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PLANTING AND ESTABLISHMENT OF TREESON DIFFICULT SITES

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ABSTRACT

The increasing demand for space for roads, services and footpaths and the use of old industrial sites for new housing developments have created new challenges for those organisations involved in the planting and establishment of new or replacement street trees. It is increasingly uncommon to plant trees in relatively undisturbed soils.

This paper uses examples from a number of case studies of failed tree plantings to identify the key issues in successful planting and establishment. The most common problems associated with low success rates include inadequate planning and site evaluation, poor quality stock, planting too deeply, the use of organic matter in backfill and insufficient depth and volume of soil.

Once identified, the causes of tree failure can then be avoided. The long term success of new landscapes requires knowledge of the principles of plant biology and soil science.

1.0 INTRODUCTION

Those of us who have grown up in older established parts of our major cities and regional areas probably take for granted avenues and parks full of established trees. I, for one, despair of the streetscapes and landscapes of the future. The huge changes in the physical environment of streets, new residential developments and parks established on recycled industrial estates, the fear of litigation and the economic “bottom line”, create new challenges for today’s horticulturalists and arborists.

To quote from one of my papers delivered at last year’s TREENET Symposium: *The long-term success of street tree plantings is the end result of a complex process involving many players. To date it would seem that there has been a fair amount of good luck rather than good management. As streets and roads become more intensively developed, the number of constraints to be considered in the tree selection process increases. Community expectations continue to broaden. Society is becoming more litigious. Managers must be more accountable financially, environmentally and commercially. All of these factors make it more important than ever to develop a systematic process of tree selection and establishment that delivers the benefits to which we all aspire* (Fakes, 2000).

One of the aims of TREENET is to promote a much more systematic approach to the establishment of our future streetscapes.

Tree planting and establishment are fundamental steps in this process. I have been called onto several newly developed landscape projects to advise on why the trees have failed. I am not the only person to have noted that there are some fundamental problems with the process. A quote from Maleike and Hummel (1992) possibly sums it up: *Of all of the cultural practices, those associated with improper planting have probably killed more landscape plants than anything else. For example, a tree killed* *by root rot may never have been infected if it had been planted in a planting hole with proper drainage.*

Included in any list of factors associated with the failure of tree plantings would be inadequate site analysis, poor design, inadequate or incorrect standard specifications which are not site specific, poor quality stock, sloppy planting practices and inadequate or destructive maintenance procedures. It is essential that everyone involved in the process of tree planting and establishment understand the biology and physiology of trees, their environmental requirements and the principles of soil science. Consistently, it is the below ground aspect of planting designs and tree establishment that leads to failures.

This paper considers tree establishment in situations where there have been often gross disturbances to the natural soil profile. It considers the desirable characteristics of a growing medium for trees as well as the common problems occurring in many current landscape soil mixes. The paper also discusses planting and establishment procedures that contribute to the failure of many new trees to thrive in new landscapes. Examples are drawn from a number of case studies. Whilst most of the examples are from landscape situations, the principles apply to street plantings.

The issues are not new and are well covered by Bernatsky (1978), Kozlowski (1985, 1992), Harris *et al* (1999), Craul (1992), Watson & Neely (1994), Hitchmough (1994), Watson & Himelick (1997) and many other researchers and authors. However, it appears that sound and sensible principles of plant growth and soil management go unheeded in many modern landscapes. The costs of failure can be great. Jim (1993) reports on the failure of a massive landscape planting in Hong Kong where thousands of plants of over 50 species suffered mortality rates of 10-100% over a period of less than one year. The main cause of the problem: failure to properly evaluate the pros and cons of a soil and its suitability for selected plant material before its use in the project because it was deemed too expensive to do so.

By studying failed and failing landscapes and tree plantings we can identify the causes and then consider how to treat them if possible but more importantly avoid them in the future. As with many tree problems, actual failure or death may take several years; thus valuable time for the establishment of long-term healthy trees is wasted. Similarly, once a tree is showing major symptoms of stress there may be no sensible treatment. Most good tree management involves anticipating the problems and then avoiding them.

CASE 1:

Reported problems and background:

Quite a number of Eucalypts in a two to three year old significant public place were showing signs of instability including leaning and socketing at the base. The socketing was much worse in windy and wet conditions. A number of trees had been replaced due to blowing over in storms or development of an unacceptable lean. The trees had healthy canopies and good trunk calliper and taper. The trees were planted in groups two years prior to inspection from 100 litre bags into constructed beds at least 600 mm deep and at least 5 m wide by 20m long. The beds appear as islands of trees within expanses of paving. The landscaping was part of a massive construction project in which the natural soils were removed and all pre-existing levels were changed.

General observations:

A healthy looking tree with a dense canopy but on a serious lean was excavated. A number of observations were made.

