Adaptations of Australian Tree Species Relevant to Water Scarcity in the Urban Forest

G.M. Moore

Abstract. Water is a valuable resource, but its preferred use by society for other, higher priorities has resulted in a scarcity for the urban forest. However, the value of the urban forest in providing environmental and ecological services that have significant benefits for human health, well-being, and the liveability of cities demands the reconsideration of the priority of water use by the urban forest. Health authorities are advocating the value of urban greenspace that may require the use of water, especially storm water, as climate change threatens more severe heatwaves.

Trees have an important and long-term role in water-sensitive urban design that efficiently uses and reduces pollution from storm water. Knowledge of tree root systems and their interaction with soils means that irrigation can be targeted in a way that maximizes the efficient and effective use of water. Understanding stomatal behavior also allows optimal timing of irrigation for photosynthetic efficiency while capturing the benefits of transpirational cooling, which may reduce extra deaths during heat waves. The economic, social, and health benefits justify the efficient and effective use of valuable water.

Key Words. Australia; Drought; Foliage; Root Adaptation; Urban Water Use.

Recently, much of the east coast of Australia was gripped with a prolonged period of lower than average rainfall. The State of Victoria had entered its fourteenth consecutive year of below-average rainfall (Bureau of Meteorology 2011). Since then, there has been record rainfall and flooding in much of the region, and the media have reported the general relief that the drought had finally broken.

The dry period may have been a drought and part of natural cycles of perhaps five hundred years or more, but current meteorological data are too recent to reveal such patterns. However, the dry period, recent major storm events, changes in rainfall patterns, and summer flooding are consistent with predictions made over the past two decades in relation to climate change. It is too early to trumpet the end of the dry period—one season of above-average rainfall should not obliterate the trend of the previous fourteen years.

So the focus on water scarcity, availability, and the efficiency of water use in the urban forest is timely and of great urgency in the context of the Australian environment and climate change more generally. However, is there really a scarcity of water for the urban forest? In cities as diverse as Melbourne, Victoria, and Perth, Western Australia, Australia, only about 8%–9% of the available potable water is used for general open space purposes. This includes both public and private (back and front gardens) open space, and even less water is allocated to trees in the urban forest (Victorian Department of Sustainability and Environment 2006; Victorian Department of Sustainability and Environment 2007).

Water is a precious commodity, but it is only scarce because other priorities for its use are seen as being more important than open space and the urban forest. No one would deny that the first priority for potable water is to meet the drinking and health needs of citizens. However, in every State, the greatest users of water by far rest in industry and agriculture (Victorian Department of Sustainability and Environment 2004; Victorian Department of Sustainability and Environment 2007). No one would suggest that the urban forest should be irrigated at the expense of drinking water or at a cost to human health or life. The issue is about using a valuable resource sustainably and effectively to capture maximum benefits, including environmental benefits (Nowak et al. 2010). Research must inform the management practices that are required to maintain the urban forest, using water effectively, efficiently, economically, and sustainably.

The Priority for Water and the Urban Forest

While urban forests are beautiful and decorative, these attributes often conceal the many functions and services that they provide to cities to the point where their social, health, economic, and environmental benefits are overlooked (McPherson 2007; Moore 2009; Nowak et al. 2010). What else delivers so many benefits immediately, and benefits that last centuries into the future, prolonging healthy lives and making cities both sustainable and liveable? Urban forests have been
silent assets to cities for decades and even centuries. They are major and essential urban infrastructure (Daniels and Tait 2005).

Cities are biodiversity hot spots due to the variety of habitats available in public and private open space, especially the diversity of plantings in domestic front and back yards (Daniels and Tait 2005). The requirement for tree managers is to establish a priority for the urban forest in the allocation of a precious and valuable, rather than scarce, commodity (Connellan 2008). Society will allocate water to items for which there is an economic and political imperative.

For most of its history, the price of water in Australia has been subsidized, however, it does have a real economic value and in most States increasing water prices are moving toward that value (Victorian Department of Sustainability and Environment 2004; Victorian Department of Sustainability and Environment 2006; Victorian Department of Sustainability and Environment 2007). To maintain the urban forest, water must be used effectively and efficiently. There can be no going back to the days of profligate water use and year-round emerald green lawns (Moore 2009). The environment and economy cannot sustain such an approach (Water Resources Strategy Committee 2002). How well informed are the practices governing the use of water in the urban forest and what are the research needs that would enhance best management practices?

