FROM THE GROUND DOWN

THOMAS PERRY

Research suggests new ways to approach street-tree planting

BY JAN GOLDSTEIN, NINA BASSUK, PATRICIA LINDSEY AND JAMES URBAN

The two rows of willow oaks adjacent to the National Gallery of Art in Washington, D.C., were intended to form a symmetrical allée when planted in 1978. The lopsided growth pattern obvious in this photograph has been caused by the difference in the amount of available soil; the smaller soil volume in the tree pits next to the street cannot hold enough water to meet the trees' needs.

While strolling down Washington, D.C.'s Pennsylvania Avenue past the National Gallery of Art, even the most casual observer will note that the trees growing out of tree grates next to the street are only about half the size of the trees growing in a lawn area on the other side of the sidewalk. Yet both rows of willow oaks were the same size when planted in 1978. That the grate-planted trees have had far less twig growth each year leads to the conclusion that this planting will never fulfill the design intent envisioned, that these trees will never become the majestic matches they were meant to be. What is to blame for this phenomenon and how are landscape architects to address this problem? The answers lie beneath the walk, in the ground below.

The roots of a tree are vital, yet it is the roots that are most frequently overlooked and disrupted in the urban environment. The typical street-tree pit, which already is inhospitably sandwiched in a narrow strip between the road and sidewalk, often competes for space with underground utilities, subways and building foundations. The small volumes of compacted soil that the roots have access to are either poorly drained, or more likely, cannot hold enough water to meet demand, and the trees experience periodic to prolonged drought. Simply put, lack of soil accounts for most urban tree survival problems.

Many factors in the urban environment exacerbate the soil problem. Water is added to the soil primarily through rainfall. Much of this essential water is lost, however, either as runoff over impervious paved areas, through drainage beyond the reach of roots or as evaporation from the soil surface. The little remaining water the tree has access to is taken up by the roots and moves through the tree to the leaves, where most is evaporated through transpiration in response to the demands of sun, wind, temperature and humidity. Urban conditions such as reflective and absorptive surfaces that release heat, thereby increasing daytime and nighttime temperatures and drying the air, create a "heat island," which increases the tree's water needs. If water is scarce, tree growth will slow. Under extreme conditions, the tree may die.

Further, as a tree grows larger it requires more water, and hence more soil. How much water, then, is enough? Assuming a typical 4 ft. x 4 ft. tree pit with approximately 48 cubic feet of good soil, a maximum of six gallons of water will be available to the tree at any given time. How long will it be before the tree depletes this source? Conversely, what size tree will six, 10, 50 or 500 gallons of water support and over what time period? The answer requires the establishment of the relationship of canopy size to the tree's water use. It also necessitates being able to estimate how stressful a given site is. Finally, if water needs can be predicted, what soil volumes do we need to store this water?

In an effort to bracket minimally adequate soil volumes for any given size of tree, research projects guided by Jim Urban, ASLA, and Nina Bassuk of the Urban Horticulture Institute, assisted by Patricia Lindsey, took strikingly different but complementary approaches.

Funded by a National Endowment for the Arts grant, Urban devised and conducted an exhaustive comparative case study of more than 1,300 mature trees from projects in intensely developed urban settings. Most of these sites were designed by nationally ranked design firms, and many were award-winning, setting precedents for urban design and execution. Through field surveys, interviews and examination of contract documents, Urban was able to amass a large database, from which he attempted to evaluate the effects of soil volume and other factors such as location within the design, maintenance, species and construction details relative to tree health and longevity.

Urban's 13 projects had many stories to tell, some obvious, others more obscure. The "average" tree in his study had been in place for 17 years (range: 10-27 years), was planted initially into 149 cubic feet of soil (range: 40-600 cu. ft.) and had grown less than 1/4" diameter breast height (DBH) per year (range: .03-.51"). The average tree was typically in fair to poor condition although, on one project, all original trees were rated excellent; on another, all had died and been replaced at least once.

