One Root, Two Root, Good Root, Dead Root: 
Myths and Mythology of Tree Root Systems

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How far do the roots spread?

Tree Root Systems
What and Where are They and Why?

Root Terminology
• Over 2,200 root terms (Sutton and Tinus 1983)
• Types (Terminology)
  – Hierarchy
    • Primary, secondary, tertiary
    • Order system … first order, second order, etc.
  – Function
    • Structural, support, anchorage, tap, lateral, sinker, absorbing, etc.
    • Woody or non woody
    • Adventitious roots
• Associates of roots
  – Symbionts (Mycorrhiza and Nitrogen Fixers)
  – Free living

Extreme Taper Makeover: Tree Edition

My 2nd Grade Teacher Mrs. Anderson Told Me …

Roots grow deep like carrots…(wrong, right, or Switzerland)
The Tree Tells Us Better

Depth Factors:
- Soils
- Species

Spread Factors:
- Site
- Species
- Prediction by
  - tree height (-)
  - canopy diameter (?)
  - trunk diameter (+)

A Strong Relationship Among Trunk Diameter and Root Spread

What's the Worst that Can Happen!

How deep do tree roots typically grow

<table>
<thead>
<tr>
<th>Factor with tree importance</th>
<th>2008 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As deep as the tree is tall</td>
<td>0</td>
</tr>
<tr>
<td>Only half as deep as tree is tall</td>
<td>8</td>
</tr>
<tr>
<td>Approximately 1/3 deep as tree is tall</td>
<td>54</td>
</tr>
<tr>
<td>Typically most prevalent in the upper few feet</td>
<td>42</td>
</tr>
</tbody>
</table>

A study of builder’s in Central WI (O’Herrin and Hauer 2008)

Where do tree roots laterally extend

<table>
<thead>
<tr>
<th>Factor with tree importance</th>
<th>2008 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half way from the trunk to the canopy edge</td>
<td>15</td>
</tr>
<tr>
<td>To approximately the canopy edge</td>
<td>59</td>
</tr>
<tr>
<td>Two times or more the distance of trunk to the canopy edge</td>
<td>11</td>
</tr>
<tr>
<td>Don’t know</td>
<td>15</td>
</tr>
</tbody>
</table>
What Do Roots Look Like

Get a shovel and learn roots

Tree Root Systems Vary in Fibrosity

Fibrous (above) & Moderate (below) Rooted

Coarse Rooted

Adventitious roots and shoots (Tilia cordata)

Is this Normal? 45 days after planting

How far to roots spread?

Depends on the Site! … Spread Potential 2-3 times canopy dimensions

Root Morphology Changes

Extreme Taper Makeover: Zone of Rapid Taper

First Order, Main Order, or Structural Roots

How many depends of the species … 5 to 15 or more
Roots in a Competitive World
Horizontal spread & other species … vertical spread & oxygen

Root Spread of Alligator Juniper
Exploration Varies by Species, Soil, and Impediments

Red maple (Acer rubrum) surface roots
A site with seasonally high water table

Red maple (Acer rubrum) structural roots
From central sands of Wisconsin

An Example Normal Root System
Of a nursery grown landscape tree

An Example Normal Root System
From the Missouri Gravel Bed System
Sugar maple (Acer saccharum) Normal Root System

Six years old from seed (Photo by Gary Johnson)

Surface roots of green ash (Fraxinus pennsylvanica)

Is this Normal? On a Compacted Soil Site

Root Growth Rate and Oxygen

Growth Rate

% Root Growth Rate

Tree Planting: Pruning at Planting (Walmsley 1985)

No Evidence Compensatory Pruning is Beneficial

Transplant Shock

Allocation of Resources (Smaller Foliage & Reduced Shoot Growth)

When do Roots Grow

- An integrated system: root/shoot communication
- Pronounced autumn and spring elongation
- Declines with shoot growth and above ground allocation
- Soil moisture and temperature strongly influence
  - Moisture limitation suppresses
  - Typical temperate range 36º to 77 º F
  - Below 50º F severely limited, above 100º F becoming lethal
- Species dependent

Called Root Growth Periodicity
Tree Root Systems

What is Normal
What is Abnormal?