ADAPTATIONS RELEVANT TO WATER STRESS

Trees in the urban forest face the dilemma of all terrestrial plants: the need to balance the interaction of carbon and water cycles to allow survival and growth. If water is limited and stomata close, carbon assimilation through photosynthesis is reduced (Cowan 1981; Curran et al. 2009; Martin St. Paul et al. 2012). Thus in the urban environment, restricting water availability to trees in the urban forest may also restrict the benefits that they provide, such as their capacity for carbon sequestration (Jonson and Freudenberger 2011) and transpirational cooling.

The performance of different trees species in minimizing water loss, but at the same time maintaining carbon dioxide gain, is defined as water-use efficiency:

$$\text{Water-use efficiency} = \frac{\text{Carbon gained}}{\text{Water lost}}$$

The value of water use efficiency varies for different species and can be used to select trees that are more productive for use in cities of drier climates (Ladiges et al. 2005). Australian tree species possess many and varied adaptations to growing in arid environments (Table 1). One of the defining characteristics of many Australian plant genera is sclerophyll. Sclerophyllous trees possess large amounts of sclerenchyma tissue, which maintains cellular volume as conditions dry. It is often assumed that sclerophylls are low water users, but paradoxically many have poor stomatal control and will use whatever water is available until they wilt (Ladiges et al. 2005). Many have the capacity to survive in environments where water is limited, and managers can proactively minimize the supply of water in low-water environments using sclerophyllous trees.

Table 1. Adaptations of Australian tree species to aridity (Ashton 1975; Moore 1981; Pate and McComb 1981; New 1984; Moore 1990; Knox et al. 1994; King 1997; Atwell et al. 1999; Ladiges et al. 2005).

<table>
<thead>
<tr>
<th>Adaptation</th>
<th>Mechanism</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sclerophyll</td>
<td>Maintains cellular volume</td>
<td>Many Australian genera, such as Acacia, and members of the Proteaceae and Myrtaceae families</td>
</tr>
<tr>
<td>Altered leaf anatomy</td>
<td>Reduces leaf surface area</td>
<td>Hakea and Acacia species with rolled needle like leaves</td>
</tr>
<tr>
<td>Phyllodes/cladodes</td>
<td>Reduces surface area; reduces evapotranspiration</td>
<td>Most Australian Acacia species</td>
</tr>
<tr>
<td>Vertically hanging leaves</td>
<td>Reduces absorption of radiation</td>
<td>Many eucalypt species</td>
</tr>
<tr>
<td>Leaf/pinnule movement</td>
<td>Reduces exposed leaf surface area</td>
<td>Bi-pinnate Acacia species; Lophostemon confertus</td>
</tr>
<tr>
<td>Cuticular adornment</td>
<td>Reduces evapotranspiration</td>
<td>Many genera, such as Eucalyptus, Acacia, and Casuarina, with hairy, spiny, or glaucous leaves</td>
</tr>
<tr>
<td>Stomatal crypts</td>
<td>Reduces evapotranspiration</td>
<td>Banksia species, Hakea species</td>
</tr>
<tr>
<td>Cuticular ledges</td>
<td>Reduces evapotranspiration</td>
<td>Eucalyptus preissiana, E. obliqua</td>
</tr>
<tr>
<td>Stomatal closure in response to atmospheric vapor deficit</td>
<td>Reduces transpirationalal water loss</td>
<td>Eremophila macgillivrayi, Myoporum floribundum, Myoporum platycarpum, Pittosporum phylliraeoides, Geijera parviflora</td>
</tr>
<tr>
<td>Facultative deciduousness</td>
<td>Reduces growth but allows survival over tropical dry period</td>
<td>Some Blakella eucalypt, such as E. clavigera, E. grandiflora, and E. brachyandra</td>
</tr>
<tr>
<td>Lignotubers/basal burls</td>
<td>Rapid regrowth after foliage loss</td>
<td>Most eucalypt; Acmena smithii</td>
</tr>
<tr>
<td>Epicormic buds</td>
<td>Rapid regrowth after foliage loss</td>
<td>Most eucalypt</td>
</tr>
<tr>
<td>Deep tap root</td>
<td>Allows access to deeper soil water profile</td>
<td>E. camaldulensis</td>
</tr>
<tr>
<td>High root:shoot ratio</td>
<td>Increases soil volume accessed for water supply</td>
<td>E. camaldulensis</td>
</tr>
</tbody>
</table>
The leaves and phyllodes of many Australian species (Table 1) are isobilateral and often hang vertically, thereby reducing the surface area that is exposed to the sun (King 1997). Species such as *Eucalyptus preissiana* (Knox et al. 1994) and *E. obliqua* have prominent cuticular ledges, which overarch their stomata, creating a stomatal antechamber that reduces transpirational water loss (Moore 1981). However, the stomatal anatomy of many common street trees species remains unknown.

