TREENET

PROCEEDINGS OF THE

2TH NATIONAL STREET TREE SYMPOSIUM

6 & 7 SEPTEMBER 2001
ADELAIDE UNIVERSITY - WAITE CAMPUS
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TREENET STREET TREE SYMPOSIUM
6-7 SEPTEMBER 2001
ADELAIDE UNIVERSITY – WAITE CAMPUS

Thursday 6 September

8.30 - 9  Registration
9 - 9.05  Welcome – David Lawry (5 mins)
9.05 - 9.50  Keynote address – Judy Fakes - Planting and Establishment of Street Trees on Difficult Sites (45 mins)
9.50 - 10.30  Tim Johnson – Establishing Treenet Trial Sites (40 mins)
10.30 - 11.10  Morning Tea, Trade Displays and Tree climbing demonstration – Urrbrae House and Gardens (40 mins)

Research Papers
11.10 - 11.50  Derek Moore (Ph.D. Thesis, Melbourne Uni) - Nursery Practices and the Effectiveness of Different Containers on Root Development
11.50 - 12.10  Sarah Bone (Masters Thesis, Melbourne Uni) - Preliminary Results of a Corymbia maculata (syn. Eucalyptus maculata) (Spotted Gum) Provenance Trial using Street Tree Selection criteria
12.10 - 12.40  Aaron O’Malley (Masters Thesis, Uni. SA) - Effects of Street Trees on Soil Moisture, urban Dwellings and Pavements and the establishment of Walkley Heights in the City of Salisbury
12.40 - 1  Panel discussion
1 - 2  Lunch, Displays, Tree climbing and Air Spade Demonstrations – Urrbrae House, Gardens and Arboretum
2 - 2.30  Mark Adams – Transport SA guidelines for median planting (30 mins)
2.30 - 3  Neville Bonney - Is there a place for Australian Trees in our Streets? (30 mins)
3- 3.15  Panel discussion
3.15 - 3.45  Afternoon Tea, Trade Displays – Urrbrae House and Gardens (40 mins)
3.45 - 4.15  Sean Donaghy (Treenet) – Demonstration of the Website and Online Database (30 mins)
4.15 - 4.45  Dr Greg Moore – wrap up and thoughts on the day’s sessions
5 - 6  Happy Hour in Urrbrae House, display of wood crafted items from reclaimed street trees, tree climbing demonstration in the Garden/Arboretum
6 - 8  Informal dinner in Urrbrae House by Deliciously Different
Friday 7 September

8.30 - 8.45 Concurrent Workshops preliminary including overview of discussion topics (15 mins)

8.45 - 9.45 Workshops (1 hour)
  • Nursery Industry (Facilitator – Anne Frodsham)
  • Local Government (Facilitator – Tim Johnson)

9.45 - 10.15 Morning Tea, Trade Displays – Urrbrae House etc. (30 mins)

10.15 - 10.35 Joint Session and reporting back on workshops (20 mins)

10.35 - 10.50 Wrap up of formal proceedings with Board available for questions (15 mins)

Adjourn to Waite Arboretum and other outdoor sites for demonstrations related to Tree roots – morphology, physiology and development in urban infrastructure

10.50 - 11.30 Dr Greg Moore – Tree Root Networks: a vital ingredient of Treenet – Waite Arboretum (40 mins)

11.30 - 12.30 City of Mitcham – Techniques to reduce root damage to infrastructure – Claremont Avenue (1 hr)
  • Kym Knight – Observations of Fraxinus root damage to infrastructure
  • Mick Gooden – Use of root directors
  • Bradley Hay – Installation of root barrier
  • David Lawry – Innovative planting methods

Dr David Symon – Demonstrations of Pyrus calleryana selections, including planting of Pyrus ‘Lynington’ – Claremont Avenue

12.30 - 1.40 Lunch – Urrbrae House

1.40 - 1.45 Dr Jennifer Gardner – closing comments (5 mins)

1.45 - 3.45 Optional activities (~ 2 Hrs)
  • Setting up your Treenet Trial Site (Computer Suite – Charles Hawker Conference Centre)
  • Guided walk of Waite Arboretum starts at 2 pm (45 mins)
  • Tree climbing Demonstrations – participants in the SA Tree Climbing Competition
  • Inspection of TAFE/Urrbrae High School horticultural facilities (State Horticulture Centre)
TREENET

TREENET (Tree and Roadway Experimental and Educational Network), founded in 1997 at the Adelaide University’s Waite Arboretum, is a collaborative program providing a resource for the successful selection, production, installation and management of street trees.

Participants include state and local Governments, the nursery and allied industries, research and education sectors, utilities, landscape professionals and urban planners. By bringing together a cross-disciplinary network of contacts, Treenet aims to provide the best resource for supporting more effective street tree management across Australia. Treenet is a not-for-profit organisation funded by grants as well as voluntary contributions from participating Councils, nurseries and other groups.

Treenet coordinates with Councils to establish new street tree trial sites. These sites trial species of trees which have not previously been represented in the urban streetscape or are new cultivars which show promise for meeting the needs of Councils. The trial site program will gather data about tree performance and planting techniques. Through increasing the appropriate selection and maintenance of street trees a longer-lived, healthier and safer urban forest can be achieved.

The Treenet website www.treenet.com.au is now online. As it stands, users will be able to register to participate in trial sites and participate in the development of the system via feedback forms, email and an online message board. By early to mid 2002, after a period of development and testing in concert with prospective users, Treenet will offer online access to trial site data and the opportunity to input data online.

The major activity of Treenet is the sharing of information through our annual symposium and website. Treenet aims to improve our urban forests by encouraging scholarships and research.

Next Symposium
Adelaide University – Waite Campus 5th and 6th September 2002
TRADE DISPLAYS AND CONTACTS

ARBORMAN TREE SOLUTIONS
Contact: Marcus Lodge
Suite 51, 6 Todd St, Port Adelaide, SA 5015
Phone: (08) 8440 2464
Mobile: 0418 812 967
Fax: (08) 84402463
Email: arborman@senet.com.au

ARBORNET
Contact: Kirsty Campbell
PO Box 323, Prahran, VIC.
Phone: (03) 9510 4644
Fax: (03) 9501 4699
Email: sales@arbornet.com.au

GLENELG REGIONAL WATER AUTHORITY
Contact: Brian Jenkins
PO Box 107, Hamilton, VIC 3300.
Phone: (03) 5551 0400
Fax: (03) 5571 1342
Email: brian.jenkins@grwa.com.au

LAWRYS NURSERY
Contact: David Lawry
RMB 580 Cherry Gardens Road,
Cherry Gardens, SA 5157
Phone: (08) 8270 7700
Mobile: 0411 88 00 66
Fax: (08) 8270 7711
Email: lawrys@chariot.com.au

METROPOLITAN TREE GROWERS
Contact: John Fitzgibbon
PO Box 5135, Alphington, VIC 3078
Phone: (03) 9481 5494
Mobile: 0411 710 946
Email: metrotrees@decl.com.au

PLASTIC RECYCLERS AUSTRALIA
Contact: Bruce McDonald
67 Payneham rd, College Park, SA.
Phone: (08) 8272 5493
Mobile: 0429 942 662
Fax: (08) 8172 1696

RELLNEY CONSTRUCTION
Contact: Phillip Green
749 Port Rd, Woodville, SA 5011
Phone: (08) 8268 4844
Fax: (08) 8268 4855
Email: business@rellney.com.au

T-LINK
Contact: Philip Toy
T-Link, Somerton Park, SA 5044
Phone: (08) 8376 1644
Fax: (08) 8376 1644

TRENTCOM AUSTRALIA
Contact: Peter Lawton
10 Intrepid Street, Berwick, VIC 3806
Phone: (03) 9796 1422
Fax: (03) 9707 1679
Email: pal@cinet.com.au
SPEAKER PROFILES & CONTACT DETAILS

Mark Adams
Transport SA - Road & Landscape Design
33-37 Warwick St
Walkerville, SA 5081
Telephone: (08) 8343 2003
Fax: (08) 8343 2905
Email: mark.adams@transport.sa.gov.au

Mark Adams is presently a Landscape Architect with Transport SA and formerly Landscape Design Officer at the City of Salisbury. Mark’s formal qualifications include Agriculture, Horticulture and Landscape Architecture. Mark attained his Associate Diploma in Horticulture at VCAH Burnley in 1987 and his Bachelor in Landscape Architecture at the University of NSW in 1993.