* A 100mm deep mulch of decomposed granite had set very hard and was difficult to penetrate with a screw driver or a mattock.
* The tree had developed some major surface roots away from the lean of the tree.
* These surface roots were located between the granite mulch and the soil mix.
* Some roots were growing upwards.
* The surface roots had developed above most of the original rootball.
* There were very few roots in the direction of the lean of the tree.
* The original rootball appeared to be constricted and some roots were decayed.
* The soil mix appeared to be very compact and was difficult to dig with a mattock.
* The soil was only moderately moist in the top 200mm despite recent heavy rainfall.
* At 250-300 mm depth, the soil had an anaerobic smell.
* The growing medium appeared to be a mixture of sub-soil clay, very fine sand/ silt and organic material; organic matter was clearly visible at 300 mm depth.
* It was reported that in the initial establishment phase of the project that the irrigation system went out of control and the site was flooded on numerous occasions.

At a later stage the root ball was hosed off and compared to a number of salvaged rootballs of other trees removed from the site. The rootballs all showed that severe girdling had occurred at several stages of the production process. Almost all trees had developed some lateral surface roots above the rootball and many showed roots growing upwards. A later excavation of the planting site found the depth to be 600 mm with the same mix to the bottom and organic matter obvious throughout.

Reasons for failure:

* <u>Poor quality planting stock</u>:

All trees that were removed due to their lack of stability clearly showed girdled root systems. Girdling had occurred at several stages in the production process; it is possible that some kinking of the roots may also have occurred early in the production process. Both kinking and girdling are serious and common problems with container-grown stock. The effects of these problems include lack of stability, reduced uptake of water and nutrients, constriction of the vascular tissues within the root and in extreme cases, the tree may snap off at ground level (Hitchmough, 1994). The effects of these defects usually become more apparent as the tree develops.

An evaluation of 510 Melbourne street trees by Leers (2000) showed that a significant number of the trees had performed poorly due to poor quality stock. The performance indicator was whether or not the trees socketed at the base after applying the “Burnley Test”. The recently published TREENET *Pilot study of tree planting in South Australia* (Lawry & Gardner, 2001) found that respondents considered availability and quality of nursery stock were the most important factors influencing the success of planting programs.

The larger the tree required in a container, the greater the risk of it being overgrown. The most serious problems develop if the tree is “pot-bound” at an early stage. According to Harris *et al* (1999), the most difficult root defects to correct occur at the trunk/root interface and in the centre of the root zone. These defects occur during the initial and intermediate potting times. To correct kinking and girdling at a later stage would destroy a large number of roots and is thus not practical.

Harris *et* al (1999) also note research that showed that if *Eucalyptus sideroxylon* with severely girdled root systems developed more than five roots above the girdling, they grew normally. However, he also notes that many trees, including Eucalypts, are lost from trunk-root breakage and root girdling which could indicate that not enough roots grow fast enough to support and sustain them.

It was clear from observing living and removed trees on the site that surface roots were being produced and that, so far, the trees appeared to be receiving adequate moisture and nutrients. However, the roots were not adequate to physically support the trees. It is also difficult to say what long-term effects the girdling may have on the health of the trees. Tree failure at a young age may impair the intent of the design, however, tree failure at a later stage, when the trees are much larger, could be dangerous.

* <u>Poorly aerated soil</u>:

The soil into which the trees had been planted appeared compacted and smelt slightly anaerobic. The soil texture felt relatively fine (very fine sand) and clay was present. According to the soil specification for the project, the “Horizon A” was a mixture of original grass, humus strippings, with topsoil, subsoil, debris and lime which had been amended with 10% animal manure and 20% organic matter to a depth of 100 mm. This was placed over “Horizon B” which was the original subsoil with lime added and processed with 20% organic matter. According to soil analysis results, the original subsoil was weakly structured and relatively impermeable. Subsequent soil testing found the bulk density to be 1.8 Mg/m3 (very compacted).

Oxygen is a primary limiting factor for root growth – laterally and vertically (Bernatsky, 1978; Craul, 1992; day & Bassuk, 1994; Kozlowski, 1985; Perry, 1982). Craul (1992) suggests that roots require 3% oxygen for subsistence, 5-10% for growth and 12% for root initiation. Roots must have oxygen for root respiration and therefore root function. Gaseous exchange between the atmosphere and soil pore spaces replaces oxygen consumed by roots and micro-organisms and removes carbon dioxide produced by them. Gaseous exchange is often limited by impermeable surfaces, soil compaction and flooding (Bernatsky, 1978; Craul, 1992; Day & Bassuk, 1994; Harris *et al*, 1999; Kozlowski, 1992). It is also compromised by fine textured soils and the decomposition of organic matter at depth.

Soil compaction not only limits aeration but it also limits infiltration and drainage. According to Kozlowski (1992), compaction also creates physical barriers to root growth. A root can only penetrate pore spaces with a diameter greater than the root. When compaction reduces root elongation and expansion, less water is available to trees as the water around the root is depleted. Continuous root elongation is necessary for the absorption of adequate amounts of water (and nutrients) during the growing season.

Roots “avoid” anaerobic growing conditions by forming a shallow root system and extend themselves along the surface (Craul, 1992). This was evident with the trees in question. When conditions are wet and windy, this surface root system may not provide adequate support.

Apart from water uptake, nutrient uptake is also affected by the influence of reduced aeration on root respiration (Craul, 1992). This was yet to be obvious with these young trees.

If conditions become too anaerobic, iron, manganese and aluminium may become toxic and in extreme conditions methane may be produced (Leake, 1998).