In Australian tree species, the number of stomata varies from about 28 mm$^{-2}$ in *Persoonia* (geebung) to between 100–350 per mm$^2$ in eucalypts. The number often varies inversely with size with fewer larger stomata contrasting many smaller stomata (Knox et al. 1994). In *Eucalyptus globulus*, there are 300 stomata mm$^{-2}$, but the leaf area occupied by stomatal apertures is only about 1%. However, with stomata open, the rate of transpirational water loss is the same as for evaporation from an open wet surface; water and gaseous movement through open stomata is remarkably efficient. Thus, knowledge of stomatal rhythms and behavior is essential to understanding tree water use and survival in water-limited environments.

Trees such as *Casuarina littoralis*, *Eucalyptus calophylla*, *Eremophila macgillivrayi*, *Pittosporum phylliraeoides*, and *Myoporum floribundum* show effective stomatal control and so more efficient water use, but if water is limited then their growth rates may be slowed to the point where they are ineffective for planting in the urban forest. Similarly, species such as *Acacia melanoxylon* or *Eucalyptus grandiflora*, which reduce water use through reduction in leaf surface area, may lack the canopy characteristics and density that would make them attractive for urban forest planting.

For most Australian tree species planted in urban environments there are almost no data on basic physiological processes, such as stomatal behavior, let alone whether they are stress avoiders or tolerators in relation to water (Table 2). There are major research gaps in the use of Australian native species, as well as exotic species, growing under Australian environmental conditions. Few studies are available on water use by species such as *Acacia mearnsii*—a bi-pinnate leaved species—growing in the basaltic clays of the western plains near Melbourne. This reduces transpirational water loss. In plantations, *A. mearnsii* could lose 261 kg of water per day compared to *A. decurrens*’ 44 kg, but this was largely due to a difference in foliage density with *A. mearnsii* having a foliage mass of 69 kg, while *A. decurrens* had a foliage mass of 9 kg (New 1984). In an urban forest, a choice between these species may come down to a decision about canopy appearance, density and impact versus water use.

Table 2. Avoidance and Tolerance Mechanisms for coping with low water environments.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Mechanism(s)</th>
<th>Growth</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought avoidance</td>
<td>Grow where and when water is available</td>
<td>Unaffected</td>
<td><em>Eucalyptus regnans</em>, <em>E. camaldulensis</em>, <em>E. marginata</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>until water is limiting</td>
<td></td>
</tr>
<tr>
<td>Drought tolerance by</td>
<td>Increased rooting volume</td>
<td>Improved</td>
<td><em>Acacia mearnsii</em>, <em>E. camaldulensis</em>, <em>E. clevelandi</em>, <em>E. trivalvis</em></td>
</tr>
<tr>
<td>improved water status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increased root density</td>
<td>Improved</td>
<td><em>E. camaldulensis</em>, <em>Acacia mearnsii</em></td>
</tr>
<tr>
<td></td>
<td>Good stomatal control</td>
<td>Usually reduced</td>
<td><em>Casuarina littoralis</em>, <em>E. calophylla</em>, <em>Eremophila macgillivrayi</em>, <em>Pittosporum phylliraeoides</em>, <em>Myoporum floribundum</em></td>
</tr>
<tr>
<td></td>
<td>Capacity for osmotic adjustment</td>
<td>Usually reduced</td>
<td><em>Acacia melanoxylon</em>, <em>Acacia mearnsii</em>, <em>E. clavigera</em>, <em>E. grandiflora</em>, <em>E. brachyandra</em></td>
</tr>
<tr>
<td></td>
<td>Reduced leaf surface area</td>
<td>Usually reduced</td>
<td><em>E. camaldulensis</em>, <em>E. marginata</em>, <em>Acacia mearnsii</em></td>
</tr>
<tr>
<td></td>
<td>Larger root:shoot ratio</td>
<td>Usually reduced</td>
<td></td>
</tr>
<tr>
<td>Drought tolerance by</td>
<td>More elastic cell walls</td>
<td>Usually reduced</td>
<td><em>Acacia aneura</em></td>
</tr>
<tr>
<td>maintaining cell volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dehydration tolerance</td>
<td>Cells and physiology unaffected by reduced water content</td>
<td>Usually reduced or restricted</td>
<td><em>E. rossii</em>, <em>E. viminalis</em>, <em>Acacia aneura</em></td>
</tr>
</tbody>
</table>

