Fifteen years of urban tree planting and establishment research

Abstract

Over 200 research papers related to urban tree planting and establishment have been published since 1997. Major topics include causes of deep root systems, load-bearing soils, estimation of root space requirements, installation of root paths, use of pervious pavements, prevention of root defects in containers, a new bare root transplanting method, use of soil applied growth stimulators at planting, effectiveness of support systems, effects of mulch on soil biology, and new perspectives on tree selection. Published research is summarized and an extensive list of citations is included.

Keywords:

container, load-bearing soil, mulch, mycorrhizae, root depth, stake

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Introduction

The last thorough review of the scientific literature pertaining to planting urban trees was over a decade ago (Watson and Himelick, 1997). There have been over 200 research papers published since then. Research in some areas, such as structural soils, was just beginning and has expanded. On some subjects work has continued at a substantial pace with new questions emerging and many questions still unresolved. An example of this would be container designs to prevent root defects. Yet other areas are being revisited with a new perspective, such as mulching with a focus on soil biology. Can all of this research help us to do a better job planting trees and in turn enhance post-planting survival?

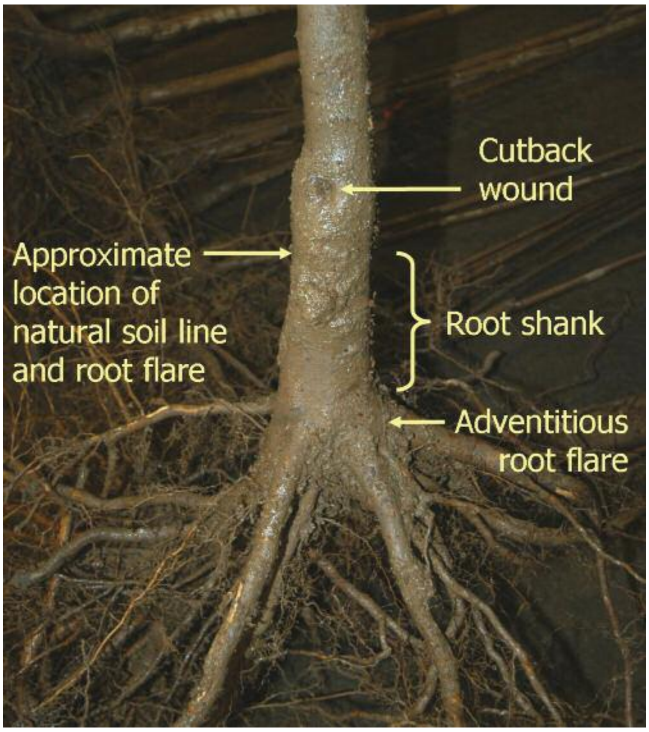
Areas of expanded research

Causes of deep root systems

Deep root systems have been recognized as a problem of urban trees since at least the 1980s (Berrang *et al.*, 1985), but the extent and causes of the problem were not understood. Studies show that up to two thirds of the uppermost structural roots of street and park trees were more than 7.5 cm below the soil surface (Watson and Hewitt, 2006). Nursery practices were first blamed for deep root systems without supporting data (Berrang *et al.*, 1985). More recently, research has shown that the uppermost roots can average 7.5–10 cm below the soil surface in the nursery fields, and in harvested root balls (Watson and Hewitt, 2006; Rathjens *et al.*, 2007). The average depth may not be alarming in itself, but a substantial number of individual trees may have roots that are much deeper to achieve this average.

Nursery production practices can contribute to deep root systems. Root pruning seedlings produces adventitious roots at the cut end of the primary root that grow rapidly. Many of the small natural lateral roots above the regenerated roots may be lost. Honeylocust (*Gleditzia triacanthos*), sugar maple (*Acer saccharum*) and callery pear (*Pyrus calleryana*) can lose up to 60% of these lateral roots when transplanted as one-year-old seedlings (Hewitt and Watson, 2009). The vigorously growing adventitious roots produced at the cut end, combined with the loss of natural laterals, has the potential to develop an 'adventitious root flare' deeper in the soil than the natural root flare. The depth of the adventitious root flare is determined by the length of the primary root after pruning (Figure 1). Even if the tree is planted at the original depth and the graft union is visible above ground, the adventitious root flare can be 30 cm or more below the soil surface.

Figure 1 Vigorously growing adventitious roots regenerated after the primary root is pruned during production, combined with the loss of natural laterals, results in the formation of an 'adventitious root flare' deeper in the soil than the natural root flare. The depth of the adventitious root flare is determined by the length of the primary root after pruning (root shank).