One of the major contributing factors to the anaerobic conditions on the site was the amount of organic matter in the soil mix. According to Handreck & Black (1994), most top soils contain less than 10% organic matter; 5-8% under long established pastures and about 2-4% for sclerophyll forests. Subsoils usually have less than 1% organic matter.

The presence of more than 5% organic matter at any depth can create problems of subsidence (Craul, 1992). Natural soil profiles rarely show any significant amounts of organic matter below 100-200 mm from the surface. Organic matter below this, particularly in poorly aerated soils, tends to be decomposed by anaerobic micro-organisms. Thus there is demand for oxygen from both plant roots and soil organisms. The products of anaerobic organism activity exacerbate anaerobic conditions. According to Leake (1994), if the demand for oxygen is severe enough, a series of chemical reactions set in and may lead to:

* a lack of soil oxygen and high carbon dioxide levels;
* the reduction and loss of nitrogen as a gas;
* root toxicity caused by reduced iron and manganese,
* hydrogen sulphide (“rotten egg gas”) production; and
* methane (“natural gas”) production.

The soil in question clearly contained organic matter and smelt anaerobic. If it was produced as specified, the quantities of organic matter are excessive in both horizons.

A number of researchers have shown that the addition of large amounts of organic matter to backfill soils does not improve growth and may have a detrimental effect (Maleike & Hummel, 1992; Perry, 1994; Smalley & Wood, 1995). Hodge (1995) also notes that with disturbed “native” soils, the use of organic amendments in planting pits is often of no more benefit than the structural improvement caused by digging and replacing the backfill. A possible exception to this could be the use of worm castes but this requires more research.

Another possible cause of the poorly aerated soils and the shallow rooting was the reported problem with the over-irrigation of the site during the establishment period. Flooding of these poorly structured, relatively fine and organically enriched soils would have significantly reduced aeration and would have encouraged rooting in the most aerated part below the granite. The diffusion of oxygen through water is ten thousand times slower than through air (Craul, 1992).

If the soil mix and then the granite mulch were installed with the use of a bobcat or similar, then mechanical compaction would have exacerbated all of the other problems. Standard specifications (ACT Public Works, 1991; Natspec, 1993) usually call for the “light” compaction of all fill progressively or in layers of 150 mm thick. This was the case on this project. The high bulk density readings would be evidence of such a process.

According to Craul (1992), soil handling, stockpiling and transporting may also lead to compaction and anaerobic conditions. These activities reduce organic matter levels, increase bulk density, decrease aggregate stability, decrease micro-organism activity (especially mycorrhizal fungi) and decrease nitrogen levels. The detrimental effects are greatest under moist conditions. The associated vibration repacks the particles closer together. A problem on large construction projects where landscape is just one aspect is that earthmoving or civil engineering companies usually carry out the bulk earthworks. Engineers and horticulturalists have diametrically opposed views on what to do with the soil; engineers compact it as much as possible, horticulturalists want as much air as possible. On large jobs the engineers generally win.

The hard-setting or crusting of the granite mulch may be the result of redistribution of finer particles and the filling-in of the gaps between larger particles. Craul (1992) reports on research that shows a 2 mm "washed-in" layer of redistributed and dispersed fine particles on top of bare urban soil profiles has a permeability 800 times lower than the layer immediately below. Decomposed granite is a commonly used mulch/ surface treatment in public landscapes in Sydney. Hard-setting and compaction are common problems and anecdotal evidence suggests that tree growth is restricted as a result of the associated poor infiltration and gaseous exchange.

* <u>Irrigation practices</u>:

The irrigation system is reported to have had problems. In the bed investigated, the outlets were located on the surface of the granite. The granite had set quite hard and runoff occurred. Any water that did get into the soil was likely to be near the surface; this may also have encouraged surface rooting. It was reported that trees in beds with the outlets below the granite were performing better.

General recommendations.

The following recommendations are general rather than specific for this case study. However, the problems outlined in this real example of a problem landscape are not uncommon with tree plantings on difficult and disturbed sites.

* <u>Stock selection</u>:

It must be made clear to all designers and specifiers that defective root systems are one of the major causes of tree failure in the landscape. Very little, if any, remedial action is possible to correct these defects. Root defects must therefore be avoided with well-grown root systems. A specification for the purchase of landscape trees such as that developed by Ross Clark (1996) should be used as guide. (This document is currently under review and a new edition should be available in 2002.)

* <u>Root pruning</u>:

Even when plants are well grown in their containers, it is important to ensure that root growth will occur in the right directions after planting. Roots grow from the ends of roots and a container is like a mould. Planting is essentially the final "potting-on" and thus plants should be root-pruned at this stage (Clark, 1998). The disruption of the roots could include shaving the outer 5-10 mm from the outside of the rootball. Other authors suggest slicing or "butterflying" the root ball (Harris *et al*, 1999; Watson & Himelick, 1997).

* <u>Soil mixes and soil handling</u>:

When specifying soil mixes consider aeration and drainage, large particles and low organic matter. Craul (1992) is an excellent reference for such specifications. Consider natural soil profiles – organic matter is near the surface and soil particle size generally decreases with depth. If recycled or previously disturbed site soils are to be used they should be analysed by an appropriate soil testing laboratory with experience in landscape soils. Apart from the soil's current status, it is important to predict how they may perform after handling. Craul (1992, p347) suggests a methodology for on-site soil investigations.