Note: Columns 1–3 of this table are extended and modified from Atwell et al. 1999. Column 4 is based on the author’s experience with these Australian species.

©2013 International Society of Arboriculture
Table 3. Australian Tree species with full or facultative deciduousness, usually in response to a dry period (Australian Plant Study Group 1980; Francis 1981; Boland et al. 1984; Snape 2002).

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>Species</th>
<th>Common name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachychiton rupestris</td>
<td>bottle tree</td>
<td>Eucalyptus leichhardtii</td>
<td>white beech</td>
</tr>
<tr>
<td>Brachychiton discolor</td>
<td>lacebark tree</td>
<td>Lysiphylum cunninghamii</td>
<td>native bauhinia</td>
</tr>
<tr>
<td>Brachychiton bidwillii</td>
<td>rusty kurrajong</td>
<td>Lysiphylum carrii</td>
<td>native bauhinia</td>
</tr>
<tr>
<td>Brachychiton australis</td>
<td>large leaf bottle tree</td>
<td>Lysiphylum hookeri</td>
<td>white bauhinia</td>
</tr>
<tr>
<td>Euclea acuminata</td>
<td>koda</td>
<td>Nauclea orientalis</td>
<td>leichhardt tree</td>
</tr>
<tr>
<td>Erythrina vespertilio</td>
<td>bat wing tree</td>
<td>Ptelephorum pterocarpum</td>
<td>yellow poinciana</td>
</tr>
<tr>
<td>Ficus superba</td>
<td>deciduous fig</td>
<td>Sterculia quadrifida</td>
<td>peanut tree</td>
</tr>
<tr>
<td>Ficus virens</td>
<td>white fig</td>
<td>Terminalia catappa</td>
<td>sea almond</td>
</tr>
<tr>
<td>Ficus fraseri</td>
<td>sandpaper fig</td>
<td>Toona australis</td>
<td>red cedar</td>
</tr>
</tbody>
</table>

It is interesting to compare a hypothetical scenario where *Pinus radiata* and *Eucalyptus rossii* are planted in the same, low phosphorus Australian soil in an urban streetscape where rainfall is low and there is no irrigation after the first year of establishment. When soil water potential falls, the *P. radiata* closes stomata, reducing photosynthetic assimilation and growth. The *E. rossii* on the other hand keeps stomata open and tolerates a decline in internal water potential. When occasional light rain falls, the *E. rossii* resumes photosynthetic assimilation immediately and commences growth (Florence 1981). The *P. radiata* does not open its stomata and the soil dries, perhaps compounded by the opportunistic uptake of water by *E. rossii*. The *E. rossii* out grows and out competes the *P. radiata* under this scenario.

Winter deciduous Australian native trees are relatively rare, with *Melia azedarach*, *Nothofagus gunnii*, and *Brachychiton acerifolius* being notable examples. Furthermore a few northern species, including some eucalypts, such as *E. clavigera*, *E. grandiflora*, and *E. brachyandra*, are facultatively deciduous during the dry period (Williams et al. 1997). This characteristic is shared with a number of other tree species, some of which are suitable for urban use (Table 3). However, there has been very little breeding and selection of these native species for urban use, and even less research on whether breeding might allow deciduousness to apply to southern winters, expanding the potential use of any of these or related species (Munne-Bosch and Alegre 2004).

Some species have stomata that respond to the vapor pressure of the ambient air (Table 1). Stomata close in response to drier air and leaf moisture content increases as a result, but transpiration reduces accordingly. Species with this characteristic could prove very useful in cities where water is limited, but while the response has been observed in some species with potential for urban use, it is largely unresearched.