These are the minimum, not maximum

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Minimum diameter</th>
<th>Minimum diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in.</td>
<td>3 in.</td>
<td>3 in.</td>
</tr>
<tr>
<td>2 in.</td>
<td>4 in.</td>
<td>4 in.</td>
</tr>
<tr>
<td>3 in.</td>
<td>5 in.</td>
<td>5 in.</td>
</tr>
<tr>
<td>4 in.</td>
<td>6 in.</td>
<td>6 in.</td>
</tr>
<tr>
<td>5 in.</td>
<td>7 in.</td>
<td>7 in.</td>
</tr>
<tr>
<td>6 in.</td>
<td>8 in.</td>
<td>8 in.</td>
</tr>
<tr>
<td>8 in.</td>
<td>10 in.</td>
<td>10 in.</td>
</tr>
<tr>
<td>10 in.</td>
<td>12 in.</td>
<td>12 in.</td>
</tr>
</tbody>
</table>

Table 6 - Root-ball diameters - field-grown trees

Bare root, more for the money
Tree Root Systems, What is Normal?

Stem girdling roots are abnormal?

Tree Root Systems What is Normal? Is this Normal?

Norway maple (Acer platanoides) as commonly observed

Tree Root Systems What is Normal? This is Normal

Norway maple (Acer platanoides) do have a root flare

Potential Adventitious Roots Formation

Green ash adventitious roots. Sugar maple adventitious roots.

What Choice Did Sugar Maple Have to Survive

Structural Roots

Mulch line

Soil line
SGR's Cause Compression of Tissue

Norway maple (*Acer platanoides*) failed from decay

Effects of SGR on Wood Anatomy

<table>
<thead>
<tr>
<th>Normal Wood</th>
<th>SGR Altered Wood</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Normal Wood" /></td>
<td><img src="image2" alt="SGR Altered Wood" /></td>
</tr>
</tbody>
</table>

This affects water and energy flow (Photos by George Hudler)

Some Tree Species Adapt Better than Others to Change

Silver maple at the river bank (Photo by Jacob Ryg)

Exposed Surface Roots in Park

Compaction may be an predisposing or inciting factor

Multiple Stress Factors

Treatments for Compaction? Do they work?

Air Tools … Air knife & Air Spade
Soil type and compaction

<table>
<thead>
<tr>
<th>Factor with tree importance</th>
<th>1989 (%)</th>
<th>2008 (%)</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Know which soils most prone to compaction</td>
<td>19</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>Know soil porosity</td>
<td>94</td>
<td>100</td>
<td>6</td>
</tr>
<tr>
<td>Know wet soil is more prone to compaction</td>
<td>88</td>
<td>100</td>
<td>12</td>
</tr>
</tbody>
</table>

Soil Compaction Studies

- **What is bulk density?**
  - Mass per volume soil (g/cm^2 or Mg/M^3)
  - What does it really mean?
    - Granite ~ 2.65 g/cm^3
    - ~ 1.4 – 1.6 g/cm^3 critical value
    - Forest soils maybe ~ 0.8 or >

- **Compaction study (Lichter and Lindsey 1993)**
  - Mass graded sites 1.75 g/cm^3
  - Control 1.27 versus 1.61 outside fencing
  - Control 0.95 versus 1.14 in disturbed area

Soil compaction affect on root systems

- Thicker and stubbier roots
- May result in shallower root system
- Inhibition of root growth
  - Soil Strength
  - = bulk density + soil moisture

How Far Away to Stay

- 3.5 to 4 meters (10 to 12 feet)
  - Howe (1973) 4 meters (13') in wooded lots
  - Miller (1993) >11 feet with utility trench
  - Hauer et al. (1993) > 10 feet

- **CRR / TPZ Recommendations**
  - 1.0 – 1.5’ radius per dia inch (dbh) of stem

Table 5. Relationship between tree lawn width and tree condition class in 1989 for construction and control trees.

<table>
<thead>
<tr>
<th>Lawn Width</th>
<th>Control</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;4</td>
<td>75.8ab</td>
<td>66.0a</td>
</tr>
<tr>
<td>4-7.9</td>
<td>74.8a</td>
<td>69.6a</td>
</tr>
<tr>
<td>8-9.9</td>
<td>80.4c</td>
<td>73.0ab</td>
</tr>
<tr>
<td>&gt;=10</td>
<td>78.2bc</td>
<td>74.2b</td>
</tr>
</tbody>
</table>

Mean in same column followed with a different letter are significantly different (0.05 level) using Student-Newman-Keuhl's.
Tree Protection Zones

**Good, Bad, and Ugly**

**Good**

PRZ = 1-1.5’ root radius for each inch of dbh

**Bad**

**Ugly**

What Would Happen …

If You Break Concrete When You Plant Trees?