Sarah Bone
The University of Melbourne - Burnley College
500 Yarra Boulevard
Richmond, Victoria 3121
Telephone: (03) 9250 6873 Mobile: 043 8877 991
Email: s.bone@pgrad.unimelb.edu.au

Sarah Bone is currently undertaking a Master of Applied Science (Horticulture) at The University of Melbourne, Burnley Campus under the supervision of Dr Greg Moore and Dr Peter May. Sarah developed her research interest in arboriculture as an undergraduate at Burnley College receiving her formal qualification (Bachelor of Applied Science Horticulture Hons.) in 1999. Sarah’s Masters research The Urban Horticulture of Corymbia maculata focuses on developing a performance profile of the species as a street tree, and improving the form of the tree through provenance selection. Sarah works part time as a consulting arborist with a Victorian based company, Tree Tactics.

Neville Bonney
Greening Australia (South Australia)
5 Fitzgerald Road
Pasadena SA 5042
Telephone: (08) 8372 0120
Email: bonney@greeningsa.org.au or nbonney@adam.com.au

Neville Bonney has had a lifetime involvement with Australian flora, both as an horticulturalist, revegetator and bush botanist. He also lectures on many aspects of those subjects and he is a person who has a strong empathy with nature and is passionate about his interests in Australian plants. He has a strong interest in economic opportunities of Australian native plants. He is an author of many books related to Australian flora and is currently co-authoring a new book in relation to the bush food industry. He currently works for the national organisation, Greening Australia, where as one of his duties he coordinates the Farm Forestry Support Program for South Australia.
Sean Donaghy
TREENET, Urrbrae House, Adelaide
University - Waite Campus
Glen Osmond, SA 5064
Telephone:  (08) 8303 6728
Fax:    (08) 8303 6826
Email:  treenet@adelaide.edu.au

Sean Donaghy has been involved with TREENET since February 2001. Prior to that he had been a project manager, multimedia and web site developer on a freelance basis and with companies such as Media Evolution and Strategic Ecommerce Limited. Projects he has been involved in have been varied: multimedia components for music CD releases, presentations for companies, web site development, ecommerce, editing, and audio recording and restoration work. Apart from TREENET, Sean is also actively involved in on-line business and publishing. Sean has a general interest in the practical possibilities of computers, with particular reference to producing easy to use systems for the management of information via the Internet.

Judy Fakes
Ryde College of TAFE
14 Selborne Street
Burwood, NSW 2134
Telephone:   (02) 9448 63
Email:  judy.fakes@tafensw.edu.au

Judy Fakes is an Agricultural Science graduate from the University of Sydney. She has specialised in the teaching of the theory and practice of soil science and arboriculture at Ryde College of TAFE since 1979. She has been involved in the development of most of the TAFE NSW courses and modules which relate to arboriculture and has been a member of the Australian Standards committee which developed the pruning standard and has worked on other draft tree standards. She was also part of the working group which developed the WorkCover (NSW) Code of Practice for the Amenity Tree Industry. Since 1984 she has worked closely with the electricity supply industry in the area of pruning trees near powerlines. Apart from teaching, she finds some time to do some private consulting work on interesting projects.

Anne Frodsham
South Australian Nursery Industry Development Officer
Nursery and Garden Industry SA
C/- SARDI, Plant Research Centre, GPO Box 397, Adelaide, SA 5001
Telephone:  (08) 8303-9578
Fax:  (08) 8303-9424
Email:  frodsham.anne@saugov.sa.gov.au

Anne Frodsham is the SA Nursery Industry Development Officer working to assist production nurseries and media suppliers in SA adopt industry best practice to ensure the supply of consistently good quality product. Her special interests are water, pest and disease management. She has over 20 years experience in horticulture and entomology. She worked at CSIRO for many years as an Information Officer and Science Communicator, followed by 8 years in the U.S.A. as an agricultural freelance writer/editor and Research Support Specialist (IPM) within the Entomology Department at Cornell
University. She is the co-author of two manuals on IPM and biological control, several industry Nursery Papers and other articles on pest management and nursery hygiene.

**Jennifer Gardner**
Waite Arboretum  
Adelaide University - Waite Campus  
PMB 1, Glen Osmond SA 5064  
Telephone: (08) 8303 7405  
Fax: (08) 8303 6826  
Email: jennifer.gardner@adelaide.edu.au

Jennifer Gardner has been Curator of the Waite Arboretum at the University of Adelaide since 1986 when she completed her Ph.D. on the systematics of Stigmoderini (Coleoptera: Buprestidae). Under her curatorship the Arboretum eucalypt, oak and pear collections have doubled; the watercourse, banksia, palm and cycad collections have been developed; and the Arboretum has been promoted much more widely to the general public as well as to those with a specific interest in street trees. She is also responsible for the establishment and management of the 130 ha Waite Conservation Reserve and the development of the gardens of the Urrbrae House Historic Precinct. With David Lawry, she founded TREENET in 1997 and has been its Executive Officer since its inauguration. Through TREENET she hopes to raise the profile of the Waite Arboretum and increase the use of this very valuable resource.

**Tim Johnson**
Technical Officer, Park & Gardens  
City of West Torrens  
165 Burbridge Road  
Hilton, SA 5033  
Phone: (08) 8416 6273 Mobile: 0419 031 622  
Fax: (08) 8443 5026  
Email: tjohnson@wtcc.sa.gov.au

Tim Johnson is a technical officer with the City of West Torrens, where he has began work as a gardener in 1989 following landscaping experience in the private sector. In his current position he supports staff and clients in Council’s urban greening, biodiversity conservation, park maintenance and customer service roles. Tim has a Bachelor Degree in Applied Science (Wildlife and Park Management) and Postgraduate Diplomas in Outdoor Education, Applied Science (Recreation) and Business Administration.

**Kym Knight**
Arbortech Tree Services Pty Ltd  
PO Box 25  
Cockatoo Valley SA 5351  
Telephone: (08) 8523 4222  
Fax: (08) 8523 4222  
Email: arbortech@adelaide.on.net

Kym Knight is the Managing Director and principle Arboricultural Consultant with Arbortech Tree Services Pty Ltd, a contracting and consulting firm based in South Australia. He trained at Yarrabee Horticultural College in SA and VCAH Burnley in Victoria, revelling in the training environment and making valuable contacts all over
Australia. He has been a passionate advocate for quality and professionalism in arboriculture since his initial involvement in the early eighties and remains steadfastly committed to the advancement of his profession. A founding executive member of the Australian Chapter of the International Society of Arboriculture and founding Chairman of the South Australian Society of Arboriculture, he has been involved at all levels of the tree care industry. He believes his membership on the Board of TREENET will further help to provide the new ideas and challenges needed to promote a better Arboricultural industry.

