

Soil Issues for the Urban Forest

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Abstract

Trees form a vital part of the amenity and aesthetic landscape of built up areas. Trees are not inert objects and traditionally there has always been conflict between the needs of trees and the needs of infrastructure installation in urban areas. Very often the needs of trees takes second place and longevity and form of the trees is compromised.

In the last 10 years there has been a significant growth in the understanding of tree root physiology and, more importantly, this has translated into great advances in our ability to plan for tree rootzones. Some innovative designers are already employing these modern techniques and improved growth rates together with better protection of structures from root damage is already being seen.

The principles of root physiology and how “gap graded” and “structural” soils offer cost effective solutions to improving the lot of urban trees while reducing the risk of infrastructure damage is explained.

Tree Root Systems

The roots of plants can only live and grow under certain soil conditions. The basic determinant of the structure of mature root systems is the distribution of oxygen in soils. Table 1. illustrates the effect of oxygen levels and soil density on tree root function.

Table 1. Soil Properties for Root Growth and Function

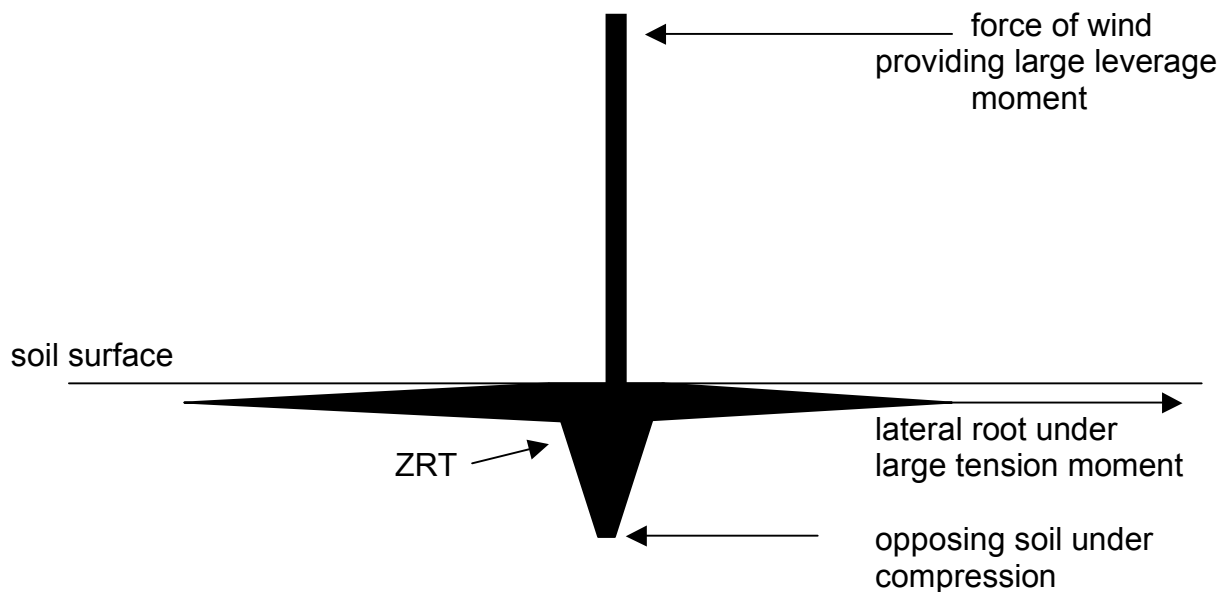
Soil Property	minimum	maximum
Partial Pressure of oxygen in soil atmosphere	21 %	21 %
survival	2.5%	21 %
growth	5 %	21 %
root initiation	12 %	21 %
nutrient absorption	15%	21 %
Bulk Density for adequate aeration	NA	
sands		1.8 g/cc
sandy loams		1.7

loams	1.55
clay loams	1.5
clays	1.4

The atmosphere is 21% oxygen. As one goes down a soil profile oxygen levels generally drop and the rate they drop depends on many factors. Gas diffusivity and demand rates drive the diffusion equations and are obviously affected by pore space relations (soil particle size distribution and density) distance from the free atmosphere, and gas consumption or production rates (rate of use of soil oxygen eg by the root itself and by decaying organic matter). The interaction of these factors lead to a fairly predictable distribution of roots in a soil in the following sequence-

1. The germinating seed sends down a “tap root” in an attempt to drought proof itself.
2. As the “tap root”, a juvenile structure, meets soil layers with less than 5% oxygen in the soil air it must stop growing, it cannot grow below 5% partial pressure of oxygen.
3. As this occurs new lateral branching roots are formed further up the soil where soil oxygen levels are 12% or better.
4. These laterals spread out in soil layers with 12-15% partial pressure of oxygen initiating new laterals and absorbing nutrients in the all important topsoil horizon.
5. With time the “tap root” and major laterals suberinise (becomes woody) to form the classic “zone of rapid taper” or ZRT which form the majority of the structural roots that keep the tree upright against the forces of wind. These ZRT roots hold the tree up largely via a classic lever and fulcrum model where the moment of leverage (wind in the branches) is opposed by a fulcrum (the bottom of the ZRT tap root) and an opposing moment, the tension strength of the horizontal lateral root.

