The Landscape Below Ground III Researcher Summit White Paper

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Following the conference presentations, a researcher summit was held at the Morton Arboretum to assess the current state of root and soil research and identify future research needs. Seven distinct subgroups were identified within the broader topic of urban soils and root systems. They include: Nursery Production and Planting; Structural Root Depth; Construction and Infrastructure; Tree Stability; Root Growth and Development; Soils (physical, chemical, and biological properties); and Soils Management and Root Responses. Overall research priorities developed were distributed across all seven of these areas (see *Top 10 Research Priorities*, page 391). Throughout each of these subgroups, several overarching themes emerged. They include a need for more collaboration, the establishment of long-term studies, translation of existing research into many languages, and a greater understanding of the complexity of the many issues that span all segments of the green industry. To maximize the impact of root and soil research on the industry, results and conclusions must be synthesized and distributed in a means suitable for the intended audience. The list of potential audiences include city officials, consumers, tree care and other green industry professionals, urban planners, civil engineers, and landscape architects. Educating consumers and industry groups that professionalism and quality have value is a key step in promoting tree health.

Introduction

Through the research and education efforts of universities, government entities, and private and non-profit organizations, many in the general public are now aware of the environmental, economic, and social benefits associated with urban trees. This, coupled with findings on the effects of climate change, has prompted many municipalities to invest more heavily in urban forest planting and management programs. Large-scale planting initiatives are underway around the world, with million-tree initiatives in New York, Denver, and Los Angeles, and a five-million-tree program in Sacramento. Mexico City has announced a plan to plant an astounding 1 billion trees over a four-year period.

Despite these noble intentions, planting trees *en masse* in urban environments may not generate the benefits desired if their belowground health is compromised by limiting soil conditions or poor root management. For example, carbon sequestration, a common consideration given the current climate change debate, is closely related to tree growth rates (Nowak et al. 2002). Other benefits such as shading, particulate filtration, rain interception, and a tree's appraised value are all greatly influenced by tree size. If property owners and municipalities are to reap the greatest return on their invested time and labor, the belowground health of trees must be addressed.

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What soil and root management practices are needed to promote urban tree health and stability? What nursery production and planting practices limit the effects of initial transplant stress, while also reducing long-term root and lower trunk defects? How do urban tree root systems and soils vary from those found in more natural system and what are the potential consequences of these difference?

While urban root and soil research continues to advance, there are still many questions left unanswered. The Landscape Below Ground III conference, held October 6–8 at the Morton Arboretum in Lisle, Illinois, served to bring researchers and practitioners together to share recent discoveries and prioritize future research efforts.

Following the conference presentations, a one-day researcher summit was held at the Morton Arboretum's Thornhill Education Center in Lisle, Illinois. This summit provided the researchers who presented earlier in the week a forum to interact and discuss future research needs. Facilitated by the United States Forest Services's Lisa Burban, the summit served as an assessment of the current state of root and soil literature, key research players, and major deficiencies within the field.

At the start of the summit, Dr. Susan Day reported on the International Society of Arboriculture (ISA) Science and Research Committee (SRC) root growth and development literature review. She noted a lack of information regarding root architecture at the species level in urban environments. What information she did find was mostly qualitative in nature. Dr. Day noted that root growth and development was documented more thoroughly in traditional forestry journals; however, the research focused on trees in natural systems that are not easily replicated in the urban landscape. She also noted that while there was a greater volume of growth and development studies in the silvicultural literature, the information is still largely region and species specific. Also, the majority of the research she collected tended to investigate northern temperate tree species. The results of these works may have somewhat limited applicability when dealing with tropical and subtropical systems.

After Dr. Day's presentation, summit attendees devoted the rest of the day to assessing the current state of root and soil science. This information was used to develop a list or research priorities. To help focus discussions, attendees divided themselves into one of seven groups:

- Nursery Production and Planting
- Structural Root Depth
- Construction and Infrastructure
- Tree Stability
- Root Growth and Development
- Soils (physical, chemical, and biological properties, etc.)
- Soils Management and Root Responses (mulch, fertilization, amendments, etc

Once divided, each group considered the following questions:

1. What are the three to five most significant findings in your group's area of research?
2. Who are the key players in your group's area of research?
3. What are the three to five biggest research questions left unanswered (or not even asked) for your group's area of research?

Ultimately, the first two questions were included to guide the prioritization of research needs and are not discussed in great detail within this paper. The final research priorities and discussions surrounding these future endeavors within each of the seven topic groups are included below.