David Lawry
Lawry’s Nurseries
580 Cherry Gardens Road
Cherry Gardens, SA 5157
Telephone: (08) 8270 7700 Mobile: 0411 880 066
Fax: (08) 8270 7711
Email: lawrys@chariot.com.au

David Lawry is an Agricultural Science graduate from the University of Adelaide Waite Campus, majoring in horticulture and economics. He had his first practical experience with planting street trees during Uni holidays – working for the Mitcham Council. After three years teaching he commenced his business as a nurseryman in 1975, specialising in the production and sale of native trees and trees 20 years later led David to re-evaluate his contributions thus far to the urban landscape and the verdict wasn't good! All of those Prunus and Queensland Box trees he planted 30 years earlier for Mitcham were either long gone or in the process of removal. In the late 70s his evangelical zeal for anything native and his reassuring sales pitch contributed to the planting frenzy of vigorous Eucalypts, Willow Myrtles and Melaleucas in the streets of South Australia and elsewhere. Whilst happy to have provided work for so many in managing his inappropriate selections of Australian forest trees for confined urban precincts he prefers to think that his future business activities will have a more positive and enduring outcome. To that end, together with Dr Jennifer Gardner at Adelaide University, he founded TREENET in February 1997 and continues to serve as Chairman of the Advisory Board.

Derek Moore
School of Agriculture
Charles Sturt University
Wagga Wagga, NSW 2678
Telephone: (02) 6933 2714
Fax: (02) 6933 2812
Email: dmoore@csu.edu.au

Derek Moore is a lecturer in Environmental Horticulture at Charles Sturt University’s Wagga Wagga campus. He is also completing a PhD part-time at the Burnley campus of the University of Melbourne investigating the effects of nursery propagation and production systems on the root systems, establishment and post transplant success of native Australian trees selected for urban use. At CSU he has overseen the establishment of an irrigated fully replicated collection of twenty different olive cultivars for future research projects and has recently been given responsibility for the management of the university’s mature olive cultivar collection.
Gregory Moore

The University of Melbourne - Burnley College  
The Boulevard,  
Richmond, Vic. 3121  
Telephone: (03) 9250 6800  
Fax: (03) 9250 6885  
Email: g.moore@landfood.unimelb.edu.au

Greg Moore has been Principal and Head of Burnley College of the Institute of Land Food Resources at Melbourne University since 1988. Prior to that he had been a Senior Lecturer and Lecturer in Plant Science and Arboriculture at Burnley from 1979. Apart from a general interest in horticultural plant science and ecology, Greg has a specific interest in all aspects of arboriculture, which is the scientific study of the cultivation and management of trees. He has contributed to the development of Australian Standards in pruning and amenity tree evaluation and has been a major speaker at conferences in Australia, Hong Kong, USA and New Zealand in recent years. He was the inaugural president of the International Society of Arboriculture, Australian Chapter. He has been a member of the National Trust of Victoria’s Register of Significant Trees since 1988 and has chaired the committee since 1996. Greg has been on the Board of Greening Australia (Victoria) since 1989 and has been an active member of various sub-committees of that organisation. He has been involved with the Agriculture and Horticulture subject at VCE level since its inception and has been involved in the setting of all the examinations in that subject. He has also served on a number of industry and TAFE sector committees, especially those that deal with curriculum and accreditation matters. He is currently supervising eight post-graduate students and continues to pursue an active research profile in any matters that relate to trees in the urban environment. He has written one book, contributed to another and has had some 50 research papers and articles relating to tree biology and management published.

Aaron O’Malley

School of Geoscience, Minerals and Civil Engineering  
Structural Materials and Assemblies Group  
University of South Australia  
Mawson Lakes Campus  
Mawson Lakes Boulevard  
Mawson Lakes SA 5095  
Telephone: (08) 8302 3491  
Mobile: 0402 308 963  
Fax: (08) 8302 3451  
Email: omaap001@students.unisa.edu.au

Aaron O’Malley (B.Sc. Hons) completed a Bachelor of Science in Environmental Management in 1999 and a graduate Honours degree in 2000, at the University of South Australia. Aaron’s Honours thesis was titled, ‘The water relations of mature street trees using a Wescor in-situ hygrometer in the City of Salisbury’. Aaron is now undertaking his Masters Degree in Civil Engineering at the UniSA which is funded by the LGA Mutual Liability Scheme and the City of Salisbury. His Masters thesis is investigating the influence of immature street trees on seasonal soil moisture changes, and hence soil movements in a new urban development at Walkley Heights. Aaron has worked closely with his supervisor Don Cameron and the City of Salisbury in this research area.
David Symon

c/o Plant Biodiversity Centre
PO Box 2732
Kent Town SA 5071
Telephone: (08) 8228 2352
Fax: (08) 8215 0078
Email: DSymon@denr.sa.gov.au

David Symon is an international authority of the taxonomy and biology of the Solanaceae, for which research he was awarded a D.Sc. in 1996. He was on the academic staff at the Waite Institute and Curator of the Waite Arboretum for more than 30 years before retiring in 1985. During this time he established the pear collection and with the late Roy Pearce kept the pear flowering record for many years. He is well respected as an intrepid field botanist and plant collector as well as a scientist, and still very actively engaged in research.
PLANTING AND ESTABLISHMENT OF TREES ON DIFFICULT SITES

Judy Fakes, Head Teacher of Arboriculture, Ryde College of TAFE, NSW

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:**

* **Poor quality planting stock:**

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.

* Poorly aerated soil:
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.

* Irrigation practices:

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.

* Stock selection:

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.)

* Root pruning:

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).

* Soil mixes and soil handling:

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 2 m 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:**

* Root-rotting organisms:

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.

<table>
<thead>
<tr>
<th>Pot or Bag size (litres)</th>
<th>Depth of container (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 (8”/ 200 mm pot)*</td>
<td>200</td>
</tr>
<tr>
<td>10 (10”/ 250 mm pot)*</td>
<td>250</td>
</tr>
<tr>
<td>16 (12”/ 300 mm pot)*</td>
<td>300</td>
</tr>
<tr>
<td>25 **</td>
<td>350</td>
</tr>
<tr>
<td>45 **</td>
<td>425</td>
</tr>
<tr>
<td>75 **</td>
<td>510</td>
</tr>
</tbody>
</table>
* 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.


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 tillth.
* 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). If 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.

References


ESTABLISHING TREENET TRIAL SITES

Tim Johnson, Technical Officer Parks & Gardens, City of West Torrens

The City of West Torrens has been involved with TREENET street tree trials since 1998. Council’s approach to establishing tree trials has progressed over time, with current methods based on experience gained over this four-year period. The methods used in West Torrens will not be applicable to all situations though they may assist with development of techniques appropriate to other areas.

1. Rationale

Many conferences, workshops and seminars have for decades detailed the need for increased street tree research and improved information standards. A recent survey of local government (Lawry, D. & Gardner, J. 2001) confirmed these needs and revealed overwhelming support for the TREENET project.

The survey revealed 71% of respondents were dissatisfied with the current range of species used for street planting. 93% of respondents indicated they were interested in testing new varieties. Factors influencing the success of planting programs were also detailed by respondents and given a rating from 5 (very influential) to 1 (not influential.) The influencing factors and their ratings are summarised below:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Average Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Availability / quality of information on suitable species</td>
<td>3.9</td>
</tr>
<tr>
<td>2. Availability / quality of nursery stock</td>
<td>4.1</td>
</tr>
<tr>
<td>3. Difficult site conditions</td>
<td>3.4</td>
</tr>
<tr>
<td>4. Availability of funds</td>
<td>3.9</td>
</tr>
<tr>
<td>5. Availability of human resources</td>
<td>3.8</td>
</tr>
<tr>
<td>6. Access to specialist knowledge/skills</td>
<td>3.3</td>
</tr>
<tr>
<td>7. Vandalism</td>
<td>3.7</td>
</tr>
</tbody>
</table>

The survey showed that along with staff and budgets, improved information and stock range are seen as highly relevant to the success of greening programs. TREENET has the potential to guide, support and share the required street tree research and resulting knowledge between all stakeholders.