Figure 2. The forces acting on a tree in wind



Thus in nearly all soils the structure of a tree root system is a “root plate” not a root ball. The root ball model, so widely promulgated does not exist. Tap roots do not exist in the classic sense, and it is true to say, as has been observed by arborists, that about 90% of a trees root system is in the top 200mm of soil. The root system spreads widely and shallow in the classic root plate. The spread of the root system, as seen in Figure 3, can be up to 2 times the canopy height. Notions of “drip line” of the tree being the extent of root spread are fictitious.

Figure 3. The Actual Root System of an 80 year old Oak.



After Watson (1997).

Implication for Civil Engineering

We all love trees in our urban environments. They provide shade, mollify temperature fluctuations, provide habitat, and aesthetic pleasure. In any development work these days it is often required that ancient or venerable old trees, rare trees or vegetation types or any trees for that matter must be retained on development sites. In almost all cases landscape plans will be required which nearly always involve tree planting. This often conflicts with engineering requirements, and while improving, the treatment of tree root systems or the provision of effective rooting volumes has not been good in the past.

For these reasons the longevity and health of our urban trees is usually a fraction of that in nature. Classic failures of established trees are often seen in the following circumstances-

1. After a period of heavy rain wind results in toppling of trees, classically tall form eucalypts on shallow sandy soils. Root plates, now vertical, are clearly visible. Mechanically the soil has saturated and lost strength to the point where the tension roots fail due to soil sheer failure.

2. After trenching close to tall form trees wind from the direction of the trench causes the tree to fail. Mechanically the critically important tension roots on the windward side have been severed and the tree has no resistance to the wind moment.
3. Filling over the rootzone even in layers as little as 100mm deep totally kill the root system and the tree dies or slowly goes backward in health often resulting in failure at some future time. The fill, particularly if clayey with low pore space has cut off oxygen diffusivity to the established root system to the point where the roots actually die (less than 2.5% oxygen) or cannot grow a new functional root system (less than 5% oxygen).

Preserving mature trees

There are many approaches to preservation of tree root systems. Probably the best guide is "Trees and Development" (Matheny and Clarke 1998). Only general comments are made here-

1. The ZRT or Zone of Rapid Taper is part of the "critical rootzone" and cannot be impacted upon in any way. It usually extends about 5 times trunk diameter.
2. Drip-line. Within the drip line of a tree (read canopy spread but actually defined as the zone of secondary thickening or woody roots) up to 30% destruction of roots is usually tolerated by healthy specimens and up to 50% by very tolerant healthy trees.
3. Outside the drip line 50% and up to 70% root destruction is tolerated.

These are guides only and provide for an estimate of the immediate impact of development only and a desire to prevent catastrophic failure. Obviously any rootzone loss at all will impact on the longevity and health of the tree.

A consideration of all these factors leads to the notion of a "tree root protection zone" where development should not occur and building activity and other forms of disturbance should be eliminated. This can only be guaranteed by 1.8 metre chain or weld mesh fencing, building contractors respect nothing less. A general formula of 12 to 18 times trunk diameter depending on form of the tree (more for tall form trees) seems to provide a fair general survivability for mature trees.

Planting new trees

There are really two questions that should be asked when considering tree planting-

1. Will the mature form of the tree pose a danger to built structures?
2. Will the tree be provided with an adequate root zone so that it can grow in a healthy and safe manner and not pose a danger or not provide an adequate form?

Trees are often blamed for damaging structures, either services or building footings. In only one case in 15 years can I clearly conclude that a tree has damaged a building. In this case a row of large Melaleucas were planted within 2m of a building within older style strip footings on moderately reactive clay. In my estimation damage is only possible where the following train of circumstances occur-