The Built Environment: Green Versus Grey

What’s Wrong with this Tree

Trees and Roots Need Room to Grow

And so does the built environment! … Conflict or a design challenge

Selecting Trees: **Design for Final Size**

(Image by James Urban)

Restricted Planting Sites, Try Small Stature Trees

Selecting Trees: **Design for Decline**

In this corner …

Pit versus Vault

Green versus Grey

Trees planted ~ 1988 and look similar in 1998
Selecting Trees: Design for Decline

Sometimes trees just get in the way

May take several 2 to 8 years before symptoms (Day and Bassuk, 1994)

Infrastructure Needs: Avoid Design for Decline

Utilities, roads, sidewalks, buildings, etc.

Infrastructure Needs: Avoid Design for Decline

Watt were they thinking?

The upside of construction damage

It started with a request to verify verticillium wilt.
The Root of the Cause: Stem Girdling Roots (SGR’s)

Buried Roots and Stem Girdling Roots (SGR’s) Question’s

- How Common
- Impacts on Tree Health
- Economic Impact
- Treatment
- Prevention

“Buttress roots of affected trees are nearly always several inches deep! … rather than near or over, the soil surface as they do in the forest.” (Dilias et al. 1992)
“Girdling roots ... frequently caused by careless transplanting ... aggravated by an excess of organic matter applied near the trunk”

1942, Rush Marshall
Care of Damaged Shade Trees
USDA Farmers’ Bulletin No. 1986

H. M. Van Wormer, 1937
Proc. 13th Shade Tree Conference
Decline of Sugar Maple Trees
– Followed 2 years of drought
– 60% were declining, 100% w/ severely girdled roots
– 40% in good condition, few girdling roots

Hemlock Felled by it’s Own Roots

1937, H. Watson
The Scottish Forestry Journal.
51(1):62

“... many plants suffer less from their roots being shortened than from their being doubled back during planting.”

1874, Robert Hartig
Important Diseases of Forest Trees
(1894 English Translation)

1664, John Evelyn
In: Sylva, or a discourse of forest trees
“never enter the stem deeper than you found it; for profound burying very frequently destroys a tree.”

SGR’s and Rediscovery

“most functioning roots were near the surface” and injury would result if these were buried

1618, William Lawson
A New Orchard & Garden
“...the unspeakable benefit of many hundred years shall be lost by the audacious attempts of an unskilled arborist”

1618, William Lawson
A New Orchard & Garden

SGR’s are not a new phenomenon, however the problem has become more apparent in recent times

but why?

Potential Causes of SGR’s

- **Nursery culture** (planting, cultivation)
- **Tree planting** (deep holes, root balls sinking into backfill, buried by landscape fill, excessive mulch)
- **Changes to established trees** (fill over roots, excessive mulch, water table change, soil compaction)

**Myth:** Stem Girdling Roots Do not Occur Naturally
Stem Girdling Roots Can Occur in Nature

Ultimate forest competition, paper birch versus paper birch

Root conflict on ancient sitka spruce (Picea sitchensis)

Plant Part Grafting Commonly Occurs in Nature

Roots graft to roots!

Plant Part Grafting Commonly Occurs in Nature

Stems graft to stems!

Plant Part Grafting Commonly Occurs in Nature

Root and stem tissue do not graft!

Where is the Root Collar?

What is the Root Collar?

The part of a plant where the stem and root system meet.
What happens from SGR's

Sudden tree failure(s) from SGR's during wind storm.

Photos by Johnson and Hauer

How Soon Can SGR's Form?

Little leaf linden 1 year after planting 10 inches deep.

Barrier Angle (°)

Correction Angle: Least-squares

Corrected angle: Barrier angle

Buried Root Systems, How Common?

- 76% of 33 Trees from 24 species (1995, Brian Maynard, U of Rhode Island)
- 90% of 100 Sugar maple trees (1997, Ben Johnson, U of Minnesota)
- 93% of 417 Trees (1991, Bartlett Tree Research Laboratories)
- 94% of 202 Green ash and Linden trees (1999, Jeff Borst, U of Minnesota)

How Soon Can SGR’s Form?

Freeman maple 4 years after planting 6 inches deep.

Photo by Johnson (Wilson, B. 1967)
SGR’s, How Common?