Some species of Australian urban trees come from populations that have wide and extensive natural distributions in environments where water availability varies (Wheeler et al. 2003). There are good data to inform provenance selections for many forest species (Hamrick 2004; Broadmeadow et al. 2005; Craft and Ashley 2007; Gouveia and Freitas 2009), but arboricultural data on Australian species of amenity trees are not so easily accessed. Studies on provenances of *Lophostemon confertus* (Williams 1996) and *Tristaniopsis laurina* (Looker 2001), from different climate and soil conditions, have been undertaken and would allow urban selections for drier climates. Even if species’ ranges are limited, there may be the option of selecting different species from within a genus. This is the case with the genera *Eucalyptus* and *Acacia* within Australia, where there are large numbers of related species occupying a broad range of habitats.

Oftentimes eucalypt-dominated forests it is common for different species to occupy environments that become increasingly drier (Fensham and Holman 1999). This gives rise to the concept of a displacement series, of often-related species, which replace each other over an ecotone of increasingly arid environments (Pate and McComb 1981; Shepherd et al. 2008; Holman et al. 2011). As this happens, species have a tendency to show characteristics (Table 4) that better adapt them to the drier conditions. These characteristics could be used by urban forest managers as a guide for what species might be suitable for urban planting in drier conditions, but very little research has been applied to the urban context.

Good Australian data support the use of irrigation under singular mulches in general, and mixed particle size organic mulches in particular (Connell et al. 2000; Handreck and Black 2002). Early morning subsurface irrigation regimes that permit trees to open stomata early to maximize photosynthesis before water becomes limiting are based on sound tree physiology. In many species, stomata are often closed by about 2:00 pm, especially if soil water is limiting (Eamus 2006). Furthermore, for many tree
species evapotranspiration cools them, reducing the risks of heat damage, especially on hot windy days, the frequency of which is likely to increase under climate change. Such irrigation also captures at least some of the general and environmental benefits that the urban forest provides in terms of transpirational cooling.

Table 4. Characteristics of a eucalypt displacement series from wetter to drier environments (Pate and McComb 1981).

<table>
<thead>
<tr>
<th>Characteristic altered as environment dries</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Greater root:shoot ratio</td>
</tr>
<tr>
<td>• Increasing root:shoot ratio in response to water stress</td>
</tr>
<tr>
<td>• Slower stomatal response to decreasing xylem water potential</td>
</tr>
<tr>
<td>• Slower decline in leaf turgidity with increased water stress</td>
</tr>
<tr>
<td>• Lower rate of transpiration in wetter soils</td>
</tr>
</tbody>
</table>

ROOT ARCHITECTURE AND WATER USE

When a tree seed germinates in natural soils, the radicle emerges and usually develops into a tap root. In Australian native tree species, such as *Eucalyptus* and *Acacia*, it is not uncommon to find a seedling of 20 mm height with a primary root of 150–200 mm in length (Moore 2008). This root then rapidly develops as a tap root, anchoring the young tree, providing necessary water and nutrients and the framework from which lateral roots develop (Awe et al. 1976). In most urban trees, however, the tap root should be considered a juvenile characteristic, which only persists for the early establishment phase of the tree’s life cycle (Ashton 1975; Moore 1990).

The root systems of mature trees have a tendency to be spreading and relatively shallow (Watson and Neely 1994). The typical urban forest tree root system consists of a shallow spreading root plate of lateral spreading roots complemented by the presence of descending (or vertical or sinker) roots, which usually occur around the base of the tree or close to the trunk, where oxygen is more readily available and where nutrients and organic matter are being actively recycled (Coile 1937; Perry 1982). While the lateral roots are often within 200–300 mm of the soil surface, descending roots may grow to depths of 1000 mm or more. There are also descending roots farther out along the root plate, which have a tendency to be smaller in diameter and shallower in their descent. These roots may persist for a number of years before they die back and are replaced (Moore 1995; Smith and Moore 1997).

This common pattern of urban tree root architecture has profound implications for the application of water. However, there are few data on the variations in root architecture for native and exotic trees and almost none comparing Australian native species. Many irrigation regimes assume that roots are close to the trunk and under the drip line of canopies. This seems to be the case for species such as elms, but is not necessarily the case for eucalypts and other species where exposure of root systems with an air knife shows the presence of major structural roots within the drip line but very few, if any, fine absorbing roots (Moore 2008). The absorbing roots are often 10 m or more from the trunk and concentrated where moisture levels are higher.