If stockpiling site soils, handle them drier rather than moist; handle as little as possible; store in several small piles of < 1.8m high for sandy soils and 1.2 m for clay soils; store for as short a time as possible and protect from erosion (Craul, 1992).

* Compaction:

If compaction will be an on-going management problem it may be preferable to devise and blend a planting medium that can withstand compaction. Research in the United States has shown that blends of soil with rigid, porous, preferably inert materials can withstand compaction for long periods of time (Day & Bassuk, 1996). Materials studied have included sintered fly ash, expanded slate and rocks such as crushed limestone (Grabosky & Bassuk, 1995). Patterson & Bates (1994) monitored control soils and variously amended soils in a heavily visited landscape at intervals of 22 years. They found that soils amended with expanded slate and sintered fly ash had significantly lower bulk densities and higher total pore space than cultivated and undisturbed soils.

On a site with a silty loam soil, plots amended with coarse sand performed worse than the control. Harris *et al* (1999) states that at least 45% of the volume of a soil mix needs to be sand before the mixture begins to have some of the properties attributed to sandy soils.

The use of "gap-graded" soils has been an integral part of the construction of sports turf playing surfaces such as bowling greens, golf greens and sports fields (Adams, 1994). Gap-graded soils are those that are missing a particular range of particle sizes. When compacted they retain macro pores (Leake, 1998). A soil blend commonly used in Sydney for these purposes is "80:20" – 80% sand and 20% sandy loam.

An extreme example of these soils is the "structural soil". Structural soils are a blend of graded aggregate, (for example crushed basalt 40 or 60 mm in diameter), sandy soil, a tiny amount of well-composted organic matter and a very small percentage of clay for cation exchange capacity. The aggregates can be compacted to structural loadings whilst retaining large macropores and the "filler" soil provides the chemical and physical requirements of plant roots. The most extensive use of these soils in Australia so far has been in the construction of the Railway Precinct and Olympic Boulevard at Homebush Bay, the site of the Sydney 2000 Olympics. Brisbane City Council has also used variations on structural soils in some of their CBD tree planting projects.

The down-side of these soil blends includes leaching and low water-holding capacity, however, once a planting is established it is far easier to add water and nutrients than it is to add air. Structural soils are very expensive and their use will be restricted to high value landscapes where pedestrian or vehicular traffic is high and the trees are to be planted in paved areas.

The use of a backhoe or excavator to aerate and decompact soils prior to the installation of a soil mix or as soil preparation prior to planting has been shown to be beneficial (Rolf, 1994). Craul (1992) also suggests that the correct sequencing of site works is important and should be such that one phase of the project does not interfere with another. A common practice is to grade and compact the sub-grade layers, then spread and level the top soil mix and then carry out other operations such as installation of irrigation, paving and so on. Usually this involves traversing the top soil with machinery thus compacting it before planting. He suggests having all of the deeper services and drainage installed and then backfilled. Then the next lower services, such as irrigation, should be installed and backfilled to an appropriate depth below the final grade. The depth of the final grade should relate to the type of plants to be installed.

Remediation of compacted soils once plants are established is difficult. Aeration by compressed air has been found to be of limited value, particularly if the area is to be recompacted by pedestrian or vehicular traffic (Day & Bassuk, 1994). Compaction is best planned for and minimised during the construction and planting phase.

* Mulches:

The mulch used in this case study was decomposed granite. The choice appeared to have been based on aesthetic considerations. This is a product that continues to decompose and as such there will inevitably be problems with the distribution of particles and pore spaces affecting water infiltration and gaseous exchange. This is not a gap-graded material. Anecdotal evidence from Darling Harbour in Sydney suggests that a mixture of 50% gravel (about 5 mm) and 50 % decomposed granite is a more permeable option; however, it is still far from perfect.

Where possible and practical, organic mulches are the best choice for most tree plantings. The benefits of mulching have been widely published; key effects are weed suppression, a decrease in evaporative losses from the soil and the promotion of soil organism activity. May (1993) suggests that for stock up to 200 mm pot size, an area of 1 m in diameter should be mulched and for larger stock an area up to 2m in diameter. He also suggests that the first growing season is the most critical for tree establishment and that mulch levels should be maintained for at least that long (longer if possible). Mulch also protects trees from mower and whipper-snipper damage (a common cause of poor establishment).

Leake (pers. comm, 2001) suggests that organic mulches should be installed to a maximum depth of 75 mm. This is adequate for weed control and will not compromise water infiltration or gaseous exchange.

CASE 2:

Reported problems:

On a recently completed major public landscape, a significant number of plants of a range of species were declining or dead. The planting was completed 6 months prior to inspection and a number of plants had already been replaced. The main species affected were *Macrozamia communis* (Burrawang), *Syzygium luehmannii* (Lillypilly) and *Tristaniopsis laurina* (Water Gum). The landscape was part of a major project involving the creation of new soil levels with large beds for the planting of trees and shrubs and lawn areas with occasional trees.