2. Components of a Successful Street Tree Trial

It is useful to consider tree trials in terms of four fundamental components: staff, the site, trees and time. While numerous factors affect each of these four components it is critical that a simple focus is maintained. The primary objective of tree trials is simple, it is to establish trees in sites with differing conditions and to observe and record their performance over time.

2.1 Staff

West Torrens is fortunate to have an enthusiastic and knowledgeable outdoor workforce, the leaders of the landscaping and arboriculture teams being responsible for initiating and
driving the street tree research program. Maintaining the program has been relatively simple, supporting and working with colleagues who are constantly extending it. The challenge is to keep pace with such staff.

2.2   Trial Sites

West Torrens is caretaker of approximately 700km of road verge, over 120 reserves, bikeways, linear parks and over $120 million in other properties. The range of potential trial sites is enormous.

Site conditions

The physical, social and political characteristics of a site will determine its suitability for a tree trial, they include:

- Soil
- Average rainfall
- Groundwater, irrigation water quality & availability
- Aspect
- Prevailing wind
- Distance to coast (i.e. salt, weather effects)
- Distance to school (i.e. vandalism)
- Nature of pedestrian and/or vehicular traffic
- Size of the nature strip or planting area
- Local residents – individuals & groups, eg. ratepayers associations
- Local politicians
- Utilities & infrastructure

(examples only, list not intended to be exhaustive)

Some site characteristics (typically the physical ones) remain relatively fixed in our timeframes while others may vary. TREENET aims to compare tree performance relative to fixed characteristics such as soil and average rainfall, which can be quantified and recorded. Following the initial establishment period, tree performance will generally relate to the suitability of the tree to these physical site conditions.

The social and political characteristics of a site will often determine the type of trial that can be undertaken, so they should be determined through effective consultation prior to works beginning. An effective consultation strategy will assist trial planning and will normally increase support for the research.

Site selection

Social, political, horticultural and budgetary considerations all impact trial site selection.

The trial must be large enough to give reliable data, but small enough to limit losses should the species/site combination prove unsuitable.

West Torrens a typical trial might involve five to ten trees, requiring five to ten nature strips. Depending on the level of confidence in the site/species compatibility a larger or smaller trial may be established.

Any site where tree planting can be limited to about ten trees is a potential trial site. Traffic islands, cul de sacs and short streets are all ideal. Adelaide’s typical grid layout often uses short links between longer roads, these may be useful but caution is required when setbacks are reduced on corner properties. A long street with few existing trees, trees that are deteriorating or have other problems may also provide an ideal trial site,
allowing species to be exhibited as possible candidates for replacement of the entire avenue when the need arises.

2.3 Trial Trees
There are many factors to consider when selecting stock for a species trial, including:

- species
- subspecies
- provenances
- hybrids
- selected forms
- litter
- infrastructure impacts
- availability
- adaptability to local conditions
- hardiness
- stock type
- stock size
- history / extent of cultivation
- nursery (reputation/service standard/stock quality/delivery schedules)
- client requirements
- mature size
- life expectancy
- hazard development potential
- disease resistance, etc.

The detailed information required to select a tree relative to the above criteria will in most cases be unavailable. Systematic testing of trees under varying conditions will assist TREENET to provide this information but it will involve increased risk in the short term. Replicating successfully established trials in neighbouring areas may be a safe place to begin tree trials, as would extending an existing local trial that shows promise into areas with slightly differing site conditions.

Selecting an unknown tree for trial is an obvious risk. To minimise the risk, small trials are recommended. Extensive research should be undertaken to gain an initial indication of the tree’s potential prior to planting. Texts, arboreta, colleagues, the Internet and nurseries are all useful sources of information. They should be used to guide species trials, but never to replace them. The ultimate compatibility of the species/site combination will only be revealed by time.

2.4 Time
Social and political views, opinions and fashions vary with time. As trials develop at any given site new cultivars will be released, tenancy of the properties will change and planning laws may be reviewed. It must be within the trial site host’s ability to maintain the trees up to an age where their characteristics can be determined regardless of changing views or fashions. An effective policy on long term street tree management is essential to the success of street tree trials. The recent TREENET local government survey (Lawry, D., & Gardner, J. 2001) showed only 40% of respondents had a formal tree management policy.
Tree growth rates vary. Trees that develop slowly may be less desirable to stakeholders in the short term. Property values, amenity, shade and habitat may not improve as rapidly with slower species as they might have with faster growing trees. If a species is known to grow slowly, it should be tested in a site where it will have minimal impact and where there will be no pressure to replace it.

3. Site & Tree Combinations

3.1 Experience, Local Knowledge & Logic Vs Assumption & Hearsay

Whether learned through educational resources or personal endeavour, knowledge is based on experience! Knowledge of trees is based on experience with them. When planning a tree trial it is essential that limitations in knowledge be recognised.

Characteristics of seedling trees are often variable. Logically, therefore, the suitability of a particular seedling or selection to a given site may vary from that of others within the species. When experience is limited to a small number of seedlings of any species it will give only a limited knowledge of the species. To assume that all examples of a species have the same characteristics as the limited examples on which one’s experience is based may lead to the rejection of the most suitable tree for a particular site.

Characteristics of genetically identical trees are generally more consistent throughout horticultural applications than seedling varieties. Characteristics of cultivars from within a species tend to vary more between the different varieties than between seedlings of the species. It should be recognised, therefore, that different varieties of a species might develop differently on a given site.

The simplicity of the above logic is often ignored or confused in practical horticulture. Because a new selection has the same species name as others or seedlings planted in the past that failed, its use for a particular site may not be given serious consideration even though it might perfectly suit the requirements and conditions. The characteristics of new selections should therefore be tested and determined under a varied range of conditions.

3.2 Which comes first, the site or the tree?

Street trees are typically selected to match site conditions, amenity considerations and other requirements, often in response to site determination based on decay of existing trees coupled with social or political influence. These are exactly the conditions in which a TREENET trial should not be established. The pressure to establish an effective avenue can be immense under these conditions. A proven and reliable type should be used in these situations, established by usual means to give the highest chance of success.

Research should be separate from a normal greening program. Neither the trial trees nor staff should be subject to external or unrealistic constraints or expectations when undertaking research planting.

Staff should focus primarily on tree selection, conduct an extensive literature search on the tree and then apply local knowledge in the search for a site in which it might be expected to grow well. This is in complete contrast to the more common procedure of applying a limited knowledge of the available tree varieties to the task of making the best tree selection for a given site.

4. Monitoring a Tree Trial Site

Developing a simple but adequate means of recording relevant details about tree trials has involved much discussion, debate and compromise. Increasing the amount of standard
data required will increase staff time requirements and so would ultimately reduce the number of sites that can be managed. Reducing the standard data requirements may reduce the usefulness of the database.

The TREENET database is an evolving work-in-progress. Feedback mechanisms have been built into the system to allow it to develop further, so standard requirements may vary with time.

4.1 Standard data entry

The following standard data requirements have been determined with the aim of optimising the usefulness of the database (aimed at local government and the nursery industry as “standard” users) while minimising the time commitment for data collection. To improve efficiencies, data collection has been divided into two standard forms. The forms will be available on-line, where data will be able to be entered directly by the participant.

Form 1. Client Identification.