There is an urgent need for data on the root architecture of Australian urban tree species. It is vital to know where roots are, why they develop where they do, and how much water they are capable of removing from soil in their vicinity. It is also essential to know where, and at what depth, water should be supplied for efficient and effective irrigation (Connellan 2008). There is a popular view that trees absorb water from deep in the soil profile and that only “deep soaking” is effective irrigation over summer. Current knowledge of root architecture suggests that this is not the case for urban forest trees, but there is little research to inform the debate. Consequently, water restrictions that limit irrigation of urban trees have been imposed rather than allowing an occasional irrigation of the absorbing root plate near the soil surface. This has resulted in higher levels of stress and the deaths of many mature trees in the urban forest over the past decade.

CONCLUSION

There has been great public interest in efficient and effective water use and conservation. However, the debate has often been fuelled by anecdotal information rather than being informed by data on water use by different plant species. There have been debates about whether trees—native or exotic—should be irrigated over the summer, and suggestions that perhaps nature should take its course and trees left to die. In many parts of southeastern Australia, restrictions to water use have been applied to gardens, parks, and streetscapes without data to support the impositions. Does restricting irrigation actually save water, and what are the consequences of the restrictions on trees and society as a whole? It has been argued that the use of water during days of extreme high temperatures could reduce ambient temperatures by both surface evaporation and transpirational cooling (Nicholls et al. 2008; Loughnan et al. 2010), thereby reducing the number of excess human deaths that occur during heat waves.

Australia’s major cities are not only urban forests but biodiversity hot spots (Daniels and Tait 2005). The parks, gardens, streets, and front and backyards constitute an urban forest that is very diverse in its range of species that generate myriad habitats and niches. High-density urban developments and inner city renewal make it virtually impossible to grow trees in places that were once green and leafy. Water scarcity is exacerbating the loss of urban vegetation cover, but there are many alternate planting options available to urban tree managers, if they are prepared to use the data that are available, largely from forestry research, on the root, foliage, and physiological adaptations of many Australian tree species to arid environments. There is an urgent need to obtain similar data for tree species commonly planted in urban environments. The costs of such research would be more than offset by improved water use efficiency and the benefits that effectively managed urban forests provide.

At a time of climate change, it is concerning that trees in the urban forest—in both private and public open spaces—are threatened by a scarcity of water that is not just imposed by rainfall decreases and climate change but by water restrictions as well. Water is a valuable commodity in limited supply, but by using the knowledge and data provided by research on the adaptations that many Australian trees have to water stress, much can be done in selecting and managing tree species for use in the urban forest that will allow amelioration of the heat island effect, reduction in wind speed, provision of shade, and reduction in energy use. Such outcomes should ensure enhanced economic viability, capture the health and social benefits that trees in the urban forest provide, and offer valuable green infrastructure that will contribute to the long-term sustainability of cities.
LITERATURE CITED


G.M. Moore
Senior Research Associate
University of Melbourne, Burnley
500 Yarra Boulevard
Richmond, Australia 3121


Resumen. El agua es un recurso valioso, la sociedad da prioridades para su uso, por lo que se ha dado lugar a la escasez para el bosque urbano. Sin embargo, el valor de los bosques urbanos en la prestación de servicios ambientales y ecológicos, que tienen beneficios significativos para la salud humana, el bienestar y la habitabilidad de las ciudades, exige el replanteamiento de la prioridad de uso de agua por el bosque urbano. Las autoridades de salud están defendiendo el valor del espacio verde urbano que puede requerir el uso de agua, especialmente el agua de lluvia, ya que el cambio climático amenaza con olas de calor más severas. Los árboles tienen un papel importante y de largo plazo en el diseño urbano, que utilice eficientemente y reduzca la contaminación de las aguas pluviales. El conocimiento de los sistemas de raíces de los árboles y su interacción con los suelos significa que el riego puede ser más objetivo de manera que maximice el uso eficiente y eficaz del agua. La comprensión del comportamiento estomático también permite la sincronización óptima del riego para la eficiencia fotosintética y la obtención de los beneficios del enfriamiento por transpiración, lo que puede reducir las muertes adicionales durante las olas de calor. Los beneficios económicos, sociales y de salud justifican el uso eficiente y efectivo del valioso recurso hídrico.