Trees can be deliberately planted too deep in the field nursery in order to hide the graft union, reduce sprouting from the root stock, and protect the graft area from herbicides. When trees are planted with the graft below the soil, this increases root depth by an additional 5–10 cm. Soil accumulated around the base of the trunk accidentally from cultivation, or deliberately to deter weed seed germination, can increase root depth even more if not removed before harvesting. Though these trees with deep root systems can grow well in the high quality soil of the nursery, they may struggle to survive when harvested with the uppermost roots deep in the root ball and planted on difficult urban sites with heavy soils and poor drainage (Day and Harris, 2008).

Structural roots can be too deep in containers as well. Vigour can be reduced (Bryan *et al.*, 2010; Harris and Day, 2010). A dense mat of small roots can fill the soil above the woody roots that form the root flare and defects can be increased as roots are deflected up and back across the upper portion of the root ball (Fare, 2006; Gilman and Harchick, 2008). This can prevent planting the woody roots at the correct depth without removing a substantial portion of the roots in the root ball.

This concern over deep roots and root defects in the root ball has led to a practice of removing the soil or substrate from traditional root ball and container stock before planting bare root. The primary reason for it is to be able to see and correct root defects. This bare rooting process may limit the planting season compared to the original root ball stock, but both experience and research are limited at this point (Appleton and Flott, 2009).

Load-bearing soils

Prior to the development of load-bearing (a.k.a. skeletal or structural) soils, the only option to provide root space under pavements was very expensive vaulted systems that suspend pavements above the soil in order to prevent compaction of the soil. Load-bearing soil must provide a favourable environment for root growth while also supporting the pavement. The first load-bearing soil was Amsterdam Tree Soil (Couenberg, 1993).

Amsterdam Tree Soil is a coarse sand mix carefully compacted to a specific density with aeration provided through spaces in the pavers placed over the soil. This system has been shown to be effective in providing vigorous trees and stable pavements for many years. More recently, other load-bearing soils types have been developed. Most load-bearing soils use stones to create a network of interconnected spaces that are filled with soil for root growth. Systems developed in Europe are often created on site by first putting down gap graded stone of preferred size, and then working the loam soil into the spaces between the stones with a mechanical vibrator. In the United States, pre-mixed soil is often transported to the installation site.

Early tests of load-bearing soil mixes in containers showed that stone-soil mixes could support better root and top growth than compacted soils or road base materials (Kristoffersen, 1999). The root-crown ratio was greater in stone mixes than topsoil alone (same soil volume), indicating a larger root system was needed for absorption of water and nutrients when the soil was diluted in the mix (Kristoffersen, 1999). Above-ground growth was limited by net soil volume rather than the total volume of the stone-soil mix (Loh *et al.*, 2003).

When mixed and installed properly, stone-soil mix compacted to 1.85g/cm^3, and greater, did not did not reduce macropores or restrict root penetration in the soil between the stones (Grabosky and Bassuk, 1996; Grabosky *et al.*, 2009). A stone-soil mix can hold 7–11% moisture by volume (similar to a loamy sand) with high infiltration, good drainage and aeration (Grabosky *et al.*, 2009).

In field studies at three and ten years after installation, growth (diameter breast height, height, canopy width) of trees growing in load-bearing soil and a nearby tree lawn was similar (Grabosky *et al.*, 2002; Grabosky and Bassuk, 2008). Contrary to this, other reports show that trees in non-compacted soils in open planters (Bühler *et al*., 2007) or covered by suspended pavement (Smiley *et al*., 2006), out-perform all structural soil mixes. Stone-soil mixes can be a useful compromise in situations where high quality non-compacted soils cannot be used, but will likely not support tree growth as well over time as the same volume of quality soil.

Trees were more stable in load-bearing soils than traditional tree pits due to greater root length in gravel-based skeletal soil (Bartens *et al*., 2010). This is supported by a computer model in which a 20% soil/80% granite chip mix was optimum for withstanding wind forces required to uproot trees (Rahardjo *et al*., 2009). Load-bearing soils can also provide stormwater storage (Day and Dickinson, 2008).

Root paths

Root paths are narrow trenches installed in a compacted subgrade under pavement to provide a path for roots to grow from restricted planting pits to open spaces on the other side of the pavement. Commercially available strip drain material is usually installed in the trench and then backfilled with loam soil (Costello and Jones, 2003; Urban 2008). Paths can also connect individual planting pits to gain some of the benefits of a shared root space. This technique holds promise, but there is not yet any research available to support it.