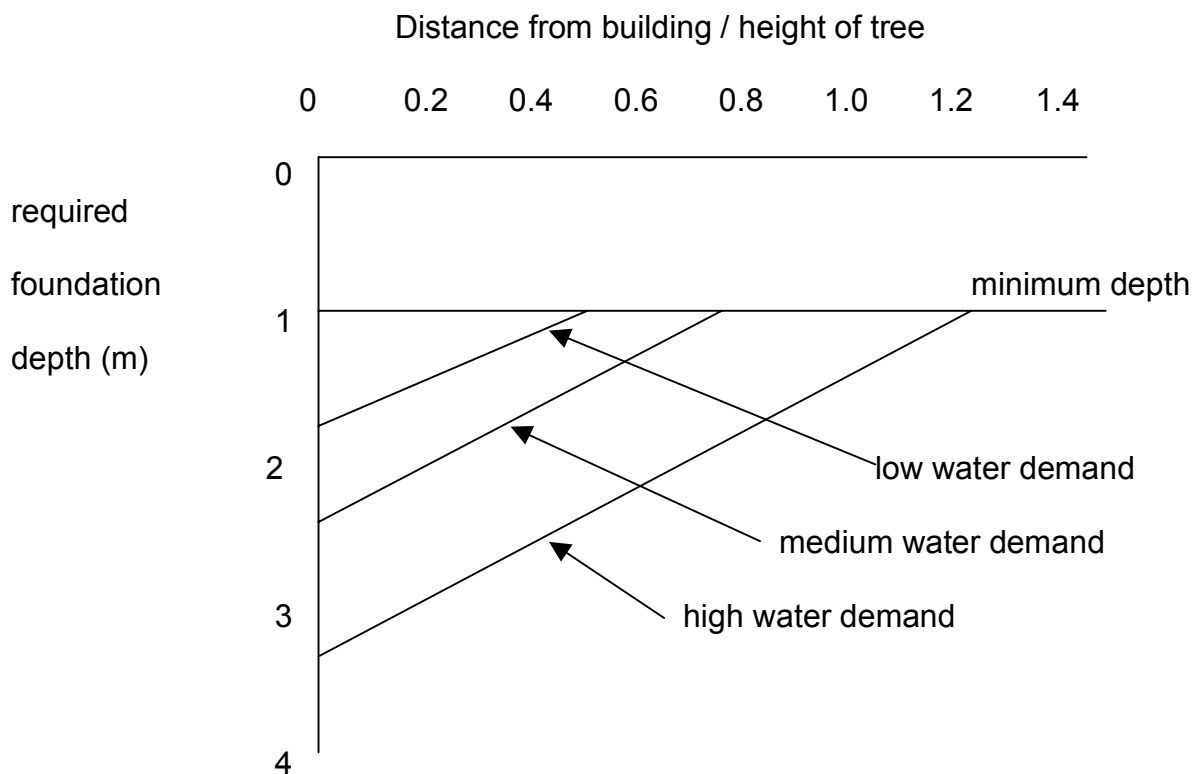
- soil is moderately reactive, unreactive soils such as sand provide almost no danger,

- the tree has special adaptations to tolerate low soil oxygen levels. Melaleuca for example grows in swamps and has special adaptations to allow roots to grow in low oxygen environments that allows them to grow deeply into heavy clay soils (ie under the footings) which other trees simply could not tolerate.
- footings are inadequate for the soil reactivity class
- trees are planted in close proximity, so close that they are in fact within the ZRT or certainly within the zone of secondary thickening
- the soil is subject to severe and prolonged wetting and drying cycles.

It is a combination of shrink/swell phenomena in reactive soils and mechanical lifting by roots as they suberinise (or go woody) that causes the damage. If any one of these factors were not present then the tree will probably not cause the damage.

Deciding just how close a tree should be is not an exact science but the following table reproduced from Bradshaw et al 1995 for highly reactive clays provides a good guide.

Figure 4. Distance recommendations for planting trees on reactive soils.



After Bradshaw et al (1995)

Remember these are for deep highly reactive soils only, the depth requirements can be reduced for less reactive or non reactive soils. The expected mature height of the tree should be used to derive the distance/height ratio.

Of course, foundation design also has a lot to do with it and a piered and beamed foundation is likely to resist shrink/swell forces much better than simple strip footings.

Protection of services installations is also important. The use of glued joint PVC pipe drains has greatly decreased the incidence of roots filling drains and cracking earthenware pipes but roots will still penetrate backfilled services of many types. They do this because the backfilling medium favoured by engineers is a “gap graded” type of material that flows, compacts easily to its full compaction and does not move or react thereafter. Unfortunately this type of medium favours tree root growth as well because even in the fully compacted state such gap graded media provide adequate pore space and good soil oxygen levels. In many instances roots will actually prefer your backfill medium to their natural (probably compacted and anoxic) surrounding soil.

The only solutions are to provide a different kind of medium for backfilling ie an evenly graded medium with high density or to use root barrier techniques. Root barriers are becoming more effective but research is needed in providing a backfill medium that does what the engineer wants but does not favour root growth.

Some new techniques

Gap graded soils are providing some new and exciting possibilities for better tree growth, longevity, and safety for our urban trees. Some techniques that have worked are-

1. Removal of compacted natural soil around venerable specimens and replacement with a “golfing green” type of soil. This is a gap graded soil with usually less than 5% in the silt and clay fraction and a predominance of medium sized sand particles. They are similar to services backfill soils but may have organic matter added.
2. Use of gap graded soil in a planting “vault” type structure for street trees. This is known as the “Amsterdam soil” or planting method (coenburg DATE).
3. Use of “Structural Soils”. Pioneered by Grabosky and Bassuk (1995 and 1999) these are essentially a bimodal particle size distribution where a rock matrix (usually 45 to 200mm diameter railway ballast) provides a physical support for roadways, footpaths etc and a “filler soil” partially filling the pore space in the ballast provides water and plant nutrients. They are designed to be laid under roadways, footpaths etc and provide increased rooting volume without compromising pavement stability. They can have enormous compressive strength sufficient for any level of trafficability. We do not use them unless high levels of traffic are anticipated, usually only in the most intensely used urban environment, for example around the Olympic railway station.

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