General observations:

In the areas in which the dead and dying plants were growing, the site soil was inspected and found to be wet to a depth of 300 – 350 mm where it became saturated and free water was found. The programmed irrigation had been cancelled for at least 3 months and watering had occurred only infrequently due to the imposition of water restrictions in a recent dry spell. A sub-surface drainage system was reported to have been installed.

A number of root balls were inspected for moisture content. Recently planted stocks from 120 mm containers were wet and some of the larger, more advanced trees had varying moisture levels. Some of the large super advanced trees had dry root balls despite the surrounding soil being moist to wet. Moist to wet site soil was found on top of these rootballs to a depth of 20-30 mm.

A number of dead and dying Burrawangs and Lillypillies were removed. They had roots that were sitting in very moist soil above an almost saturated clay layer. A number of the Lillypillies were showing symptoms that looked like those from the pathogen *Phytophthora cinnamomi*; that is, leaves wilting, yellowing and dropping or remaining on the plant and turning brown as they wither and die (Marks *et al*, 1982). The root systems did not appear to be physically defective, i.e. kinked or girdled.

Possible causes of failure:

* <u>Root-rotting organisms</u>:

Samples of root and soil mix were sent to a plant pathologist and the presence of both *Phytophthora cinnamomi* and *Pythium* sp. was confirmed. Both of these fungi cause root rot. Of the two, *Phytophthora* is the most serious. *Pythium* species are commonly found with *Phytophthora* as they prefer similar conditions and spread in similar ways.

According to Marks *et al* (1982), *Phytophthora* root rot is favoured by the following conditions:

* saturation of the soil for short periods of time, usually after heavy rain (or irrigation) or as a result of run-off from hill slopes and drains;
* poor internal soil drainage;
* soils of low fertility containing little organic matter; and
* soil temperatures above 16°C.

Combinations of these factors greatly aggravate the disease. In wet conditions the organism produces very large numbers of motile spores that are propelled through wet soil by tiny flagella. In dry conditions the organism survives by producing thick-walled spores that can survive for many months (Tattar, 1978).

Of the conditions described above, the most relevant to this site are saturated/ wet soils, poor drainage and suitable soil temperatures. The soil test results indicated a reasonably fertile soil. The soil was well mulched with organic matter [mulching is one of the methods of reducing the impact of *Phytophthora* by increasing the numbers of other soil organisms}. However, the very poor drainage would make it very difficult for beneficial soil organisms to survive.

There are many possible sources of the disease including:

* pre-existence on the site before construction (the site in question was grossly disturbed and had a long history of imported soils);
* contaminated imported “top soils”, and or
* present in contaminated nursery stock.

Regardless of the source, the environmental conditions on the site favoured the pathogens instead of the plants.

* Drainage:

Adequate drainage is essential to the success of any landscape. Low soil oxygen levels and wet conditions favour the pathogens and inhibit successful plant growth and those beneficial soil organisms that compete with the pathogens. Wet soils will favour the spread of both root rot organisms. Poorly drained soils can be prone to flooding or saturation after heavy rainfall or through over irrigation. According to Kozlowski (1985), flooding quickly depletes the soil of oxygen and produces a number of deleterious effects on plants including reduced shoot, root and girth growth, arrested leaf initiation and expansion, death of fine absorbing roots and induces premature leaf senescence.

The drainage problems on this site and many other similar sites could have been caused by a number of factors including:

* inadequate depth of “top soil” over compacted subsoil;
* too many fines in the soil mix leading to clogging of the filter fabric around the drains; and or
* poor location and installation of sub-soil drains with respect to planting holes of advanced specimens.

* Trees planted too deeply:

According to Watson & Himelick (1997) and Ball (2000), planting too deeply is the most common mistake made during planting and is almost impossible to correct. In my experience this is a chronic problem with the landscaping industry. Unfortunately, a number of widely used “standard” industry specifications state that the soil must be excavated to 100 mm lower than the depth of the root ball. When loose soil is placed back in the hole, the weight of the rootball (especially that of super-advanced trees) could easily lead to structural collapse and then subsidence.

There are a number of possible problems associated with planting too deeply:

* water penetration into the root ball may be impeded if the soil into which the tree is planted is finer in texture than the potting mix; this creates a perched water table;
* mechanical damage may occur to the base of the stem; this may predispose the tree to infection by secondary organisms; and
* gaseous exchange between the rootball and the atmosphere may be compromised.

Even if a tree is planted correctly, the root ball may subside if the soil into which it is planted is very high in organic matter. As the organic matter decomposes there is a loss of soil volume. The demand for oxygen and the gases produced by soil organisms could exacerbate any problems with aeration.

Recommendations:

* Correct planting depth:

Ensure that the level of the rootball is level with the finished level of the soil FOREVER! A simple way of achieving this is to dig the hole to the depth of the rootball. Extra care needs to be taken with bare-rooted trees.

* Drainage:

The need for drainage must be based on a clear understanding of the needs of the plants to be grown and a thorough investigation of the drainage characteristics of the site. Drainage design needs to be based on sound principles. Sub-soil drains only remove water when the drains are at or below the impeded layer. In very heavy clay soils, water movement may be extremely slow and the value of drains may be limited; i.e. water needs to get into the drain before it can be removed (Hitchmough, 1994).