Pervious pavements

It has been suggested that pervious pavements would improve the soil environment beneath pavements for better tree growth, but research has not yet shown this to be consistently true. Soil oxygen was insufficient for root growth (<12%) for prolonged periods beneath two of five pervious paving products tested on park footpaths (Couenberg, 2009). There were no differences in soil oxygen and moisture between impervious and pervious pavements and no difference in tree growth rates, leaf water potential or gas exchange (Morgenroth and Buchan, 2009; Volder *et al*., 2009). The latter two studies were conducted on research plots with pavement less than 1.5 m wide and water and oxygen may have been able to diffuse under the pavement from the edges just as easily as through the pores. If soils are compacted under the non-porous pavements, the resulting poor soil aeration and penetration resistance itself are likely to be factors limiting root growth rather than the pavement type.

Areas of continued research

Container design

Many root problems in the landscape can be traced back to nursery containers. Because the natural spread of the root system is restricted by the container, lateral roots reaching the sides are redirected. There may be no difference in tree growth during nursery production or in the initial years after planting in the landscape (Gilman *et al*., 2003, 2010a), and so the problem can go undetected until it is too late to correct it.

Circling roots were first to be recognized as a problem. Circling roots can strangle the plant several years after planting as both the roots and the stem grow larger, especially if they are located on the top half of the root ball. Various pot designs with ridges and openings were developed to minimize circling roots as early as the 1980s (Appleton, 1993). Tests of numerous container designs have shown that they can reduce the number of circling roots, but ascending, descending or kinked roots can still develop (Marshall and Gilman, 1998; Gilman *et al*., 2009; Amoroso *et al*., 2010; Gilman *et al*., 2010a).

Root defects caused by container walls persist after repotting or transplanting unless pruned (Zahreddine *et al*., 2004), and therefore many defects are hidden from view because they are found below the substrate surface (Gilman *et al*., 2010b). Multiple layers of circling roots that develop within the root ball from successive stages of production can be difficult to detect and impossible to correct.

Vertically slicing the root ball edges reduces circling roots, but not descending roots or interior layers of circling roots (Gilman *et al*., 2009). Descending roots do not stabilize the tree as well as the normal horizontal radially-oriented roots. Trees from containers had one quarter the root cross sectional surface area into landscape soil compared to field-grown trees, further reducing stability (Gilman and Masters, 2010). Root ball shaving to remove all roots on the surface of the root ball can eliminate the descending roots and produce a more normal root system with many radially-oriented roots (Gilman *et al*., 2010).

Growth stimulators

Many compounds have been marketed as biostimulants to be applied to the soil at planting. Contents of these may include growth hormones, nutrients, vitamins, sugars, amino acids, humic acids, extracts of plants, and beneficial rhizosphere fungi and bacteria.

Application of organic products, such as humates and plant extracts, at planting have shown only limited benefit to root or shoot growth of trees. Species vary widely in their response (Kelting *et al*., 1998a, 1998b; Ferrini and Nicese, 2002; Fraser and Percival 2003; Gilman, 2004; Sammons and Struve, 2004).

Sugars have been tested as a post-planting treatment to increase growth and establishment of trees. In most studies, the sugar was applied to the soil two or more times. Some sugars can increase root and shoot dry weight, and increase root-shoot ratio. Results are promising but inconsistent among species, sugars and application rates included in the limited trials (Percival, 2004, Percival and Fraser, 2005, Percival and Barnes, 2007, Martinez-Trinidad *et al*., 2009). It is not clear whether the soil-applied sugar increases beneficial rhizosphere organisms or is used directly by the tree.

Paclobutrazol, a growth regulator used primarily to reduce shoot growth on trees, can also increase root growth under certain circumstances. Paclobutrazol applied at planting doubled root growth on black maple (*Acer nigrum*) in the first season, but not the second. The lack of root response in the second season may be related to overall growth rate of the tree. The growth regulating effects of the spring-applied paclobutrazol were delayed until the second season, when shoot extension and leaf size were only 5 and 30% of control trees, respectively. This strong above-ground growth reduction likely caused the lack of root response in the second season. Growth of green ash (*Fraxinus pennsylvanica*) roots was unaffected by paclobutrazol treatment in either year (Watson, 2004). Gilman (2004) reported that paclobutrazol slowed top growth but did not affect root growth of transplanted live oaks (*Quercus virginiana*).

The benefits of mycorrhizal associations of tree roots are well known. Inoculations with mycorrhizal fungi have proven beneficial to trees when planted in soils lacking the appropriate fungi, such as strip mine reclamation sites. Urban planting sites can be of very poor quality, but they do not always lack appropriate mycorrhizal fungi for trees.