Information required:

| ? Organisation name | ? Telephone number |
| ? CEO’s name         | ? Mobile telephone number |
| ? Contact name       | ? Facsimile number      |
| ? Address            | ? Email address         |
Form 2. Trial Site Information

Information required: ( ▼ indicates categories selected from drop-down menu)

<table>
<thead>
<tr>
<th>Site Type/Purpose</th>
<th>Site Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial site type</td>
<td>State</td>
</tr>
<tr>
<td>Purpose of trial site</td>
<td>Suburb</td>
</tr>
<tr>
<td>Species</td>
<td>Street</td>
</tr>
<tr>
<td>Cultivar</td>
<td>UBD Reference</td>
</tr>
<tr>
<td>Deciduous/evergreen</td>
<td>Lat/Long/GPS reference</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proximity to Services</th>
<th>Site conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service types</td>
<td>Average annual rainfall</td>
</tr>
<tr>
<td>Pipe/conduit material</td>
<td>Verge treatment</td>
</tr>
<tr>
<td>Horizontal distance</td>
<td>Soil pH</td>
</tr>
<tr>
<td>Vertical distance</td>
<td>Soil texture</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nursery Stock Supplier</th>
<th>Nursery Stock Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nursery or Supplier</td>
<td>Container type</td>
</tr>
<tr>
<td>Supplier Mail Address</td>
<td>Stock caliper / diam. (mean)</td>
</tr>
<tr>
<td>Supplier Phone number</td>
<td>Container volume</td>
</tr>
<tr>
<td>Date of planting</td>
<td>Soil (backfill)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nursery Stock Details</th>
<th>Nursery Stock Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container type</td>
<td>Container volume</td>
</tr>
<tr>
<td>Stock caliper / diam.</td>
<td>Soil (backfill)</td>
</tr>
<tr>
<td>(mean)</td>
<td>Canopy spread (mean)</td>
</tr>
<tr>
<td></td>
<td>Height (mean)</td>
</tr>
</tbody>
</table>

4.2 Ongoing monitoring and records

TREENET’s ongoing data requirements and monitoring intervals are yet to be finalised but are likely to include trial tree measurements, notes and a site summary.

Tree measurement & recording

Ongoing records will be useful to give an indication of growth rate variation due to site conditions and/or stock types and management practices. It is anticipated that this information will be made available by TREENET for selected purposes, primarily for further research. West Torrens uses a standard spreadsheet (Microsoft Excel 97) to simplify recording and data storage. The first part of the record contains a site and plant summary as shown below.
### TREE NET Records, Acer buergerianum, Byron Avenue Netley

#### Species
<table>
<thead>
<tr>
<th>Botanical name:</th>
<th>Acer buergerianum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Name:</td>
<td>Trident maple</td>
</tr>
<tr>
<td>Family:</td>
<td>Aceraceae</td>
</tr>
</tbody>
</table>

#### Location
<table>
<thead>
<tr>
<th>Street Name:</th>
<th>Byron Ave Netley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location Details</td>
<td>House frontages/verges</td>
</tr>
<tr>
<td>Number Planted:</td>
<td>24</td>
</tr>
</tbody>
</table>

#### Plant Stock
<table>
<thead>
<tr>
<th>Form (open/spring ring/pot):</th>
<th>O/R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree Size:</td>
<td>1m tall 10mm cal</td>
</tr>
<tr>
<td>Supplier:</td>
<td>Freshfords Nurseries</td>
</tr>
</tbody>
</table>

#### Site Details
<table>
<thead>
<tr>
<th>Soil Description</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>7.5</td>
</tr>
<tr>
<td>Verge treatment/s</td>
<td>Lawn</td>
</tr>
</tbody>
</table>

#### Planting Date/s
| 1998 |

#### Photograph Dates
| 21/10/98 |

Extending to the right of the above on the same worksheet is the table shown below, which is used to record individual measurements. The format of this table is then repeated across the spreadsheet to the right, allowing subsequent measurements to be easily compared.
<table>
<thead>
<tr>
<th>Street No.</th>
<th>Height m</th>
<th>Trunk caliper mm</th>
<th>Canopy diameter m</th>
<th>Tree condition</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a</td>
<td>1.8</td>
<td>12</td>
<td>0.3</td>
<td>excellent</td>
<td>branches at 500mm</td>
</tr>
<tr>
<td>2a</td>
<td>1.5</td>
<td>16</td>
<td>0.6</td>
<td>excellent</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>13</td>
<td>0.4</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>13</td>
<td>0.8</td>
<td>excellent</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>10</td>
<td>0.3</td>
<td>excellent</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.8</td>
<td>15</td>
<td>0.3</td>
<td>excellent</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1.8</td>
<td>12</td>
<td>0.3</td>
<td>excellent</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1.8</td>
<td>12</td>
<td>0.3</td>
<td>excellent</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1.3</td>
<td>7</td>
<td>0.2</td>
<td>poor</td>
<td>leaf burn</td>
</tr>
<tr>
<td>9</td>
<td>1.2</td>
<td>8</td>
<td>0.3</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.4</td>
<td>7</td>
<td>0.2</td>
<td>V/good</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.2</td>
<td>8</td>
<td>0.3</td>
<td>excellent</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.2</td>
<td>7</td>
<td>0.4</td>
<td>V/good</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.3</td>
<td>8</td>
<td>0.3</td>
<td>excellent</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.2</td>
<td>7</td>
<td>0.2</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.2</td>
<td>7</td>
<td>0.2</td>
<td>good</td>
<td></td>
</tr>
</tbody>
</table>

Ideally all organisations should use a standard system for recording purposes, though differing resource levels may prevent this. It is expected that a standard method will be refined through Internet, symposium and workshop feedback during the initial years of operation of the database.

**Trial site summary**

A simple document summarising the progress of each trial site could easily be linked to the database, detailing information on maintenance, pests, issues and problems. The document would also provide an opportunity for the trial site hosts promote their organisation and to showcase their work. The Ohio Street Tree Evaluation Project (see [www.hcs.ohio-state.edu/ODNR/Urban/ostep.htm](http://www.hcs.ohio-state.edu/ODNR/Urban/ostep.htm) and note that the address is case sensitive!) gives an indication of what is possible, a page is reproduced below as an example.
Sunburst Honeylocust - *Gleditsia triacanthos* 'Sunburst'

Brooklyn (Cleveland Area)  
8815 Morton  
Planted: 1967  
Site: 7' Tree Lawn

1971 Comments: The trees are upright spreading, uniform in size and habit, and fit well into this size tree lawn with shallow setback houses. There are utility lines overhead on one side of the street. Due to the unusual foliage color of bright yellow in the spring, these trees could be used better on shorter street, cul-de-sacs, etc., where only a few trees are used in a limited area.

...as the street appeared in 1997
1997 Comments: These plants are in 7' tree lawns and they have survived nicely. These plants tend to be slow-growing compared to other honeylocust selections. Plants have caused a considerable amount of disruption to the sidewalk. One resident that we talked with loved the atmosphere that these plants created.

Ninety-two percent of the overall planting survived (70 of 76 trees). 1997 data on the table are based on five trees.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>22.2'</td>
<td>24.0'</td>
<td>25.6'</td>
<td>--</td>
<td>42.4'</td>
</tr>
<tr>
<td>Caliper</td>
<td>4.4'</td>
<td>5.1'</td>
<td>6.1'</td>
<td>--</td>
<td>17.6'</td>
</tr>
<tr>
<td>Spread</td>
<td>15.2'</td>
<td>17.2'</td>
<td>18.6'</td>
<td>--</td>
<td>38.4'</td>
</tr>
</tbody>
</table>

Follow the link to view a QuickTime movie of the above photos (large file! 398K).
Contributing data on established sites

Information about existing avenues could be summarised and data logged with TREENET to record past experience, eg:

TREENET Trial Site Summary

Site: Malurus Avenue, Lockleys, South Australia
Species: White cedar, Melia azedarach
Date Planted: Arbor Day 1936
Page updated: July 1999

Details

Average annual rainfall: 450mm
Verge treatment: Kikuyu lawn, dolomite & bare earth
Soil pH: Neutral/slightly acidic
Soil texture: Sand
Average tree height: 10 metres
Average canopy spread: 12 metres
Average trunk circumference (1m AGL): 2200mm

History / Cultural notes
Trees supplied to residents and students of Lockleys Primary School on Arbor Day in 1936 for community tree planting project.