On closer inspection, Urban recognized some interesting trends in his data. Trees planted in 200 cu. ft. or more of soil were in better condition than nearly all their counterparts in smaller volumes. Below this soil volume, tree vigor and condition generally—but not always—decreased with decreasing amounts of soil. Occasionally, trees in smaller soil volumes significantly outperformed those in larger tree pits. However, these trees almost always had access to soil outside of their original pit, leading Urban to conclude that their roots had "broken out" and found additional rooting space elsewhere.

Bassuk and Lindsey examined actual water-use rates and subsequently calculated the necessary supportive soil volume. They determined whole-tree water-use rates for a total of 72 trees representing four very different species: *Amelanchier* 'Robin Hill Pink,' *Tilia americana* 'Redmond,' *Sophora japonica* 'Regent' and *Fraxinus americana* 'Autumn purple.' Tree height and stem caliper were also recorded.

To determine water use, the trees, growing in 15-gallon containers, were weighed before and after a 24-hour period. The container surfaces were covered to prevent evaporation from the soil in order that the differences in these two values would represent water lost solely from transpiration. These measurements were taken periodically over the summers of 1987 and 1988 and related to readings taken from a nearby U.S. Weather Bureau Class A evaporation pan. This pan is filled with water and equipped with a micrometer gauge that measures daily water level changes. Importantly, evaporation from these pans reflects the major environmental influences also governing whole-tree water loss: sun, temperature, wind and humidity. Because the pan measures evaporation as water lost per unit area of pan surface, and transpiration is measured on a unit leaf area basis, the two may be conveniently compared.

The challenge is to create larger, more suitable soil environments for city street trees. Unfortunately, landscape architects today are still working with outdated and woefully unrealistic installation details, planting specifications and procedures that answer to a bygone era of less-intense development.

Bassuk and Lindsey established that the rate at which water is transpired from a leaf is proportionally related to the rate at which water is evaporated from the Class A pan. Using a statistical model, it was found that if total canopy size and pan evaporation were known, then the total water loss for that tree on any given day could be accurately predicted. This is a simple and very useful relationship. Since the rates of pan evaporation are published by the National Oceanographic and Atmospheric Administration (NOAA) for all areas of the country, the estimated water loss from a tree could be adjusted to account for climatic differences from region to region.

They also found that total canopy size was the primary determinant of water use. The amount of water lost was very similar among the four species studied and differed only as total canopy size differed. This means that individual water use rates might not have to be established for each species, and just one rate could be used.

The relationship between water use and leaf area was examined more closely by Bassuk and Lindsey. It was determined that instead of using actual leaf area (a figure hard to obtain), one could substitute crown projection (CP), which is the ground surface area, in square feet, enclosed within the dripline of the tree. When information on crown projection, crown density and pan evaporation is coupled with determinations of soil water-holding capacity and precipitational data, minimally adequate soil volumes can then be specified.

As an example, Bassuk and Lindsey calculated that a tree with a 20-foot canopy diameter (or 315 CP) and an average canopy density would use approximately 30 gallons of water a day in Ithaca, New York. The daily pan evaporation value used was derived by taking the highest mean monthly value over a 30-year period (NOAA data) and dividing by the number of days in the month. A total of more than 300 cu. ft. of soil with good water-holding capacity would be needed to support this tree, then, through a 10-day rain-free period. Growing large, mature trees would require significantly greater volumes of soil—up to 1,000 cu. ft.

Water-use rates and subsequent soil volumes for a representative range of major U.S. cities

SOIL VOLUME METHODOLOGY

Estimated critical soil volumes are presented for a representative range of U.S. cities using the soil volume methodology. The tree in this example has a crown diameter of 20 ft. and is about 35 ft. in height. Calculations were based on a tree with a crown projection of 315 ft. and an average leaf area ratio of 4.

