IS THERE ANYTHING NEW TO SAY ABOUT SOIL AND TREES?

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Abstract

This paper presents some current thinking and experience regarding the relationship between soil quality and tree performance. It presents information on the restoration of soils damaged during construction work, and also provides a summary of current thinking on soil profile construction. It concludes with some thoughts on the future of providing quality soil environments for urban trees.

Introduction

In this presentation I will be discussing some recent research that relates to the ways in which soil affects tree growth. At the outset, it is important to clarify that this paper is primarily directed towards the role of soil in tree establishment. There is clear evidence that soil conditions affect successful tree establishment and that there are benefits to understanding and possibly modifying soil conditions as part of the planting process. While soil changes can affect mature trees, there is little clear evidence that in such a circumstance tree health can be recovered by addressing soil issues. Since urban development usually results in damaged soil, this paper will address some of the strategies that can be used to enhance tree performance in difficult environments. In general, the approaches taken to remediate damaged sites are either to rehabilitate the soil material that is left on site, or to build a new soil profile entirely. In the interests of sustainability, the former approach is preferable as it minimizes the amount of new soil material required for the project, however on some sites soil is either not present or is completely unsuitable for use and in those cases new profile construction is required.

Useful Resources

Finding specific reference material to solve problems of urban and landscape soil can be difficult, however four resources stand out. These are: Australian Standard AS4419 *Soils for garden and landscape use*; two books by Philip Craul (Craul (1999), Craul and Craul (2006)), Leake and Haege (2014), and the chapter by Bassuk and Day in Calkins (2012).

A4419 has been around for about 16 years and, while still useful, is in need of an update. It sets out a group of properties that a soil blend must meet to be considered as useful in landscape applications. The “soils” that are categorized in the standard are blends of mineral soil and organic matter. The testing procedures described in the standard are widely used in labs that evaluate soil mixes, however in my view, the major limitation of the standard is that it doesn’t attempt, except in the most general way, to explain how various mixes could be used in landscape construction. So, as a consequence, one can’t ask a supplier to provide a soil that meets AS4419 and necessarily expect to get a product that actually meets your needs. There is going to be “soil” material in the market place that meets the standard but will not be fit for purpose in some applications. The user has to be quite well informed about the standard to be able to use it effectively.

Philip Craul has written two books that can be used to provide a sound basis for planning soil improvement or replacement. These are *Urban soils: applications and practice* (1999) and *Soil design protocols* (2006) which was co-written with his son Timothy. Until recently these were, to the best of my knowledge, the only books in English that specifically addressed the quite unique situation of designing soils for landscape and other urban applications. They are valuable for two main reasons. The first of these is in the setting out of approaches to soil design and the provision of explanations of the relevant principles of soil behaviour. The other is in the use of templates for the soil requirements of different landscape components. Craul calls these components “landscape elements”, and for each landscape element an outline of the soil profile requirements of that element are provided. For example, “Open trees in turf” will have a different profile to “ Covered trees” which relates to trees planted in paving.

As an introduction to the design of soils these books are invaluable, however they are of limited immediate practical use, as Craul is careful to avoid making specific recommendations for soil use. However, in both books there are useful case study sections that show how these principles have been applied to actual projects.

Leake and Haege's *Soils for landscape development* (2014) is a very valuable source. It does two main things. The first of these is to provide good advice for soil problem solving in landscape situations. This includes discussion of the minimum soil requirements for various types of vegetation, and also a good discussion of landscape drainage. The second is to provide a series of template specifications for different soils for use in landscape projects. These can be cut and pasted to attach to landscape specifications to provide a set of properties that must be met for a soil to be regarded as fit for purpose for a particular application. For instance, there are six different topsoils described. Three of these are for turf and lawns with different levels of use, and three are for garden beds with different quality expectations. There are also a series of specialist profiles for applications such as trees and green roof construction. The information provided is based on the authors' decades long experience in the evaluation and specification of soil for landscape projects in Australia. As will always be the case with textbooks, the user has to understand the background to the advice in order to choose the most suitable set of specifications for a particular job. Having said that, I do think that Leake and Haege (2014) is one of the most directly useful publications provided for the landscape professional. I would hope that as the industry becomes more aware of this book and its contents, soil suppliers will be able to start thinking about the blends they are selling in terms of how they meet the different requirements of the template specifications.

Meg Calkins' *The sustainable sites handbook* is a guide to sustainable landscape development and contains an excellent chapter on soil, co-written by Nina Bassuk and Susan Day. This chapter is a source of advice and methods for consultants and practitioners who need guidance on how to evaluate soil properties for various landscape projects.