Trees lopped at intervals in the past, decay resulting. Verges maintained with glyphosate herbicide or by mowing.

Issues

Litter and seed germination are major concerns. Seedlings commonly appearing in gardens, reserves and roadsides, where growth is often rapid and destructive.

Malurus Avenue Lockleys
000

Substantial root system, footpath/curb & watertable lifting/cracking common.
5. Conclusion

The potential of the TREENET project is enormous. The interactive database will allow relevant records to be filtered and summary notes reviewed quickly and easily. Data on current research will be made readily available, making it possible to check the progress of species and cultivars that have recently been introduced, to see what is on trial in nearby areas and to check on plantings in similar conditions from around the globe. TREENET’s roles are to coordinate the trials through liaison with the nursery industry and local government, to guide and assist further research, and to disseminate information. The challenge to local government is to get involved, to lead the research and benefit from the project.

Reference

Lawry, D. & Gardner, J. (2001) TREENET Pilot study of tree planting in South Australia Horticulture Australia Project No: NY00042 (June 2001), Adelaide University
NURSERY PRACTICES AND THE EFFECTIVENESS OF DIFFERENT CONTAINERS ON ROOT DEVELOPMENT

Derek Moore, School of Agriculture, Charles Sturt University, Wagga Wagga, NSW

Introduction

Trees can be very long-lived and the successful establishment of all trees in any given landscape requires a knowledge of their biology and also depends on a combination of important factors which include site assessment and analysis, plant selection, site preparation, planting techniques and post-planting management input. This is as true for trees being planted for amenity purposes as it is for trees in commercial plantations. Yet time put into appropriate cultivar selection, site analysis, site preparation and ongoing management can all be wasted if the quality of the container grown plant material is poor.

In Australia the vast proportion of nursery grown trees spend some part of their life containerised, usually in a rigid plastic pot of some type (Lawry & Gardner 2001). The challenge facing nursery growers producing trees is to not only optimise canopy growth but to ensure that the root and shoot system have been managed to ensure that they don’t have a negative impact on long-term growth and even survival. Container production systems can be quite successful but nevertheless there still remain a number of very serious concerns about the quality of the root systems of many that are being produced by many container nurseries. This is despite a substantial body of research related to this issue and the many products and techniques that have been developed to improve root systems eg Harris (1967); Whitcomb (1988); Appleton (1995); Struve et al (1994); Arnold and MacDonald (1999).

This paper will briefly explore the nature of such containerised root distortions and the deleterious impact that they can have on the long-term health, vigour and stability of the tree once planted into the environment. It will then critically examine tree growing with reference to the role different containers can have on the production of quality root systems and will conclude with some practical advice regarding the evaluation of container grown trees for root defects.

Root system quality and landscape establishment

Unfortunately because trees are very long lived it can take years for problems of poor quality root systems to become apparent and often it isn’t realised that the problem was poor nursery production practices which crippled the root system and doomed the tree at planting.

Foresters, arborists, various landscape managers and others who have witnessed the windthrow, lack of vigour or death of trees which can be attributed to container induced root distortions have all learned that a healthy root system is essential for successful tree establishment and long-term health.

The challenge to containerised tree growers is simply stated: produce container grown trees with a root system that has the potential to develop those architectural, engineering and biological characteristics approximating those of a natural root system because this ensures the tree has the best chance to become fully and successfully established. It is currently beyond question that poor root system quality at planting can result in trees
subject to poor growth, windthrow, trunk breakage at ground level and the premature failure of plantings.

**Major nursery-induced root defects**

Root system defects in container grown trees can be traced to two elements in the nursery production system: the techniques used in the nursery to handle the plant at the propagation phase and the effect the containers have both on root growth and the subsequent root architecture.

**Kinked roots** usually occur when the struck cutting or seedling is pushed into a dibbled hole in the container growing medium. Unless this is done with extreme care it is likely to cause serious angular distortions in the main roots of 90° or more just below the level of the container medium. It is easy to understand how this can occur when you realise the length of a seedling’s root system can be more than 20 times its height at the four leaf stage. Such kinking (known in SE Australia as J-rooting) can be the source of serious, major structural weakness at the trunk / root interface as the tree grows. In extreme cases J-roots can lead to the trunk of the tree lying in the soil a bit like a ball in a socket and the stem can simply snap off at this point a number of years after planting (Hitchmough 1994; Ford 1996).

**Circling roots**, which begin to circle in the nursery container, have the potential to girdle the trunk or major roots as the tree grows in the landscape. They occur most frequently in round, smooth sided (or almost smooth sided) containers with sloping sides but can be found in most container designs at varying frequencies particularly if trees are held in the container for too long. Such circling roots can girdle the trunk or other roots as they grow radially and lignify and restrict the flow of water and metabolites through the root-crown area. They have been clearly implicated in tree stress, decline and lack of stability (Whitcomb 1988). Trees may survive and grow with apparent vigour for a number of years before the effect of such root crippling becomes apparent. The consequences for the tree is that the resultant root system architecture can lead to it being unable to adequately anchor the tree in the ground. Such failures are potentially catastrophic.

Observation of a large range of different tree species in the landscape both here and overseas has revealed that the poor performance of many is a direct result of such kinked and circling roots. Unequivocally, kinked and circling roots can not only restrict the growth of trees but can be the cause of their death.

**Production alternatives to improve tree root systems**

There are a number of alternative production systems being put into commercial practice in Australian nurseries today which include physically pruning the roots at every potting on stage of the nursery production process (Clark 1996) and variations of container design (Moore 1998). Those variations include the use of internal ridges designed to guide roots down rather than around, channels to guide root growth to holes in the container walls where the roots are air pruned, the use of low profile containers, the use of chemical root pruning agents such as copper hydroxide infused paint and various combinations of the above. 

*There is no prescription available for an ideal nursery production system for trees. It does seem though, that a production system which not only prevents kinking and circling but also stimulates the development of well branched, fibrous roots is the most desirable because such a root system can proliferate rapidly into*

Reducing kinked roots

There are two potential solutions to the problem of root kinking (or J-roots). The first is to eliminate dibbling (where a hole is formed in the container medium and the germinated seedling or struck cutting is removed from its propagation environment and placed in the hole). If dibbling is unavoidable, careful root pruning before transplanting and the elimination of dibbling has been shown to be of benefit (Harris 1967), but even the most careful management of this might not guarantee the absence of j-roots.

An alternative is the direct seeding of the crop either into the final production container or an intermediate one. This technique does require an increased area for propagation, as well as a need for high quality seed and possibly increased culling of variable seedlings, nevertheless it simply eliminates any possibility of inducing severely kinked roots through inappropriate handling.

Reducing circling roots

There has been some work published detailing techniques to overcome circling roots of container grown trees prior to planting them out, including making vertical slices through the root ball, ‘butterflying’ the rootball or vigorously cutting off any apparently circling roots, (eg Flemer, 1982; Gouin, 1984) but such techniques are of doubtful value. Removing up to 90% of a tree’s roots totally negates the advantages of growing trees in containers in the first place and is therefore a nonsense. Common sense dictates that the elimination of root distortions during the nursery production phase of a tree’s life is the sensible approach and a number of alternatives are now available to the nursery industry.

Container design modifications

Internal ridges

There have been reports of ridges on container walls being used to minimise root circling and in this their use has some success (eg Warren & Blazich 1991; Appleton 1995) although their effect can be lost as more root mass builds up. Hughes (1994) argues that the standard Australian forestry tube (square containers with internal ridges and air pruning at the bottom) while reducing the incidence of circling roots, can still be problematic for further container growing because it has the effect of concentrating root tips at the bottom of the container which inhibits the development of lateral roots in the top 10 cm of the root system and leads to problems for further container growing.