Mycorrhizal colonization of littleleaf linden (*Tilia cordata*) street trees and forest trees were similar (Timonen and Kauppinen, 2008). Mycorrhizal inoculum present in urban soils was greater than in forest soil (Wiseman and Wells, 2005). Growth rate has generally been unaffected when trees are treated with commercial inoculants at planting (Gilman, 2001; Ferrini and Nicese, 2002; Abbey and Rathier, 2005; Corkidi *et al*., 2005; Wiseman and Wells, 2009). Colonization can increase after planting without inoculation (Wiseman and Wells, 2009). The quality of the inoculum may be a factor. Mycorrhizal colonization of roots rarely exceeded 5% after treatment with commercial inoculants, but roots were up to 74% colonized when treated with lab-cultured inoculant (Wiseman *et al*., 2009).

Support systems

The need to stake newly planted trees and methods of staking continue to be researched. Unstaked field-grown trees transplanted with soil balls remained upright in ambient wind conditions and were tolerant of moderate to heavy simulated wind loads in pulling tests seven months after planting (Alvey *et al*., 2009). Bare root and container-grown trees may require support until lateral or anchor roots develop, but seldom more than one year (Eckstein and Gilman, 2008).

Two stakes with separate flexible ties are commonly used but provided inadequate support when tested (Eckstein and Gilman, 2008). The depth to which the stakes are driven into the ground is a factor in the strength of the two-stake system. Three stakes may provide better support (Alvey *et al*., 2009). Three-point guying systems and root ball stabilization systems that have structure or straps over the root ball (Figure 2) and are anchored into the soil at the bottom of the planting hole provide the best support. (Eckstein and Gilman, 2008; Alvey *et al*., 2009).

Figure 2 Research shows that root ball stabilization systems that have structure or straps over the root ball provide the best support. Some systems have straps over the root ball that are anchored into the soil at the bottom of the planting hole instead of stakes (Eckstein and Gilman, 2008).

Soil balls need to be supported during handling and transport. Traditional burlap and twine are sometimes chemically treated to slow degradation. These treated materials can still be intact and very strong after two years, and starting to girdle roots (Kuhns, 1997). Wire baskets are often used in place of twine. Gauge of the metal used varies and little formal research has been done on the speed at which the wire rusts away. Thicker gauge wire baskets have been observed to still be minimally rusted after 25 years (Watson and Himelick, 1997)

New perspectives on traditional topics

Mulch

Research on the use of mulch has been reported for decades and the basic benefits are well established and still being reinforced. Mulch can increase growth and establishment of newly planted trees (Cogger *et al*., 2008; Ferrini *et al*., 2008; Arnold and McDonald, 2009; Percival *et al*., 2009). Mulch did not improve establishment of North American desert plants (Singer and Martin, 2009).

Growth increases are likely due to increased moisture availability due to reduced evaporation from the soil surface. However, when rainfall or irrigation is light, the mulch can reduce the amount of moisture reaching the root ball (Gilman and Grabosky, 2004; Arnold *et al*., 2005).

Most trees benefit from complex fungal dominated soil microflora, such as is developed under the litter layer in established woodlands over long periods of time. Disturbed urban soils, where trees are often planted, are often bacteria dominated and are more typical of grassland plant communities. Optimum tree health is dependent on re-establishment of fungal dominated soil biology. Application of mulch can enhance successional processes by which soil biology becomes progressively more complex, the ratio of fungi to bacteria increases, and tree growth increases (Soil and Water Conservation Society, 2000).

Bare root transplanting

The traditional method of bare root transplanting has been mostly replaced over time by root ball stock because the planting season is more extended. The Missouri gravel bed system produces large fibrous root systems and allows bare root stock to be planted throughout the growing season. Bare root trees are heeled in a bed of 6.4 mm screened pea gravel mixed with 10% (by weight) masonry sand (Starbuck *et al*., 2005) or 40% calcined clay for greatly increased water holding capacity (Bohnert *et al*., 2008). Contractors are once again transplanting large trees bare root as they were before heavy equipment was available to move large, heavy root balls. Pneumatic excavation tools have made excavation of the root systems easier. Trees up to 66 cm dbh have been moved successfully according to anecdotal reports, but there is no published research on transplant survival and establishment rates.

Tree selection

Diversity is often lacking in urban landscapes. It is not unusual to have large numbers of popular species planted in cities. In Hong Kong, the top ten dominant species are 55.7% of the population, and *Aleurites moluccana* constitutes 12.9% of the tree population (Jim, 1997). In Chicago, the ten most common species account for 45.7% of the urban trees (Nowak *et al*., 2010). In Nordic cities, 30–90% of all trees planted are a single species (Sæbø *et al*., 2003). In other European cities, only 3–5 genera usually accounted for 50–70% of all street trees planted (Pauleit *et al*., 2002).

