AT THE ROOT OF IT

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Take a look at any tree and you will find yourself doing one of two things: either staring up into the canopy or looking down at the ground. You might readily see what you are looking for in the canopy, but when you look at the ground, chances are your brow will furrow, you'll look this way and that, you'll contemplate, maybe poke the ground with a stick or pull a soil sample. Watch any tree expert inspecting the root zone and you will see that look: surmising what is going on below ground, looking for clues.

Some of us have always felt the root system is the most important part of the tree—the key to health and longevity. Yet, roots have always been difficult to study. New technologies such as air excavation tools and ground-penetrating radar (GPR) are making root inspection easier than in the past, but learning about roots is still a tedious and imperfect process. These tools, especially GPR, are suitable for visualizing larger roots, as thick as your little finger or so. Fine roots are another animal entirely. As one commentary in a prestigious academic journal put it, "the fine roots … are a royal pain to study … to promote sanity, this complex network has often been sampled in ways that fail to relate the structure of the intact system to resource acquisition" (Pregitzer 2002). Even tireless and ambitious graduate students have been felled by the difficulty of studying fine roots.

The fine root system is complex, and its study is still an area of emerging research. The structure, function, birth, and death of fine roots, as well as interactions with symbiotic fungi and other soil biota, are revealing themselves to be more complicated than previously imagined.

Those in the tree care profession have additional complications to add to the mix: pavement, utilities, heat, contamination, and other typical impediments of the built environment. "Now where are the roots?" we ask ourselves. The question cannot be avoided if we are to provide the best diagnosis, treatment, and protection for existing trees as well as the best growing conditions for future trees. Through considerable research effort, entire root systems of trees have been excavated and their allometry (relationship between size and shape) described with the data at hand. We have thus been able to make broad statements about root extent, leading to significant changes in how we view and manage the belowground portion of the tree. These statements take form in arboriculture classes and educational publications as rules of thumb: (1) Tree root systems extend out 2–3 times the dripline, (2) most roots are in the top foot (30.5 cm) of soil, (3) roots extend out about 1.5 times the height of the tree, and (4) more than 60 percent of the absorbing root system is beyond the dripline.

Many times we have taken our students out to estimate root location with these techniques—forming circles around trees, watching amazed students ponder the extent of root systems. Are these rules of thumb wrong? No, they were certainly correct for the excavated research trees, and experience tells us they are not far off for many other trees. Yet it is time to take a fresh look at their estimating techniques. Many of these experiments were conducted with forest trees or young nursery trees, predominantly in the eastern United States. Research on mature urban and landscape trees is still very difficult to come by, especially on root systems, but enough new information is available to merit taking another look at tree roots. Recently we took part in a comprehensive review of scientific literature from around the world related to urban and landscape tree roots. There remains a lot we do not know about tree roots, especially urban and landscape trees, but there is more scientific information now than ever before.

Do Roots Really Go Out That Far?

They can and they do. It continues to surprise most of us when we excavate and follow an individual tree root to see how far it goes. But in our analysis of existing research, we uncovered a few concepts that changed the way we look at roots:

Canopy width and tree height aren't very useful for estimating spread of the root system, even on open-grown trees with few or no belowground obstacles. Most studies we analyzed found a consistent relationship for a particular tree species of a particular size and in similar growing conditions—but when different types of trees were grouped together, predicting root spread from canopy width or tree height produced estimates that were equally incorrect among analysis as one might otherwise be correct.

Trunk diameter is a much better predictor of root spread. Trunk diameter is about as good as it gets for estimating root spread of unobstructed trees. For young trees [less than approximately 8 in (20 cm) in diameter], the ratio of root radius to trunk diameter in the documented studies was about 38 to 1. That is to say, a 6 in (15 cm) diameter tree can have a root system that extends nearly 6 m, or 19.7 ft out from the trunk (about 19 ft per 6 in). There were not enough data to determine the relationship for conifers. Furthermore, the trunk diameter of palms does not increase with age or size, so this relationship cannot be applied to palms.