Air pruning of roots

Another concept shown to have considerable potential are containers that allow roots to be air pruned by using openings in the sides or the base of containers. Root tips reaching such openings are dried out and stop growing. Such containers are designed to prevent the development of circling roots and have been shown to alter the growth and distribution of roots within the root ball (eg Whitcomb 1981; Arnold and MacDonald 1999). Instead of
being concentrated around the sides and bottom of the container, roots in such containers are smaller in diameter and more evenly distributed throughout the rootball and develop a large number of root initials. This enables much new root growth once the tree is planted out. Many containers use this approach, examples available in Australia include SpringRing® containers, the RocketPot®, the Rootmaker® and the Lannen System. A number of commercial Australian tree producers have taken up this technology.

In a trial at Burnley, that compared the effect of an air pruning container (200 mm SpringRing®) with a standard 200 mm standard rigid plastic container on the root system quality of a range of native landscape trees, the trees were grown on for nine months in the two production container types and then planted out. They were then dug up 8 months after planting out and root quality assessed by examining the root systems at the outer edge of the production container rootball.
### Table 1. Effect of production container on root quality in landscape trees

<table>
<thead>
<tr>
<th>Species</th>
<th>Container type</th>
<th>Number of circling roots</th>
<th>Number of emerged laterals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allocasuarina verticillata</td>
<td>200mm rigid plastic</td>
<td>22.4</td>
<td>25.8</td>
</tr>
<tr>
<td>Allocasuarina verticillata</td>
<td>200 mm Spring Ring</td>
<td>0.0</td>
<td>74.6</td>
</tr>
<tr>
<td>Casuarina cunninghamiana</td>
<td>200mm rigid plastic</td>
<td>21.8</td>
<td>123.8</td>
</tr>
<tr>
<td>Casuarina cunninghamiana</td>
<td>200 mm Spring Ring</td>
<td>1.4</td>
<td>132.8</td>
</tr>
<tr>
<td>Callistemon viminalis ‘King’s Park Special’</td>
<td>200mm rigid plastic</td>
<td>14.2</td>
<td>141.8</td>
</tr>
<tr>
<td>Callistemon viminalis ‘King’s Park Special’</td>
<td>200 mm Spring Ring</td>
<td>0.2</td>
<td>196.0</td>
</tr>
<tr>
<td>Eucalyptus leucoxylon</td>
<td>200mm rigid plastic</td>
<td>6.6</td>
<td>75.2</td>
</tr>
<tr>
<td>Eucalyptus leucoxylon</td>
<td>200 mm Spring Ring</td>
<td>0.2</td>
<td>161.6</td>
</tr>
<tr>
<td>Corymbia (syn. Eucalyptus) maculata</td>
<td>200mm rigid plastic</td>
<td>14.0</td>
<td>38.0</td>
</tr>
<tr>
<td>Corymbia (syn. Eucalyptus) maculata</td>
<td>200 mm Spring Ring</td>
<td>0.2</td>
<td>106.8</td>
</tr>
<tr>
<td>Lophostemon confertus</td>
<td>200mm rigid plastic</td>
<td>28.7</td>
<td>101.5</td>
</tr>
<tr>
<td>Lophostemon confertus</td>
<td>200 mm Spring Ring</td>
<td>1.3</td>
<td>199.3</td>
</tr>
<tr>
<td>Waterhousea floribunda</td>
<td>200mm rigid plastic</td>
<td>8.4</td>
<td>22.2</td>
</tr>
<tr>
<td>Waterhousea floribunda</td>
<td>200 mm Spring Ring</td>
<td>0.0</td>
<td>33.2</td>
</tr>
</tbody>
</table>

Moore (unpublished data) Generally, the trees grown in the air-pruning Spring Ring® container had superior quality root systems, both in terms of the number of circling roots and the number of lateral emerging into the surrounding soil.

**Chemical pruning of roots**

A different approach to the reduction of circling roots that is also being used by commercial Australian tree growers, involves the use of copper compounds to chemically prune the roots of container grown plants. The use of copper compounds to inhibit root tip growth has been reported since early 70s (Furuta et al., 1972). Several commercial formulations have been marketed with SpinOut® (Griffin Corp.) perhaps the best known. SpinOut® is copper hydroxide infused latex paint that is applied to the interior surfaces of the container where it acts as a growth regulator. In effect root tip growth is inhibited, which stimulates branching and ultimately results in a fibrous root system (eg Struve and Rhodus, 1990).
Recent research at Burnley has shown that SpinOut® can reduce circling roots and improve root system quality, but that it is not a perfect solution to the problem. Table 2 shows the results of an experiment with *Corymbia* (syn. *Eucalyptus*) *maculata* (Spotted Gum) seedlings grown in 50mm tubes, 50mm tubes coated with SpinOut® and the air pruning Rootmaker® pots.

**Table 2.** The effect of propagation container on a number of seedling quality parameters in *Corymbia maculata*

<table>
<thead>
<tr>
<th>Seedling quality parameter</th>
<th>50 mm tube</th>
<th>50mm tube with SpinOut®</th>
<th>ROOTMAKER®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (mm)</td>
<td>238</td>
<td>202</td>
<td>216</td>
</tr>
<tr>
<td>Number of roots emerged one week after potting</td>
<td>30.6</td>
<td>71.4</td>
<td>281</td>
</tr>
<tr>
<td>Number of lateral roots from tube after 6 months</td>
<td>0.9</td>
<td>9.4</td>
<td>10.8</td>
</tr>
<tr>
<td>Number of circling roots / plant</td>
<td>6.8</td>
<td>3.9</td>
<td>2.6</td>
</tr>
<tr>
<td>% plants with circling roots</td>
<td>93</td>
<td>80</td>
<td>40</td>
</tr>
</tbody>
</table>

(Moore, unpublished data)

In this experiment, the propagation containers were direct seeded and the resultant seedlings grown for 18 weeks before potting on into 200 mm production containers. The one week data was for seedlings examined one week after potting. All the other data was for seedlings grown on for six months. The circling roots were assessed at the outer edge of the propagation containers. It’s clear that both the copper treatment and the air-pruning Rootmaker® modified the root systems of the seedlings but these data suggest that at the tubestock stage at least, root circling problems are difficult to entirely overcome.

Without undertaking an exhaustive analysis of the data gathered it is apparent that both chemical pruning and air pruning do have an effect on the number of new roots emerging from the rootball. Interestingly, the implication from this data is that the Rootmaker container caused more root initials to develop than the either the standard tube or the tube coated with Spin Out®.

The data gathered relating to the production/propagation container interface at 8 months is also interesting in that clearly both Rootmakers and Spin Out® achieved increased lateral root development. The relationship between the numbers of emerged roots at 7 days compared with the number of lateral roots developed at 8 months is not yet clear though.

**Evaluating trees for root system defects.**

Two points need highlighting:

1. *Kinked roots and girdling roots have unequivocally been identified as a cause of tree stress, decline and death.*
2. There have been no studies which have identified how severe the kinking or circling has to be before a tree’s root system has been crippled to the point where the long-term health and performance of the tree will be compromised.

The obvious consequence of this is that tree root systems must be inspected to detect any serious deformities. A visual inspection of the rootball surface is not sufficient because serious defects can and do occur in different zones within the rootball. It will be necessary to wash the potting mix from the roots.

The following general guidelines are presented to aid the assessing the root systems of container grown trees, regardless of species, size or intended landscape function. They are based on the work of Harris et al (1999, pp. 614-615) and Gilman (1997, pp. 44-47). All trees (or a representative sample) should be carefully inspected.

A lot can be learned by inspecting the tree while it is still in its container and then looking at the periphery of the rootball. The reality though, is that a number of serious deformities may be out of sight within the rootball and it will be necessary to remove some or all of the container medium.