Soil resource evaluation

The start of any decision making about soil and tree planting has to be an audit of the soil resource at the planting location that allows the determination of what soil is on site, what its properties are, and whether any of these are limiting to tree growth. Sampling is best done by either collecting an undisturbed core (for example, using a Dig Stick®, or by inspecting an exposed profile in a trench dug with an excavator or back hoe. Both approaches allow clear observation of horizon boundaries. As a minimum, the following soil information is a suggestion (to at least a depth of 500 mm):

- texture (noting changes with depth)
- structure (friability, penetrability, bulk density)
- aggregate stability/dispersivity
- permeability to water (on site percolation test, not lab testing of saturated hydraulic conductivity)
- pH and salt content
- nutrient status
- general information on site such as previous history, annual cycle (eg waterlogging, cracking) can also be useful.

The process of conducting and interpreting an audit may require specialist input.

This process assumes that we know what properties are important. For agricultural and horticultural crops we often have quite good understanding of the minimum requirements for productivity, allowing land to be rated for potential use (eg Cockroft and Dillon, 2004). The complexity of the plant palette available in the urban context is both a hindrance and an opportunity in this respect: a hindrance because we are often are poorly-informed about plant tolerances; and an opportunity because where we do know tolerances, tree selection techniques can be used to allow planting on sites where conditions are potentially limiting.

Two recent studies from the USA (Scharenbroch and Catania (2012), and Scarenbroch et al. (2017) have used detailed site investigations to identify the most important properties of soils and sites in terms of tree performance.

In the first study, soil pH, salt content, bulk density, water stable aggregates and soil organic matter were the most important properties although this study was based in a relatively small urban area with limited soil variation. In the more recent study, most variation in tree growth in a number of sites across the NE USA could be explained by looking at the open surface area around the tree and the level of soil compaction. This latter work is interesting in as much as it suggests that complex soil amendment projects may not be required in many cases.

Remediation of site soil

One of the approaches to improving growing conditions where site soil has been physically degraded by development work is to work with the soil resource on site. By reducing the requirement for bringing new, "manufactured" soil to the project, this approach can improve project sustainability, as long as the soil meets the requirements of the planting. On disturbed, compacted sites, profile drainage may be a major limit to tree survival and growth. To get a feel for how well (or poorly) a site is drained, the most useful measure will be an on-site measurement of infiltration rate. One such test is the percolation test, where a hole is dug and filled with water and allowed to drain several times. The hole should have vertical sides and be as deep as the largest containers that are to be planted at the site. The hole is filled with water several times and allowed to drain before the final test where the time taken for the hole to empty is recorded (Bassuk and Day, 2012). Where a planting hole takes longer than 24 hours to drain the soil is likely to limit plant growth or force plant selection towards species that tolerate wetter soil conditions. Laboratory assessment of saturated hydraulic conductivity (a drainage rate surrogate test used for blended soils) is not useful in this circumstance unless it is proposed to harvest the site's soil, stockpile it, and then reuse it once the development process is complete.

At the end of the site evaluation a judgement can be made as to whether the site soil is suitable for the proposed planting without modification, whether it requires minor tweaking (adjustment of pH, application of fertilizer), whether it requires significant inputs (importing of new topsoil, soil loosening/decompaction), or whether the site requires the construction of an entirely new soil profile. To make these choices you must be able to compare the needs of the planting type being proposed with the conditions that the site is going to provide, based on the soil audit. Remember also that plant selection is cheaper than soil modification, especially where soil is poorly drained.

Decompaction

Loss of soil structure and soil compaction are common problems on development sites. Poor soil protection and traffic pressure are to blame. The industry standard treatment for soil compaction is soil loosening by cultivation (Rolf, 1994). How this is done will depend on the scale of the project and varies from hand digging, through ripping with tyned equipment, to the use of excavator buckets to lift and loosen soil. To get the best results from cultivation the soil should be relatively dry as the aim is to fracture the soil mass into smaller units, but not so dry as to cause dust formation. If soil testing has indicated a benefit from the use of gypsum this can be incorporated at the same time. The depth of cultivation required is dependent on the kind of vegetation being planted and the depth to which compaction can be detected. Over time, some of the benefits of cultivation will diminish as aggregates collapse and as the weight of soil bears down on deeper layers. That said however, cultivation is well regarded as a soil improvement method, is relatively simple to perform can result in improved tree growth (Cass (undated), Rolf (1994), Somerville et al, (2018). Where mechanical root injury is to be avoided, compressed air excavation is an alternative to mechanical disruption (Fite et al, 2011).