* Pathogens:

Whilst it is possible to treat pathogens such as *Phytophthora* and *Pythium* with fungicides such as phosphonic acid, the effect is generally short term and on-going applications are required. The best long-term solution is to avoid the problem by ensuring good drainage and a medium in which plants are able to thrive. *Phytophthora* resistant, vigorous healthy plants in a well-drained fertile soil rich in organic matter would be the best option.

* Start again:

In many landscapes/ streetscapes where major problems have arisen, the best solution may be to start again. However, this is often unlikely to occur because the money allocated to the project has been spent. Where physical site conditions are too expensive or too difficult to remedy, revision of the planting scheme to include more tolerant plants may be a reasonable option. Plant selection should be based on the constraints of the site or the site modified to provide a suitable environment for the chosen plant species. This must certainly be based on a thorough site analysis.

OTHER TYPICAL PROBLEMS FROM ACTUAL LANDSCAPES / STREETSCAPES

*** Inadequate depth of topsoil:**

I have seen numerous landscape plans for massed planting areas showing depth of topsoil mix to be 100 mm or 200 mm over compacted sub-grade (usually heavily compacted clay subsoils). If washed turf was to be installed on a very sandy topsoil of this depth there would probably be very few problems. However, when trees are planted into such conditions, even from 5 litre containers but generally from much larger containers, there are a number of problems that can and do develop. The most obvious one is that the root balls end up sitting in a well of water and suffer from oxygen deprivation.

Equally astounding are the instances where trees in containers of 45-300 litres are ordered for a site and the hole is dug into underlying rock in order to accommodate the trees! A basic step in site analysis is surely to establish the depth of available topsoil and then to modify the design or the specifications accordingly.

Adequate soil depth is essential for aeration and drainage, water storage and support (especially during wet conditions). Craul (1992) suggests that a (drained) depth of 450-600 mm provides sufficient water storage and rooting volume in areas of reliable rainfall. Drier areas would require deeper soils unless irrigation was supplied. Perry (1994) suggests a depth of 400 mm for good tree growth and 500-750 mm for excellent tree growth. If adequate depth can’t be provided over the entire site then greater depth at tree locations can be created provided there is adequate subsoil drainage (Craul, 1992, Fig. 9.16).

Conventional containers (pots/ bags) tend to have dimensions where depth roughly equals diameter. Large containers are often deeper than most available topsoils or specified depths of soil mix (Table 1). Perhaps thought could be given to growing plants in "low profile containers" as described by Milbocker (1994) and Gilman (1994) or perhaps designers will have to specify smaller plants in smaller containers.

Table 1: Depth of container (mm) for various container sizes.

Pot or Bag size (litres)	Depth of container (mm)
5 (8"/ 200 mm pot)*	**200**
10 (10"/ 250 mm pot)*	**250**
16 (12"/ 300 mm pot)*	**300**
25 **	**350**
45 **	**425**
75 **	**510**
100 **	**590**
200 **	**625**
300 **	**693**
400 **	**715**

(Source: *A. Salter (pers. comm.); ** Premier Plastic Products (pers. comm.))

*** Inadequate rooting volumes:**

One of the major problems affecting the survival of trees in constructed sites, particularly street trees in built up areas, is inadequate soil rooting volume. Typical planting pits are compacted and poorly drained and are often filled with organically enriched potting mixes. Any restriction to root extension will ultimately affect nutrient and water uptake that will then affect the root: shoot ratio. Mechanical support could be jeopardised and trees may even become "pot-bound" as roots girdle themselves at the root collar. The effects of restricted growth may take several years to become obvious (Craul, 1992). The problems of poor root volumes are exacerbated if the sides of the hole are glazed or smeared and the roots are unable to "escape" (Hitchmough, 1994). The true success of a street planting or landscape is not really known until the trees reach maturity and meet the intent of the design. If this fails to happen or takes far longer than anticipated, then the design or planting has failed.

Trees require large quantities of water to replace that lost by transpiration. In city environments hot reflective surfaces, wind tunnels and turbulence from passing vehicles can create additional atmospheric demands and thus increase water loss from trees. The soil should be capable of supplying adequate amounts of water to meet these needs over a period of time. In order for plants to use water there must be adequate oxygen for root respiration. To supply a tree with enough water for any length of time there must be a reasonable volume and depth of soil for adequate water storage. It should also be noted that soil water is a solution in which most of the essential elements must be dissolved and available for normal plant growth.

Lindsay & Bassuk (1991, 1992) use a "water budget" approach to establish the volume of soil required to store enough water to sustain growth between irrigation or rain events that would bring the soil back to field capacity. This is a relatively simple approach based on crown projection, leaf area index, evaporation rate, crop factor, moisture storage for variously textured soils and so on. Most of this data can be found in texts such as Handreck & Black (1994). A point to note however, is that this method assumes that irrigation is installed, or that the tree will be watered, or that when it rains there is sufficient precipitation and that whatever falls will enter the planting pit!