**Mature Trees**
- 82% of Norway Maples, 1980 Tate
- 92% of Sugar Maples, 1990 d’Ambrosio
- 94% of Norway Maples, 1990 d’Ambrosio
- 52% of Practitioner’s RCE’s, 1997 Hauer and Johnson

**Young Trees**
- 41% of Sugar Maples, 1997 Johnson and Johnson
- 31% of Green Ash, 1999 Borst and Johnson
- 41% of Lindens, 1999 Borst and Johnson

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**Percent of Stem Encircled by Roots Related to Depth.**

**Borst and Johnson 1999**

**Percent of Total of Depth to First Main-Order-Lateral Root**

**881 Sampled Trees**

Sources (Johnson and Johnson 1997, Borst and Johnson 1999, Minneapolis Park and Recreation Board 2000)

Consistent With Rathjens and Sydnor (2005)

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**Manion’s Decline Model**

- **Predominating**
  - Long-term factors
    - Crown dieback
    - Stem damage
    - Genetic factors
    - Drought
    - Air pollutants
- **Inducing**
  - Short-term factors
    - Insect defoliation
    - Drought
    - Disease
    - Air pollutants
    - Mechanical injury
- **Contributing**
  - Long-term factors
    - Bacterial root blight
    - Carbon dioxide
    - Vines
    - Root decay fungi

**Figure 10-4** Many factors, rather than a single causal agent, influence the development of decline symptoms (after Manion, 1981).

Decline of green ash (Fraxinus pennsylvanica), SGR induced.
Sugar maple (Acer saccharum) decline, SGR induced.

Reduction in tree condition as depth to structural roots increases

Depth to first main order lateral root was correlated to tree condition. As depth to roots increased, tree condition decreased. Sugar maple trees (n=100) condition rated by Dave Johnson in Minneapolis in 1997.

y = -0.3429x + 10.244
R² = 0.1545

Reduction in tree condition as depth to structural roots increases

Depth to lateral roots and stem girdling roots (SGR's) reduces sugar maple tree condition

y = -0.2333x + 10.322
R² = 0.0728

Sudden failure w/ red maple (Acer rubrum), SGR induced.

Stem girdling roots and tree loss

- Tree decline and death 82% of time
- Sudden failure of tree 18% of time

What practitioners said in 1997 survey

Tree literate spacing

Avoid sidewalk conflict with root/trunk collar
> 4 ft if possible
Street Tree Construction Study

Table 3. Percentage survival of trees subjected to construction or no construction (control) since 1989 and after implementation of construction damage minimization program.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>168</td>
<td>136</td>
<td>81.0</td>
<td>77.3</td>
</tr>
<tr>
<td>Control</td>
<td>502</td>
<td>407</td>
<td>81.1</td>
<td>81.4</td>
</tr>
</tbody>
</table>

Effects of Construction on Survival

Figure 1. Condition rating of street trees subjected to construction damage during street, curb, and sidewalk repair and undamaged control trees. (Bars are Std. Error of Mean)

Street Tree Construction Study

Table 4. Regression model Beta Coefficients relating lawn width, damage, and past tree condition on current tree condition.

<table>
<thead>
<tr>
<th>1989</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lawn Width</td>
<td>0.027</td>
</tr>
<tr>
<td>Construction</td>
<td>-6.045</td>
</tr>
<tr>
<td>Past Tree Condition</td>
<td>0.433</td>
</tr>
</tbody>
</table>

Adj. R Square .19 .043
Significance >0.000   >0.000

Effects of Construction on Condition

How are trees killed during construction?

- Roots: damage and loss
- Soils: physical, chemical, biological
- Hydrology: flooding or drainage changes
- Aboveground: physical, forest structure change

Economics of trenching versus boring (Watson 1995)

<table>
<thead>
<tr>
<th>Factor with tree importance</th>
<th>Trench ($)</th>
<th>Boring ($)</th>
<th>Difference ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base project cost</td>
<td>320,000</td>
<td>320,000</td>
<td>0</td>
</tr>
<tr>
<td>Boring cost</td>
<td>0</td>
<td>32,000</td>
<td>32,000</td>
</tr>
<tr>
<td>Trees mortality</td>
<td>44%</td>
<td>0%</td>
<td>44%</td>
</tr>
<tr>
<td>Trees removed &amp; replacement costs</td>
<td>29,000</td>
<td>0</td>
<td>-29,000</td>
</tr>
<tr>
<td>Actual direct project costs</td>
<td>349,000</td>
<td>352,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Values of trees lost</td>
<td>137,000</td>
<td>0</td>
<td>-137,000</td>
</tr>
<tr>
<td>Total savings from trenching</td>
<td>$134,000</td>
<td>- $134,000</td>
<td></td>
</tr>
</tbody>
</table>

$134,000 saved from boring, assumes trees have value
"We only drove over it a few times, besides, it is an elm and it can handle it"

Not all Construction Kills Trees

Most trees recover one-sided root loss

Two-sided root loss: dieback, deadwood, instability

Three-sided or more root damage: greater dieback,

Root Problems: Four Sided Damage

Give and Take, What Needs do Contractors Have?
What Needs do Tree Roots Have?