This relationship probably changes for older trees. First the caveats: there are a lot less data on large and mature trees for obvious reasons—and there are instances of roots extending great distances (but unfortunately the researchers who excavated them didn't record how big the tree was—data collection is not yet standardized in this arena). Nonetheless, existing studies of more mature trees suggest that root spread levels off to some extent as trees age. Thus, a tree with a 90 cm (35 in) diameter will probably have only a marginally larger root system than a tree that is 30 cm in diameter; the root system certainly won't be three times as large. In general, older trees spend a greater proportion of their resources on maintenance of tissue and less on growth. Studies have shown that older trees put more resources into the metabolically costly production of fine absorbing roots and fewer into large structural roots. This makes sense according to some current theories of plant allometry (e.g., West et al. 1999), which predicate the maximization of surface area (which determines resource uptake) and the minimization of the distance resources have to be transported.

Roads, sidewalks, and other surfaces can restrict root extension. Admittedly, there are just a handful of studies where adventurous root investigators have excavated tree roots under pavement. However, these indicate roots generally don't extend very far under intact pavement, and sometimes taper off in as little as 4 in (10 cm). In irrigated sites, root extent is sometimes confined to soil areas receiving irrigation. Other management practices, such as mulch, may also influence root spread, but such effects are not documented.

Root systems are not uniformly distributed around a tree. When entire root systems are excavated and mapped, the irregularity of root distribution can be quite striking. In addition, roots can proliferate in pockets where water and nutrients are plentiful (such as near a leaky sewer line). From our vantage point above ground, we often cannot see changes in water tables or soil that might influence root distribution. However, root extent does tend to be greater on the uphill side of trees planted on a slope, or in the case of a leaning tree, on the side away from the lean.

These findings largely affirm current practices in tree root zone protection. For example, the guideline for tree protection zones (TPZs) described by Harris, Clark, and Matheny in their text *Arboriculture: Integrated Management of Trees, Shrubs, and Vines* (2004), is based on trunk diameter. Applying this metric to the growth patterns described above, larger trees will have more of the root system protected than smaller trees. This is exactly what we want in most cases because young, high-vitality trees can withstand considerably more injury than mature trees. Tree stature varies considerably of course. Consider that a mature flowering dogwood (*Cornus florida*) may have approximately the same trunk diameter as a young, rapidly growing elm (*Ulmus* spp.). Our TPZ metrics partly account for this by using higher ratio of TPZ radius to trunk diameter for more mature trees.

What About Root Depth?

Tree roots seem to be able to grow everywhere. There are documented instances of roots penetrating cracks in rock 100 microns wide (that's one-tenth of a millimeter). They grow into sewers, buildings, basements, and even through large expanses of open air space. But somehow they rarely grow through compacted urban soils. There are exceptions though. For example, some tree species can elongate roots through compacted soil when it is softened by moisture. Also, some coarse-textured soils are less compactable than fine-textured clays, and roots may penetrate more deeply (Figure 1). Some considerations when estimating rooting depth:

Figure 1. Root depth varies by site. At the construction site pictured here (University of Costa Rica; San José, Costa Rica), nearby trees root systems can be seen to penetrate several meters deep.

There are many barriers to deep roots. Root depth is restricted by pavement, dense rock layers, compacted soil layers, and poor drainage—all common in urban sites (Figure 2). In addition, propagation techniques, nursery production, and transplanting may influence root depth. Adventitiously formed roots are more likely to grow outwards than down, but that is not always the case (Figure 3).

Species matters, but common urban tree species can grow deep roots. Root depth is species dependent, but common urban tree species such as hackberry (*Celtis occidentalis*) can grow very deep root systems if soil conditions permit. Roots for hackberry have been documented to reach a depth of 7 m, or 23 ft.