Nursery Production and Planting

Growers interested in producing quality root systems have often been driven by developing a market advantage. They have both striven to produce what is perceived as a good root system,

and also helped to shape market perception by promoting what they believe to be a good root system. Exactly what constitutes a good root system has not always been well understood. A large mass of fine roots has generally been considered ideal. There has been little focus on woody root structure beyond concerns of obvious problems such as circling roots in containers.

Recently, research and practical experience has begun to show how nursery production practices can alter structural roots permanently. These changes often occur as very small plants. Circling roots have been recognized as a problem for many years, and new container designs have been developed to minimize them. Roots growing vertically down inside the container (diving roots), sometimes caused by these new container designs, are now being associated with lack of stability after planting and establishment. Vertical roots growing toward the surface can grow back toward the stem and eventually girdle. Root pruning young, field grown trees can lead to the loss of the natural root flare and replacement with an adventitious root flare a few to many inches deeper. Such trees may fail on poor quality urban soils. Evidence of these problems often does not surface until years after planting in the landscape. Little research has been done on the long term effects.

Researchers and growers will have to continue to work together to identify root quality issues and to solve them. Modified production methods may have to be developed in order to grow quality tree root systems while still making production practical. Container designs are continually developed specifically to produce better root systems. Practices such as removing the outer portion of the container root ball (shaving) each time a plant is moved to a larger container or planted in the landscape are being researched. Preventing or correcting root defects in containers from containers was considered one of the top three research needs. Field growers are testing ways to position the adventitious root flare within a few inches of the soil surface.

Top 10 Research Priorities

1. Can we characterize the inherent root growth and development patterns for different species?
2. What are effective remediation methods for deeply planted, established trees? (*Tied for 2nd*)
3. How do we correct or prevent root defects in containers? (*Tied for 2nd*)
4. What are the characteristics of mulch that give it its beneficial properties?
5. Can we develop an effective root detection system?
6. What tools are needed for tree stability diagnostics? What guidelines for assessment are needed? Is a qualitative or a quantitative approach best? (*Tied for 6th*)
7. What rooting conditions are present in structural soil installations and how long do these conditions last? (*Tied for 6th*)
8. How do soil-water relationships influence tree growth and survival? (*Tied for 8th*)
9. Where do we position the root system at the time of planting? (*Tied for 8th*)
10. How does soil biology influence tree growth and survival?

Nursery production methods are changing as mechanization and technology improve. Change is most often driven by business concerns (economy, productivity, etc.) How are these changes affecting the horticulture? Have mechanization and the use of new materials in the nursery industry led to an increase in root defects? Use of container-grown plants has increased because benefits in production and handling, but can we produce a better root system than old-fashioned bare root? Do we know enough about how different species react to the various production methods in use?

While it is important to recognize root defects, it is also critical that common criteria for a quality root system be developed and accepted industry-wide. To accomplish this we need to understand what aspects of root quality may be critical to long-term performance of trees in the

landscape. Is a nursery produced root system that has been pruned and altered more suitable for landscapes in the long run than a root system from nature?

Standards for root systems may be needed. Such a system could be multi-tiered grading system. Reliably grading individual could pose significant challenges since only roots of bare root stock can be seen to evaluate them.

A certification system for growers may be more practical. Once the criteria for a quality root system have been developed along with appropriate production methods for attaining it, growers could be certified so customers could have confidence that the tree they are buying is of high quality.

Production of quality trees is important, but how and where those trees are planted is just as critical. Where to position the root system at the time of planting has long been a question. Until recently it has been mostly a question of how high to plant in order to minimize problems of poor drainage and aeration for root systems, especially on more sensitive species. More recently, there is increased uncertainty over just how much adjustment can be made for root systems that are too deep in the root ball without exposing sensitive tissue by removing soil over the roots. As we stand to lose our 'tough trees' to invasive pests, the most important concern may be how we can improve planting sites to accommodate a wider palette of tree species.

Structural Root Depth

Structural root depth is a complex problem that crosses several segments of the green industry. An industry-wide effort of research and practice will be needed to find solutions.

In the last 6–8 years, there has been a concerted effort to understand the extent and severity of the problem of deep root systems of landscape trees. The number of trees with deep roots is high – over half of the trees surveyed in some cases. Causes of deep roots can be found throughout the production and planting processes. Nursery practices that can alter root architecture and lead to deeper roots are being studied, and are already being modified by some growers based on the research. Deep planting in the landscape can be prevented through education.