Lindsay & Bassuk make a general recommendation of 2 cubic feet (approx. 0.06 cubic metres) for every square foot (approx. 0.09 square metres) of crown projection (i.e. the area under the tree's dripline). This translates to the soil being 600 mm deep in the area that will be within the dripline of the mature tree (Watson & Himelick, 1997). According to Perry (1994) this figure is in general agreement with other researchers. Hitchmough (1994, p378) has used the methodology of Lindsay & Bassuk (1991) to calculate soil volumes to support woody plants in fully containerised situations under Australian conditions. The results are very interesting and help explain the poor growth of many of our urban plantings, especially in unirrigated planter boxes and streets.

Craul (1992) and Lindsay & Bassuk (1991) cite other research where minimum volumes of soil for adequate tree growth range from 7 - 8.5 m^3 to optimum volumes of 17, 70 and up to 200 m^3 for medium to large trees. Many planting pits are lucky to be even 1 m^3. A generous planting hole presently specified by a major Sydney council is 2.4 m long x 1.2 m wide x 1.5 m deep or 4.3 m^3. This appears to be generous by local standards but consider that the depth is 1.5 m, far deeper than the roots are likely to grow. If we assume that the roots are likely to exploit the top 500 mm then the effective rooting volume is now only 1.5 m^3. The area of soil exposed to the surface for gaseous exchange is also an important consideration and therefore suitable volumes should not be achieved by simply increasing depth (Perry, 1994). Craul (1992) suggests that tree pit depth should be a minimum of 450-500 mm and should not exceed 600-900 mm.

Various authors discuss the ways in which rooting volumes can be increased in urban environments (Bradshaw *et al*, 1995; Couenberg, 1994; Craul, 1992; Harris *et al*, 1999; Hitchmough, 1994 and Watson & Himelick, 1997). Strategies include suspended pavements above large planting pits or vaults and linearly connected planting pits with drainage (and with or without irrigation or aeration devices). These references should be considered by anyone designing tree planting systems for urban areas. Brisbane City Council has used planting trenches with suspended slabs in some of their recent CBD redevelopments (Lyndal Plant, pers. comm.). The use of “structural soils” already mentioned and outlined by Grabsosky & Bassuk (1995) and Selvey (1998) is another strategy for dealing with the conflict of trees in paved areas.

*** Drought:**

Bradshaw *et al* (1995) estimate that in Britain about 1.7 million recently planted trees die annually from drought with an estimated cost of £4 million. I know of no figures for Australia but from observing new landscapes and street plantings I would suggest that the cost would be high. Unfortunately it is common to see recently planted trees wilting or dying from drought stress. In some instances it appears that watering immediately after planting is seen as an optional extra.

In the survey of street tree planting in South Australia (Lawry & Gardner, 2001) it was interesting to see that the council that spent the most on purchasing their trees ($280.00 per tree) spent nothing on watering and some councils spent up to 40 times more on water than the cost of the plant. On average, watering and tree purchase costs consumed the greatest percentage of the establishment costs. So maybe there is hope after all!

Most containerised plants are grown in organic potting mixes with a relatively high air-filled porosity and relatively low water holding capacity. It is not uncommon for plants in nurseries to be watered once or twice a day depending on container size. Watson (1994) suggests that up to 85% of the available moisture from containerised root balls can be wicked away when they are planted into finer textured soils. The high root density in containerised plants compared to balled and burlapped trees also tends to increase the loss of water from the root ball (Gilman, 1994).

Depending on soil temperature and moisture levels it may take several weeks or longer for roots to grow into the surrounding soil. During this time the tree is entirely dependent on its root ball for its water supply. According to Watson & Himelick (1997 p 144) root growth will stop when soil moisture content is reduced to a certain critical level. Root suberisation is accelerated in dry soils thus reducing the effective water absorbing surface. Roots do not regain their full capacity for water uptake until new roots can be produced. When plants are rewatered immediately after root elongation ceases they may not regain elongation for at least a week. The longer that water is withheld, the longer it takes to resume root growth. Prolonged drought will lead to root death. Therefore it is essential that the rootball be kept moist for successful establishment. This means frequent irrigation with controlled amounts of water directed into the root ball. When we consider common planting and maintenance practices it could be assumed that we are not seeing optimum plant performance!

As a rule of thumb, immediately after planting, the rootball should be supplied with a volume of water at least equivalent to the volume of the container from which it was planted. Hitchmough (1994) suggests a minimum of 5 litres for tubestock. For plants up to 45 litres it should be possible to bring the plant to container capacity (by plunging it into a container of water and letting it drain) within about an hour of planting. The creation of a berm at the edge of the root ball helps direct any water applied into the root ball.

If irrigation is considered necessary it should be thoughtfully designed and based on local environmental and below ground conditions. Harris *et al* (1999) and Hitchmough (1994) provide good coverage of this topic. The Lindsay & Bassuk (1991) model is also very useful for determining water requirements.

*** Failure to systematically evaluate the success or otherwise of tree plantings.**

How do we know if a planting has been successful or not? Mere survival is no mark of success. I know of no councils in Sydney that keep detailed records of the success of their new tree plantings. According to Miller (1997), good record keeping is essential to a good tree planting program. The increasing use of tree inventory systems by councils and large parks should enable better tracking of tree performance and the costs and benefits associated with tree planting.