City	One Day Soil Volume[1] (Cu. Ft.)	Rainfall Frequency[2] (Days)	Approximate Total Soil Volume (Cu. Ft.) If AWHC[3] of Soil Is: 10%	15%
Ithaca, NY	28	10	400	300
Seattle, WA	30	20	900	600
Mobile, AL	32	10	500	300
Indianapolis, IN	33	15	750	500
Minneapolis, MN	35	10	500	350
Miami, FL	36	10	550	350
Denver, CO	45	15	1,000	700
Phoenix, AZ	68	80	8,200	5,400

[1]Calculated using the highest mean monthly pan evaporation value for 20-30 years of data for each city to determine whole-tree water use. Assumes a soil available water holding capacity of 15%.
[2]Defines the critical rainfall. A minimum of 92% of all dry periods (less than 1/10" of rain) lasted this number of days or fewer for each city. Derived from 10 years of data for each city.
[3]Available water holding capacity of the soil. This represents the percent of the total water, on a volume basis, that is actually available for root uptake. Two available water holding capacities are presented for comparison here: a low (10%) and a high (15%). The AWHC of any soil mix can be determined in a lab test.

were then calculated. What emerged was a general soil volume estimate of one cubic foot of soil per one square foot of crown projection. This is assuming, however, good soil water-holding capacity and a 10-day rain-free period; to be more precise, rainfall frequency of .25" or greater would have to be established to reflect local conditions.

Recognizing that the landscape architect tends to think of tree size in terms of DBH or height more than crown projection, Urban attempted to identify a relationship between CP and DBH that would make the Cornell methodology easier to use. Further data collected from three of his original 13 sites bear out the relationship of 1" DBH=35-45 sq. ft. of CP. Thus the tree in Ithaca would have a DBH of 8-10". Further work is needed both to confirm this ratio for a wide variety of tree shapes and sizes and to accurately relate DBH to whole-tree water loss.

The possible application of this soil volume methodology to actual design situations is far-reaching. It has the potential to predict the outcome of a design once the details are studied. Prepared with this information, landscape architects may at last defend design and budget decisions from a new, horticulturally based position, rather than relying merely on aesthetics. Simply stated, the ultimate desired tree size can be used to determine tree pit dimensions. Likewise, if given a restricted ground plane for planting, or if using containers, the landscape architect can calculate what size tree can be supported by the allowable soil mass.

Even with the ability to accurately estimate the required soil volume for a tree, ensuring 300-500 cu. ft. of uncompacted soil (with adequate drainage) will require thoughtful design and detailing. Incorporating large volumes of soil into the already complex urban fabric necessitates a high degree of engineering and coordination of related structural activities.

Bassuk and Lindsey's research yielded specific recommendations for street-tree plantings.

Furthermore, while conditions in urban areas vary from one site to another, planting specifications and details rarely reflect these variations. Soils, drainage patterns and microclimatic conditions can change dramatically just from one tree to another. One consequence of this new approach to trees in the urban landscape will be the development of a fairly complex methodology in the design and construction processes.

Ultimately, we need to revise planting strategies. Ways of increasing possible rooting volume for trees at grade need to be fully exploited. These include interconnected tree pits that contain large volumes of soil under the sidewalk or grouped plantings with large shared rooting space designed to provide more than 300 cu. ft. per tree. When rooting space is simply unavailable at or below the paving areas, raised beds or containers designed to hold sufficient soil can now be specified to support tree growth of predictable size and longevity.

The challenge is to create larger, more suitable soil environments for city street trees. Unfortunately, landscape architects today are still working with outdated and woefully unrealistic installation details, planting specifications and procedures that answer to a bygone era of less-intense development. Landscape technology has not kept apace of the swift and often deleterious changes in the urban environment.

To counter such changes, scientific research and professional practice have tremendous potential to help one another—if practitioners are willing to creatively apply the principles gleaned from research and communicate their results to the research community. Such commitment and collaboration are crucial if inspired new directions in urban planting design, informed by landscape technology, are to emerge, enabling landscape architects to take the lead in replanting the urban environment. ■

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