Decompaction with organic matter addition

Recently several authors have advocated including an organic component in this decompaction work, especially where the cultivation is being done using an excavator bucket. Much of this work has been published by two researchers in the USA; Professor Nina Bassuk at Cornell University and Dr Susan Day at Virginia Tech. Professor Bassuk calls her method "Scoop and dump" soil treatment and Dr Day calls her method Soil Profile Rebuilding. Details of websites where these approaches are set out are given in the reference section at the end of this paper.

At the heart of each is the spreading of a layer of compost over the soil and then roughly mixing that into the soil with a backhoe or excavator. One variant, if topsoil is available, is 100 mm of compost incorporated to a depth of 600 mm with the backhoe then 100 – 200 mm topsoil (stockpiled site topsoil or imported topsoil) applied over the surface. If there is no topsoil available for use, or if the landscape does not require it, then 200 mm of compost is incorporated to a depth 600 mm. In both cases mulch is applied after site preparation. This work is well documented and research has shown improved soil conditions (reduced bulk density, increased infiltration rates, increased soil aggregation) and increases in plant growth. The scoop and dump/soil profile rebuilding approach has two useful aspects. One of these is that the method can be used on relatively wet soils as it is not essential to finely blend the soil and organic matter. The other is that the presence of the organic addition will help to reduce the tendency of the soil to revert to its original condition following treatment. A recent study at the Burnley campus of the University of Melbourne has been investigating the scoop and dump/soil profile rebuilding approach under local conditions and has found the same improvements in soil properties that the US work has indicated (Somerville et al, 2018). However, plant responses have varied and depend to some extent on the site conditions. For example at one location in West Melbourne, there was no improvement in plant growth rates over the experimental period because the soil was saline and this was a more important limit to growth than poor physical soil conditions. At other sites in this and a subsequent study, plant growth responses to soil loosening have been demonstrated. Soil that has been severely degraded during development work can be rehabilitated. Where the damage is physical, cultivation/loosening is a valuable pre-planting treatment. In my opinion, the scoop and dump/soil profile rebuilding approach has a great deal to recommend it, especially in landscapes where the expectations are high enough to justify the additional cost.

Building new soil profiles from scratch (soil design for soilless sites)

Rationale

There will always be situations where soil has to be imported for successful landscape outcomes. In years past, this soil was often productive agricultural soil that was harvested for use in landscape applications. As good soil has become scarcer, and as limits are imposed on soil harvesting, the soils that are available in the market place are based on blends of various mineral and organic components. What is used in a particular place will reflect the nature of the feedstock that is available locally. These "soil replacements" are called variously, soil blends, or manufactured soils. The term, designed soil, is also used on occasion. In my opinion, that latter term should only be used where a blend has been formulated to meet a specific planned outcome. That is, the soil has been designed to meet specific performance outcomes.

For the landscape designer or consulting arborist, the process has two parts. The first is identifying what the soil functional requirements of the landscape are to be. The "design elements" approach (Craul and Craul, 2006) argues that most landscapes can be split up into a relatively small number of components and each of these components has a characteristic soil profile allocated to it. This profile can be based all, or in part, on site soil, or it can be based on the use of manufactured soil blends. The second part of the process is then to develop written specifications for the soil profiles that are required, to satisfy the needs of each design element. They offer only general guidance as to the detail of these specifications although they do provide case studies to illustrate the points they are making. Leake and Haege (2014) provide exemplar generic specifications that can be used to describe the properties of the soil blends required for different kinds of landscape design elements. They also provide suggested guidelines for depths of profile layers, such as topsoil or subsoil, and also provide guidance for calculating soil volumes for trees.

Desirable properties of soil blends

A soil specification will describe the essential properties of a soil blend for a particular landscape application. Some of these are fairly obvious, including pH, salt content and nutrient status. The amount of added organic matter content is important and will be discussed later in this paper. Texture and structure are, in my view, not critical in the sense that they have to be specified, although there will be circumstances where that is routinely done. High performance turf is probably the best example. What is critical though, is the specification of the properties that are affected by texture and structure, and drainage rate is probably the most critical of these, as a poorly-drained soil will almost certainly result in substandard landscape performance.

Drainage rate of soil blends

Current thinking is that the potential drainage rate of a soil blend should always be specified and any candidate material should be tested before installation. This potential drainage rate is a laboratory test (the test is called saturated hydraulic conductivity (SHC)) and confusingly, there are three methods in use in Australia. These are: the test described in AS4419 (for landscape soil blends); the ASTM1619 test method (for sports turf originally - this tests SHC under compaction); and the McIntyre and Jakobsen method (used in Leake & Haege's generic specifications) which tests at a series of compaction levels, the level used in the specification being determined by the application that the soil is being specified for.