Most of the research on root architecture changes resulting from nursery production has been done on field grown stock. Conditions for root growth in containers are different, and preliminary information from observation and a few research studies indicates that root architecture may be altered less. More natural lateral roots may persist to form a root flare.

Planting trees with the roots at the correct depth sounds easy enough, but is complicated by the location of roots in nursery stock. If the roots in the B&B or container root ball are already too deep when the tree arrives on the planting site, removing the excess soil and exposing the portion of the root shank previously protected from the elements by soil may, under some circumstances, result in injury. It may be related to bark thickness, and the severity of temperature extremes and sun exposure. Injury does not occur frequently, but more research is needed to understand the conditions that make a tree susceptible.

The reduction in survival and growth of trees with deep root systems can be demonstrated in research plots, but is much more difficult to measure in urban plantings due to the many other factors that can also affect tree performance. Trees can grow well in high-quality, well-drained nursery soils, but do not do as well when transplanted to urban soils that are often poorly drained and aerated. Trees more tolerant of these conditions will likely be less affected.

The area most lacking in research-based information was related to effective remediation methods for deeply planted, established trees. It is a complex problem which is not easily remedied. As a tree establishes on a site, the regenerated roots tend to grow towards the surface where aeration and drainage are better, no matter where they originate. Though most of the root system maybe at the correct depth and functioning normally, the portions of the major woody roots near the base of the tree may be substantially deeper and subject to disease and other problems. Little information is available on how a deep "central core" of the root system affects the tree biologically and physiologically. Root crown excavations have a reputation of being effective in practice, but have not yet been supported by research.

Construction and Infrastructure

Whenever trees are present in close proximity to built infrastructure, the potential for conflict is significant. In highly developed urban centers, it may be difficult to locate planting spaces that give trees sufficient growing space needed to avoid problems with utilities, buildings, or hardscape. Rather than limiting one's planting options to those trees small enough or tough enough to survive in degraded or constricting urban soil spaces, arborists and other tree-literate professionals in urban planning, civil engineering, and landscape architecture are beginning to see the value in designing planting sites that accommodate growth of a larger variety of trees.

Numerous conflict management strategies have been established and more continue to emerge (Costello and Jones, 2003). Research must confirm the validity of these systems and continue to improve upon them. New strategies must emerge to cope with the wide range of potential tree and infrastructure conflicts found in highly developed landscapes. More cost-effective and less complex approaches must be developed as they will gain greater acceptance among those responsible for designing and planning urban infrastructure elements.

Where space is limited, alternative building materials such as structural soil mixes, porous paving materials, and underground support systems have been designed to bear loads while still allowing for root penetration. However, the extent and location of root colonization in these systems is largely unknown. In addition, the functional lifespan of these products not adequately documented.

The extent to which urban trees inflict damage that lessens the longevity of urban infrastructure and the costs associated with this hastened degradation are not fully known. Identifying how tree roots damage pavement and infiltrate underground utilities such as sewer pipes may lead to design changes that limit future conflicts. Alternatively, root control barriers that impede or re-direct growth may be installed if they are shown to be effective at preventing root-related damage.

Trees may be damaged when urban infrastructure is repaired and replaced or when new construction is completed nearby. When trees must be pruned back (aboveground, belowground, or both above- and belowground), what are the effects to tree health and stability? What percentage of a tree's structural and absorptive roots system can be removed without adversely affecting a tree? When is root removal too severe to justify retaining a tree? Hardscape elements and developments can significantly alter urban soils. How can one determine what soils are actually available for trees to utilize in a build environment?

Tree Stability

Tree stability is a concern throughout the life of a tree. At planting, one must decide what, if any, stabilization measures are needed to prevent a transplanted tree from shifting or uprooting. As a tree becomes larger and matures, its root system must develop sufficient anchorage to cope with increased wind-loading and tree weight. If this does not occur, catastrophic tree failure may result, potentially injuring or damaging nearby targets.

Some research has been conducted to assess root strength and whole-tree stability. However, further work is needed to create robust models that can be used to quantify these values. Stability assessment models should compare existing tree strength with site requirements (based on normal wind loading and other factors). These models could help guide hazard tree mitigation decisions directly or be adapted create standardized assessment guidelines.

In creating these models, species representing different root system typologies must be assessed to gauge differences in tree stability, especially in relation to limiting (in volume and in quality) urban soil environments. Some research is available in other related fields, such as silviculture, and should be reviewed to gauge is applicability to urban tree systems. In addition to differences found between forest and urban environments, differences in natural root systems and root systems altered by past nursery, construction, or management practices should be assessed to see how initial and long-term tree stability are affected.

