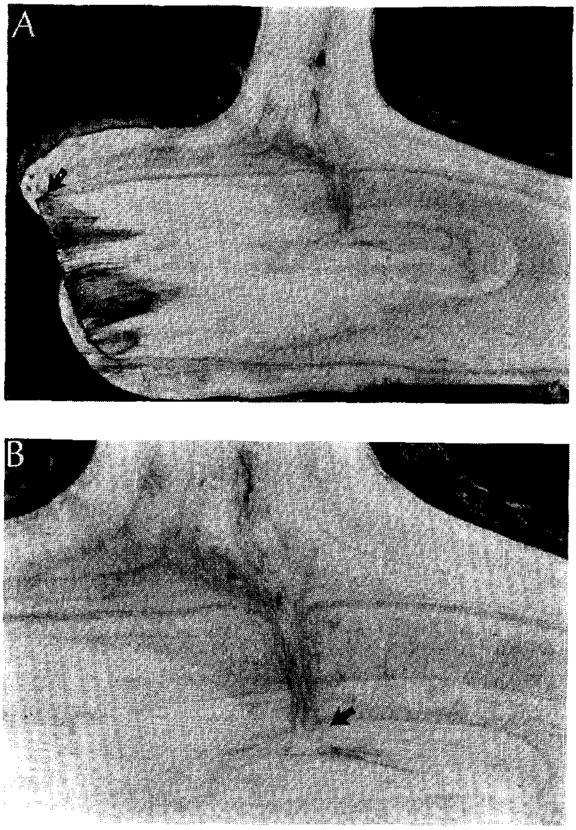

Figure 4. Lateral root growth is increased by severing the terminal root. (A) Discolored wood at the severed end indicates the diameter of the four year old terminal root when cut. New roots were initiated around the cut end, but did not persist (arrow). (B) The lateral root originated in the second growth ring (arrow), but was increasing in diameter very slowly as long as the terminal was intact. After the terminal root was cut, the growth of the lateral increased sharply though overall vigor was reduced from transplanting.

wounds. The authors will be seeking answers to these questions for future reports.

One explanation for the apparent preponderance of girdling roots on maples, as opposed to other species of trees, may be because lateral roots on maples branch at right angles whereas those of other species are at more acute angles. However, results of our measurements indicate that there were no significant differences in branching angles among the species studied. Other characteristics, such as frequency of branching, or persistence of lateral branches may be involved but were beyond the scope of this study.

Though sugar maples have nearly as many girdling roots as Norway maples, and red maples have more girdling roots than Norway maples when young, crown decline symptoms typical of girdling root problems are not common on sugar and red maples as mature trees. Girdling roots may not be long-lived in these two species. Excavation of root crowns of sugar and red maples, 21-28 years after transplanting revealed very few girdling roots. Those present were relatively small, and all were less than 12 years old. Girdling roots of similarly aged Norway maples were numerous and up to 24 years old. Why the girdling roots do not persist on red and sugar maples and do persist on Norway maples is unknown.

Conclusion

Girdling roots were very common on young trees of the three maple species studied, but not on the linden, ash and honeylocust. Formation of girdling roots is associated with transplanting and probably results from the stimulation of lateral roots when the main root is cut as the root ball is dug. In mature trees, girdling roots were present in great numbers and caused damage on Norway maples, but not on red and sugar maples. Crown decline symptoms often attributed to girdling roots on mature trees were found only on Norway maples. It is likely that constriction of vascular transport in the stem by girdling roots is responsible for crown decline in Norway maples. There was no evidence to indicate that planting too deeply was responsible for girdling roots.

An occasional girdling root can probably form in any species, but only in Norway maples do they seem to develop into a serious problem. It is the only species which might warrant routing treatment. Removal of girdling roots is probably best done 4-6 years after transplanting. Few girdling roots are formed after this time and this is a stage when these roots can still be easily removed. Careful removal of 6-8 inches of soil is usually adequate if the tree was planted at the correct depth. Care must be exercised not to remove so many roots that the tree is stressed.

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