It is pleasing to see the work done by Michael Leers (2000) from Burnley College in the evaluation of over 500 trees in Victoria. Stephen Soldatos (2001), a Diploma of Arboriculture student from Ryde College of TAFE has recently collated three years of detailed data collection on new tree plantings in Centennial Park in Sydney. This will be an ongoing process in the evaluation of stock and maintenance procedures.

An inherent component of the TREENET program is to evaluate the success of new tree plantings. TREENET has published "Recommendations on standard measurements and data collection for TREENET street tree evaluation sites". The data recommended for collection covers tree and site identification, soil characteristics, site factors, planting date, nursery stock details, tree measurements (height, spread, diameter), and survival rate and performance observations. It is hoped that the resultant data base will be a useful tool in assisting organisations with their tree selection and management practices.

CONCLUSIONS

The successful establishment and subsequent long term growth of trees in difficult and constructed landscapes is the culmination of many individually significant steps. Hitchmough (1994, p. 114) summarises these steps. Those of particular relevance to this paper are:

* The initial design should not only meet the needs of the potential users of the site but it should also meet the needs of the plants.
* In constructed and grossly disturbed sites, the needs of the trees may have to be engineered. The specifications for site works to meet these needs should be based on sound principles of soil science, plant physiology and ecology.
* Serious thought should be given to the quality and quantity of the growing medium with criteria such as volume, depth, aeration and organic matter based on fact not fantasy.
* If site and budgetary constraints limit the ideal environment then species known to be tolerant of poorly aerated restricted soil volumes should be used.
* Quality plants must be used. The cheapest a plant will ever be is when it is in its container. After planting it becomes "value added". A defective plant once planted and maintained is a waste of limited resources and is unlikely to provide the functions for which it was intended.
* Planting and establishment practices must be based on an understanding of the root system and the root environment with particular consideration given to water management.
* Remedial action is rarely possible and successful; preventative measures are the only sustainable options for the long term success of landscapes.

Finally, tree managers need to make themselves indispensable to landscape architects and landscape contractors. At the very least we need to be able to communicate the basic needs of trees to these people. Tree managers must also recognise their limitations and seek the advice and co-operation of soil scientists, landscape architects and even engineers if we are to create grand public tree plantings for the future in increasingly difficult urban environments.

A SUMMARY OF PLANT SELECTION AND PLANTING PRINCIPLES AND PRACTICES

Stock selection. **–** this should be based on the following reference.

Clarke, R (1996) *Purchasing Landscape Trees: A guide to assessing tree quality*. Natspec Guide No.2, Construction Information Systems, Milsons Point.

Key issues for trees:

- trunk must have adequate stem taper and be self-supporting in its container
- there must be good root occupancy of the root ball
- no girdling or kinking of any roots within the root ball
- roots must fill the container without being over-grown
- trees must be free from included bark (unless this is typical of the species and is known not to lead to structural failure)
- there must be adequate root volume to support and sustain the above-ground sections

Planting

* Ensure that there is an adequate depth of drained soil for the stock size to be used.
* Do not plant when the air temperature is over 35°C or if the soil is waterlogged.
* For containerised stock up to and including 45 litres, bring the plant to container capacity within one hour of planting. For stock over 45 litres ensure that the root ball is moist and that plants are not wilting.
* Remove existing turf or mulch. (Area to be specified.)
* The planting holes are to be a minimum of twice the width of the container and to the depth of the root ball.
* The sides of the hole shall be rough and not glazed.
* Ensure that all containers are fully removed from the root balls. No part of the plant shall be damaged during this process.
* Depending on container size, remove the outer 5-10 mm of the root ball.
* The plant should be centred in the hole and then backfilled with site soil in good tilth.
* The top of the root ball must be level with the finished level of the soil and must remain so.
* Organic matter must not be placed in the bottom of the hole.
* If fertiliser is to be added it should be placed in the upper section of the backfill. The type of fertiliser, rate of application and area to be covered must be specified.
* The backfill must be placed around the root ball to ensure good root contact without being overly compacted.
* The remaining excavated soil should be placed as a mound around the edge of the root ball to create a watering well.

* Each plant must be watered within one hour of planting. The rate must be specified. As a rule of thumb, apply one litre of water for every litre volume of container. The water must be applied through the root ball. The application of water must not damage the plant or dislodge the root ball. Depending on soil moisture conditions, additional water may be applied to the soil surrounding the root ball.
* If mulch is to be applied, the type, depth and area must be specified. In general, organic mulches should be applied to a radius of 500 mm from the trunk/ edge of root ball and to a depth of 75 mm.
* If tree protection measures are required such as tree guards or marker stakes, these must be installed in such a way that no damage is done to the trees. In most situations, trees should not be tied to stakes (see Stock Selection - trees should be self-supporting when purchased). <u>If</u> additional support is required, 2-3 stakes should be used. These should be driven into soil beyond the root ball and must not interfere with branches or foliage. Trees should be attached with jute webbing or other material which is flexible and which will not damage the plant. The ties must be low enough to allow trunk movement but high enough to provide support for the root ball.
* Remove all other ties and labels from the plants.

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