As with other aspects of risk assessment, root and whole-tree stability require more thorough investigation. Key root defects and root loss thresholds should be identified. Ultimately, the products of tree stability research efforts must be used to lay the groundwork for comprehensive and meaningful risk assessment guidelines. These guidelines should identify the tools and techniques are needed to carry out a basic belowground risk assessment. In addition, risk assessment guidelines should indicate when more comprehensive assessment is warranted (such as when positive decay indicators such as conks are present at the root crown), and what methods are appropriate. Standardized risk assessment guidelines could contain quantitative or qualitative assessment factors or a mix of both depending on what is deemed most appropriate for use in the industry.

Root Growth and Development

Past works have given root researchers a greater understanding of root system distribution, extent, and depth. It is recognized that these factors are influenced both by genetic controls within a species and by the soil conditions present at the site. Environmental conditions such as soil depth, compaction, abundance of water, and infrastructure elements all influence root distribution within the soil. Research and education continue to strengthen the link between tree roots belowground and the trunk and canopy aboveground. This has lead to a greater interest in root management issues among arborists and their clients.

While researchers have a generalized understanding of root system typologies, more specific knowledge of root growth and development across common urban trees species and soil conditions is needed to help refine management practices. This is such a fundamental research question which has implications throughout many of the other topics discussed at the summit. As a result, it was ranked the top research priority by summit participants.

The second research priority to come out of this topic area was the development of a root detection system. Such a system could have many applications, allowing arborists to map out major structural roots prior to a construction and researchers to observe root growth responses to treatments in a non-intrusive manner. A range of systems with varying precisions should be developed to meet the needs of each user group.

Other questions that were raised at the summit included assessing the effects of root pruning (intentional and unintentional) on trees across different age classes, and identifying specific ties between above- and belowground structure and vitality.

Soils (Physical, Chemical, and Biological Properties, etc.)

The portrayal of soil as a dynamic, living, and relatively fragile ecosystem was a major advancement in soil science. As soil science and ecology continue to progress, the importance of this biological component is continuously reaffirmed.

How exactly does soil biology influence soil growth and development? Scientists continue to discover new and complex interrelations; however, many more may still be left undiscovered. In addition, how do soil conditions, specifically water and oxygen levels, influence the soil organisms and plant roots and their relationships with one another? How does urban soil biology differ from soils typically associated with specific tree species.

As mentioned earlier, structural soils have emerged as a means of encouraging root growth under pavement. What conditions are present in these engineered fills that allow them to support a load when compacted, yet still maintain sufficient pore space to promote root growth? How long are these conditions maintained and at what point are structural soils no longer effective?

Soils Management and Root Responses (Mulch, Fertilization, Amendments, etc)

Urban soils are often very young, disturbed, and bear little resemblance to natural soils which develop over a long period of time. Subsoils are often brought to the surface and compacted.

Structure is often destroyed. Organic matter and nutrients can be deficient. Soil improvement through natural processes will take decades, or longer. When amendments, mulches and fertilizers are used correctly to improve urban soils, often development can be improved.

Mulching helps mimic the natural organic layer of a forest soil. The benefits of mulch, especially organic mulches, on root growth and plant performance have been well documented in arboriculture. Traditionally, studies have been focused on physical improvements to soil (bulk density, moisture holding capacity, organic matter content) as a means of improving root growth. More recently, the focus has begun to shift to the effects of mulch on soil biology.

Mulch comes in many forms. It is commonly derived from waste products of tree care and timber harvesting. As these techniques and equipment in these industries change, so do the characteristics of the mulch produced. Mulch products are also driven by appearance and market demand. Mulch products are seldom developed for their horticultural properties. There must be a greater understanding of the functional elements of mulch. In particular, the roles of the various fragment sizes and their interactions should be documented. What are the characteristics of mulch that give it its beneficial properties?

Many questions remain as to how mulch provides the benefits that have been documented. What is mulch's role in the urban carbon cycle? How does mulching affect urban soil biology, and can we promote similar changes where mulching is not possible around trees? What are the most effective materials?

What are the long-term benefits of mulching and other soil improvement practices? How do we increase rooting depth? How much are must be mulched is required to benefit a tree? When is mulch too deep (i.e., 'volcano mulch')?