AS4419 sets a lower limit of 20 mm/h for a soil blend to meet the standard. The soil is not mechanically compacted in this test. ASTM1619 does not have fixed minimum levels but high performance turf often requires 150-200 mm/h to ensure that drainage is retained under compaction. This method is useful in applications where the soil is likely to become compacted during installation or with use, and some prediction of the effects of this risk is needed. In Leake & Haege (2014) most landscape soil blends require a minimum of 30 mm/h under moderate compaction tested according to the McIntyre and Jakobsen method. To make this issue more complex, results from these tests cannot be easily compared with each other, or with on-site percolation tests. In most cases, to find blends that meet these rates, the blends will be reasonably sandy with textures in the range sand to sandy loam. However, stay tuned on this issue, as there are concerns that these methods are not providing reliable information. This may result in changes to standards, testing protocols, and the way specifications are written.

Organic matter in soil blends

Most commercial soil blends have organic matter added to them, often in the form of compost. Superficially this seems like a good thing as there is plenty of compost around, organic matter is seen as having useful ameliorative properties in soil management, and it is seen as environmentally responsible to be returning compost to soil and to find a valuable use for the compost generated from large-scale commercial composting operations. However, too much organic matter can be a problem in soil blends. At present, recommendations are that added organics are kept close to the soil surface (upper 200 mm of the profile only (AS4419)) as this can avoid anaerobic decomposition of compost deeper in the profile. A consequence of this is that where deeper profiles are being built, the lower, subsoil, layers must be mineral soil only. Secondly, compost and similar added organics are often only partly decomposed and so will break down further once the soil is installed, resulting in a loss of soil volume and possible changes in soil properties (Craul, 1999). Craul (1999) suggests that added organics greater than 20-25% by volume of a blend will result in shrinkage and soil volume loss. In some composts, nitrogen drawdown may also affect early tree growth.

Soil for trees in paving

This topic has been dealt with in a number of other locations and I do not propose to cover it in any detail. The approaches undertaken to enhance tree growth in pavement can be summarized as being either non-compacted soil systems (cantilever pavement (Craul,1999) and soil cell approaches (Urban, 2008)), or compaction tolerant systems (uniform coarse sand such as Amsterdam Tree Soil (Couenberg, 1994) and structural soil (Grabosky et al, 2002)).

Sustainable soils

Craul (1999) raises the issue of sustainable soils: soil blends and soil replacement materials that are not based on soil and sand resources that are being quarried elsewhere for use in landscape projects. He advocates that waste materials of various sorts could be used to replace quarried soil. These materials could include quarry waste, crushed masonry, crushed glass and properly managed waste site soil. Such an approach requires more evaluation but Sydney Environmental and Soil Labs have already used this approach at at least two sites, Homebush (Leake, 2001) and Barangaroo (Leake and Haege, 2014), using crushed sandstone as a major component of blended soils. Structural soil is another approach that could be used to value-add waste materials by converting them to soil substitutes. Tree subsoils based on crushed brick/site soil structural soil are quite feasible in my view.

I would like to also suggest that another issue of soil sustainability that must be addressed is the increasing pressure that urban soils are going to be exposed to as populations increase and green space decreases. In a recent study for City of Yarra I found surface soil bulk densities around 1.9 Mg. m^{-3} in lawn areas around trees. These extreme values were simply due to very heavy public use. Tree soils of the future will have to be able to still function as root zones under compaction and this will probably require some inventive thinking. Recent work in Europe with various synthetic topsoils for perennial plantings suggests that there are approaches that should be evaluated for trees. For example, Schmidt and Murer (2014) have successfully used blends of crushed tile and brick with compost to provide top soils for herbaceous plants. Subject to particle size distribution and responses to compaction, novel materials such as these may also be useful for supporting trees in heavily trafficked areas. For anyone interested in how one might approach formulating such blends and what their properties might be, Rokia et al (2014) describe an interesting evaluation of the properties of blends of various urban waste materials used to create what they call Technosols (analogous to Urbic anthroposols in the Australian Soil Classification).

Conclusions

Use site soil information to assist with planning of new tree planning. Try to work with site soil as much as possible, which will require a knowledge of important soil properties for predicting tree performance. Be careful when using soil blends – use good written specifications and enforce adherence to them by contractors. Ask for recent test results when seeking to match sample test results to specifications. The properties of the soil you are specifying must be provided in the specification. You can't just use a description. "Premium sandy loam" or "Premium garden soil blend" are meaningless terms and not reliable indicators of performance. These days reasonably good generic specifications are available to use. For important projects, seek professional help if you aren't certain. Considerable work has been done over the past few decades to provide approaches to tree growing in difficult locations and good advice and information is available to specify these soils. We still have to do more work to allow us to grow trees well in the increasingly heavily-used urban environment.

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