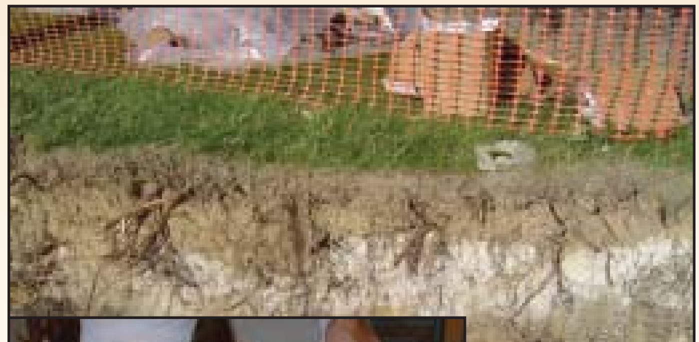

Figure 2. Root depth can be influenced by localized soil changes. ▲ (a) A layer of dense mineral material, likely an artifact of previous construction, has confined roots of this black maple (*Acer nigrum*) very close to the surface. ◄ (b) These loblolly pine (*Pinus taeda*) roots encountered a shallow water table and abruptly changed direction.

What Else Can Roots Do?

We know roots supply water and nutrients to the tree and serve a host of other physiological functions, but roots have some other tricks up their sleeves. For example, fine roots turn over quickly, meaning roots die and new ones grow on a weekly and even daily basis. Roots push their way through the soil as well. Together this means tree roots build soil structure, creating tunnels and macropores as they elongate through the soil and deposit organic matter as they die. Roots can improve drainage too, not only through improving soil structure, but the tunnels created by live and dead roots allow water to move through the soil belowground. With current interest in distributed stormwater management and bioretention systems, these characteristics of tree root systems become very important. Root systems may also develop special features to aid in mechanical stability of the tree. Buttress roots, for example, distribute mechanical stress for the tree. Pronounced buttress roots are most common on tropical trees and are sometimes associated with shallow soils (Figure 4). Tree roots can also play a role in remediation of contaminated soils, stormwater

Figure 3. The roots of this tap-rooted species grew deep, despite heavy clay soils. These clonal loblolly pine (*Pinus taeda*) were grown from rooted cuttings and planted in the Piedmont region of the southeastern United States. John Peterson of Virginia Tech's Forest Resources & Environmental Conservation department indicates the original soil surface with his right hand. Note the lateral roots have been removed, but the cut ends are beyond the photo's lower frame.

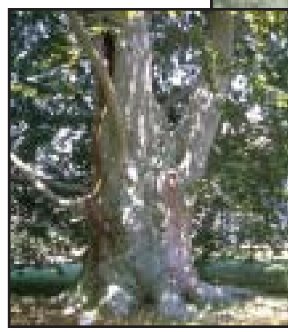

Figure 4. Buttress roots play a role in distributing mechanical stresses. ► (a) This kapok tree (*Ceiba pentandra*) growing in a frequently flooded zone in the Virgin Islands (U.S.). Kapok is known for its pronounced buttress roots, but they may be more well developed in wet areas or areas with shallow soils. ► (b) In temperate climates, buttress roots tend to be less pronounced as illustrated by this European beech tree (*Fagus sylvatica*) in South Dartmouth, Massachusetts, U.S.

filtration, carbon sequestration, and other ecosystem services. This is impressive when you think that we are not even considering the benefits we gain from the canopies supported by all of these roots!

Our society is becoming more urbanized, and trees will play a critical role in the sustainability and quality of life in these environments. To integrate trees into sustainable cities, we must understand how and where tree roots grow. We must also understand how to manage tree roots to ensure safe, healthy trees, and to minimize conflicts with the built environment. How we can manage roots to benefit trees and ourselves is the topic of the next ISA literature review.

Literature Cited

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Susan D. Day and P. Eric Wiseman are both faculty in the urban forestry program at the University of Virginia Tech's Department of Forest Resources and Environmental Conservation. With co-authors S.B. Dickinson and J.R. Harris they have recently completed an in-depth review of root development and physiology in urban trees for publication in Arboriculture & Urban Forestry. The full article can be viewed online (auf.isa-arbor.com).

A complete "Roots Bibliography" will be posted on the research portal at the ISA website in early 2010.

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Photos courtesy of Susan D. Day, James Roger Harris (Figure 4b), and P. Eric Wiseman (Figure 2a).