Finally, there has been both research-based and anecdotal evidence suggesting that there are some potential negative effects resulting from the practice of mulching. Examples include: flammability, water interception, possible manganese deficiency stemming from the use of chipped tulip poplar (*Liriodendron tulipifera*), and repelling or intercepting water. These may need to be explored further

The use of soil amendments are well understood by soils scientist, but not always by arborists. Adding sand in the appropriate amount can improve drainage. Adding too little can reduce drainage. Amending soil on an entire site may not be practical, but pneumatic excavation technology has made amending soils in the root zone of trees possible. Amending only planting hole soil may not produce the desired long-term results.

Fertilization of urban trees continues to cause generate great interest. Rates of fertilizer added to trees, shrubs and lawns in landscapes can often exceed the nutrient recycling interrupted by leaf raking. High rates of nitrogen can stimulate fine root development in localized areas near application points, but little is known about the effect on the entire root system.

Water management is an important part of soil and root system management. Everywhere, water conservation is becoming increasingly important. Research is showing smaller amounts of water can be applied while still maintaining adequate plant growth. Prudent use of mulches, soil amendments, and fertilizers to improve root growth could make even more efficient use of water resources. Can we effectively use deficit irrigation to increase water use efficiency in trees?

Technology Transfer and Education

Research purely for the pursuit of knowledge is a noble endeavor. However, most of the research conducted in arboriculture and urban forestry has direct or indirect implications on tree health, work practices, and the urban environment. To maximize the impact of this work on the industry, research results must be synthesized and distributed in a means suitable for the intended audience.

When identifying an audience for root and soil information, the list of possible message recipients is quite extensive. City officials may be targeted in an effort to show the costs associated with failed plantings and lost environmental benefits when transplanting and early care

is inadequate. Consumers can be shown that quality trees and careful maintenance are worth the added cost and effort, as they will pay for themselves in increased tree-derived benefits. Tree care and other green industry professionals not currently involved with industry groups such as ISA may be pursued as well, in an effort to further tree literacy and professionalism. Finally, other groups such as urban planners, civil engineers, and landscape architects must be reached as they often design the soil environments that are intended to support urban tree growth and development

Convincing the consumers and industry groups that quality has value is a key step in promoting tree health. While this is commonly associated with the purchase of quality plant material, it is the quality of the site and care given that often ultimately determines the success or failure of many trees. Site prep and development costs often eclipse the expenses associated with plant materials. Greater focus must be placed in this area to promote positive change. Consumer demand (and willingness to pay) for industry professionalism and superior materials and practices will have the greatest influence on the green industry as a whole.

Determining the most appropriate method of conveying a message is the final step in successful technology transfer. For example, given the nature of their work, landscape architects tend to be very visual communicators. The use of drawing, diagrams, and animations may be the best means of conveying information about underground rooting requirements to this audience. Media type is also important. Would an audience be more likely to access information as a printed publication, audio or video clip, or in an online resource? Finally, fostering widespread change may go beyond education. Public policies, industry standards, and best management practices can all be effective ways of achieving goals.

Overarching Themes

Throughout the summit discussions, several ideas emerged and re-emerged. These concepts became an overriding theme for all of the subject domains.

First, researchers need to establish more uniform and collaborative efforts when tackling any of the future research needs outlined above. Studies are that examine similar research questions but vary in methodology are often difficult to compare in a meaningful way. When investigating a factor such as compaction or deep planting, uniform methodologies should be developed that allow researchers to determine species and soil effects in different regions and climates.

In addition, key papers must be made available in a variety of languages so researchers around the world can benefit from the knowledge gained in past works. Translation efforts may greatly reduce over-replication of studies stemming from incomplete knowledge of the literature available in other languages. Even within one's language, care should be taken to examine works in peripheral fields such as horticulture, silviculture, and ecology.

Another overreaching theme involved the complexity of many of the issues being investigated. From the time a tree leaves a nursery to its eventual establishment in the landscape, it may pass through the hands of numerous professionals in a variety of industry sectors. This is further confounded by the inherently unnatural and often changing character of developed planting sites.

Finally, long-term studies are needed gauge the effects of production, planting, and root management practices. This will require both adequate foresight and sustained funding if done in a controlled environment. However, studies of this magnitude may ultimately prove to be too costly and time prohibitive given today's current systems of grant funding, tenure, and promotion. In order to gain information regarding these factors on mature trees in a timely manner, methodologies to assess large trees within the landscape need to be identified or developed.

Literature Cited

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