Though a few popular species are often overplanted, many urban areas are actually repositories for a wide range of diverse plant materials. Many cities may have upwards of 100 or more tree species planted on the streets. In milder climates, some cities have a greater number of diverse species (Bassuk, 1990; Jim, 1997). Unfortunately, most of the species are planted in very small numbers. In California, most municipal arborists indicated that species diversity was an objective of managing tree selection, but less than half actually included this in their management plans. Approved species on planting lists were much narrower than the species variety in the current inventory (Muller and Bornstein, 2010).

Concern over invasive species is growing. Invasive plants are those introduced species that can thrive in areas beyond their natural range of dispersal, are adaptable, are aggressive, and have a high reproductive capacity. Their vigour, combined with few serious disease or insect pests, often lead to outbreak populations that can dominate natural plant communities. Many municipal planting lists include some moderately invasive species. Many invasive species have characteristics that would make them the kind of 'hardy or tough trees' needed on some urban sites. Protecting against invasive species was, however, not a concern of most arborists in California (Muller and Bornstein, 2010).

Climate change may affect urban trees through rising average temperatures and changes in the amount and seasonal distribution of precipitation. Though the effects will differ somewhat from region to region, lengthening of growing seasons and changes in the range and distribution of plants are expected. Trees will be affected not only by overall temperature increases, but also by extended periods of extreme heat and cold temperatures and by frequency and severity of storm events.

Changes in plant hardiness zones have already been documented in the United States (Arbor Day Foundation, 2006). Average minimum temperatures have increased by one zone (5°C) in many areas. To some extent, less hardy plants can be used further north than in the past. However, change is slow and a single extreme cold weather event can damage or kill trees after they have been growing successfully for many years. Incorporating climate change into planting programmes can be challenging. Trees in urban areas are not as long lived as their counterparts in the natural forest. The need to consider climate change in tree selection may vary by land use. Mortality rates of trees in developed areas vary by land use (Nowak *et al*., 2004). The average life expectancy of trees planted in commercial and industrial areas may be as little as ten years, while trees may live nearly 50 to 75 years in low density residential areas.

Root space requirements

Tree root space requirements have been recommended at 0.03–0.06 m^3 of soil for each 1–2 m^2 of crown projection area of the expected mature size of the tree if above- and below-ground environmental extremes are not severe (Kopinga, 1985; Lindsey and Bassuk, 1991; Urban, 1992). More recently, a computer model has been developed that uses climatological data to estimate the soil volume necessary to provide moisture during the driest growing conditions likely to be encountered for an area. The example used is New York City where a 6 m crown diameter tree (28 m^2 crown projection area) with 17 m^3 of soil as recommended by Lindsey and Bassuk (1991), and without irrigation, would face a water deficit every other year (Figure 3). With 27.4 m^3 of soil, the tree would face a deficit only once in 10 years, but with only 4.3 m^3 of root space soil, the tree would need irrigation every fifth day to face a deficit only once in 10 years (DeGaetano, 2000). Using a different method, Blunt (2008) calculated that under British weather conditions a mature tree (size and species not specified) would require at least 50 m^3 of high quality soil with soil moisture recharged by rainfall or irrigation ten times during the growing season.

Figure 3 Each tree in a shared planting space of this size could have a crown diameter of no more than 4 m or be subject to annual drought stress without supplemental irrigation according to a computer model (DeGaetano, 2000).

Incorporation of research into practice

The true test of the value of this research is whether it is used. Individual practitioners are often eager to adopt new practices. Sometimes the slowness at which information is incorporated into national standards and best management practices can be a limiting factor. Standard revisions do not occur frequently, and the most recent research may not be included for years until after it is accepted widely. The BS 4043 Recommendations for Transplanting Root-balled Trees was last revised in 1989. The American Standard for Nursery Stock was last updated in 2004. Revisions of both of these standards are underway. Florida Grades and Standards for Nursery Stock is one of the most comprehensive grading systems published. It was written in 1998 with a minor update released in 2005. The ANSI A300 (Part 6) American National Standard for Tree Care Operations – Transplanting was published in 2005. Most of these publications are years in preparation before the publication date.

Professional associations may be able to incorporate new research more quickly into best management practices, but even those are revised infrequently despite good intentions (Watson and Himelick, 2005). There is also danger that revising practices based on limited new research will not stand the test of time. Changes in practice should be based on sound peer-reviewed research confirmed by multiple studies.

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