The first thing to do is to check whether there are any obvious kinked or circling roots at the surface and that there are no roots sticking up above the potting mix. Having done that, ensure the bottom of the container won’t move (hold it between your feet perhaps) then hold on to the trunk of the tree about two thirds up the trunk and move it backwards and forwards a couple of times. If the trunk wobbles in the container medium before it bends where you are pushing and pulling it is likely that there are either kinked or circling roots already negatively affecting the tree’s root architecture.

Unless the tree is very advanced, the root system should be able to be picked up by the trunk without any apparent root movement and should be sufficiently developed to hold the root ball together when its removed from the container.

If it is staked, untie the tree from its stake (when you do, the trunk shouldn’t lean so much as to touch the rim of the container), then remove the tree from the container and examine the roots as follows:

No large circling roots should be visible on the outside of the root ball and there should be no circling mat of roots at the bottom. It is not possible to give an acceptable diameter for these roots; it depends on the size of the rootball and the complex biology of the species grown. It would be best if they were absent. Harris et al (1999) recommends circling roots be no larger than 6 mm in diameter.

Then lay the rootball onto its side and with a sufficiently vigorous jet of water, carefully expose the roots within 5 - 6 cm of the trunk to a depth of about 7-8 cm below the root attached closest to the trunk. Both the trunk and main roots must be free of kinks and circling roots in this part of the rootball, if they’re not, the tree has severe root defects.

If the above inspections reveal no faults then the complete removal of the container medium from the entire root balls of least two trees (Harris et al 1999 recommends no more than 2% of the total number of trees) is required to inspect their centres. Again, both the trunk and main roots must be free of kinks and circling roots in this part of the rootball, if they are present, the tree has severe root defects. (This is a destructive sampling as it is likely the tree will die even if the potting mix is replaced and carefully watered).

These can only be general guidelines because there is a paucity of basic scientific research regarding the effect various container production systems have on the root growth and subsequent landscape establishment of different tree species. The work simply has not
been done. What is beyond doubt though, is that the unique environment in plant containers limits the time any plant can spend in a specific container before it must be planted, potted up to a larger container, subject to expert pruning of both roots and stems or simply thrown away.

References


PRELIMINARY RESULTS OF A CORYMBIA MACULATA
(SYN. EUCALYPTUS MACULATA) (SPOTTED GUM)
PROVENANCE TRIAL USING STREET TREE SELECTION
CRITERIA

Sarah Bone, The University of Melbourne, Burnley College

SUMMARY
Eight Spotted Gum types (6 provenances of Corymbia maculata and one each of the species Corymbia variegata and Corymbia henryi) were assessed in a field grown provenance trial undertaken in the grounds of Burnley College, Melbourne Victoria. Differences in growth rate, stem structure, tree form and health of the provenances were recorded over an eight month period (Nov 2000 – July 2001) from the planting of glasshouse raised four month old seedlings to harvest at twelve months of age. While preliminary data analysis has identified significant differences in provenances for measures of survival, growth rate and stress tolerance ($p \leq 0.05$) significant differences in stem structure and other measures of tree form have not been recorded. This paper summarises methods used to assess and measure growth traits of the 160 trees studied and presents a preliminary view of the results (project completion date March 2002).

Introduction
Urban tree improvement through selection of superior ecotypes (within tree species) is an under-utilised tool in Australian amenity horticulture. Our native trees have received relatively little attention in street tree improvement programs to date. With the growing trend of municipalities selecting alternatives to eucalypts for street plantings, the need for reliable data on the performance of our eucalypts and identification and selection of ecotypes better suited to urban situations is now greater than ever. Corymbia maculata (formerly Eucalyptus maculata Hook.) has been the subject of a number of provenance studies over the years (Larsen, 1965; Andrew 1969; Darrow 1985; Forestry Commission of NSW 1985; Tibbits 1999; Mazanec 1999) none of which have compared ecotypes using horticultural criteria. The provenance trial described in this paper was established in order to identify and recommend superior ecotypes (if any) of the Spotted Gum group using urban tree selection criteria.
Materials and Method

Eight Spotted Gum provenance seed lots were purchased from the Australian Tree Seed Centre – a division of CSIRO following assessment of a total of ten natural forest stands of *C. maculata* in NSW and Victoria in June -July 2000. From available seed lots, eight ecotypes were selected (listed in Figure 1) including one each of two other Spotted Gum species previously known as *Corymbia maculata* - *Corymbia henryi* and *Corymbia variegata*.

Trial Design & Establishment

Germination was undertaken in August 2000 and seedlings were raised in a glasshouse for a period of 4 months before field planting. Of an average of 120 plants reared from each provenance 30 relatively uniform (in height) seedlings were selected. To offset any tendency to pick the tall poppies (although this was carefully considered during tagging of plants) of the 30 selected, the ten largest specimens were removed to arrive at the final 20 for planting.

An 8 x 35m plot of sandy loam soil in the grounds of Burnley College was cultivated and covered with weed mat prior to planting. 160 trees (20 replicates of each provenance) were planted at 1 x 1.3m spacing within the plot.

Trees were planted following a randomised block design consisting of four blocks of forty trees. Each block contained five replicates of each provenance, occurring as a randomly planted row. A buffer strip was planted on the northern and southern perimeters of the plot but not on the eastern or western plot boundaries due to space restrictions.

The trees remained in the ground for a period of eight months. After an establishment phase of three months, measurements commenced and continued until mid July 2001 when trees were harvested.

<table>
<thead>
<tr>
<th>Number</th>
<th>Species</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>19102</td>
<td><em>C. maculata</em></td>
<td>Bodalla SF</td>
</tr>
<tr>
<td>19382</td>
<td><em>C. maculata</em></td>
<td>Mottle Range</td>
</tr>
<tr>
<td>19421</td>
<td><em>C. maculata</em></td>
<td>Mumbula SF</td>
</tr>
<tr>
<td>19422</td>
<td><em>C. maculata</em></td>
<td>Bodalla SF</td>
</tr>
<tr>
<td>19468</td>
<td><em>C. henryi</em></td>
<td>Myrtle Creek</td>
</tr>
<tr>
<td>19469</td>
<td><em>C. variegata</em></td>
<td>Richmond Range SF</td>
</tr>
<tr>
<td>19663</td>
<td><em>C. maculata</em></td>
<td>Curral SF</td>
</tr>
<tr>
<td>20324</td>
<td><em>C. maculata</em></td>
<td>Wingello</td>
</tr>
</tbody>
</table>

*Figure 1* Seed lot numbers and origins for Spotted Gum field trial (left) Map of locations of seed source.
**Measurements**

Trees were assessed on numerous traits of growth and early structural development – categorised as either growth rate, stem form, tree form or health and stress response (See Table 1). Both numerical and categorical data were collected. The trees were subjected to several biotic and abiotic stresses during the course of the trial. These included insect grazing and bird damage during the establishment phase, presence of a fungal pathogen as a secondary stress (isolated yet not identified), cold temperature injury and soil nutrient imbalances. Originally planned to run until the end of August, the trial was harvested in mid July 2001 due to declining growth rates and large levels of dieback and foliage distortion exhibited. The unexpected stresses did however allow for further comparison of performance of the eight provenances prompting additional measures of health and structure to be recorded.
<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>TRAIT</th>
<th>UNIT/SCALE &amp; METHOD</th>
<th>TIMING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth rate</td>
<td>Fresh weight (above ground portion of the tree)</td>
<td>kg (lopped 5mm from base)</td>
<td>At harvest</td>
</tr>
<tr>
<td></td>
<td>Fresh weight (root systems)</td>
<td>kg (root ball reduced to 20mm radius)</td>
<td>At harvest</td>
</tr>
<tr>
<td></td>
<td>Stem diameter (basal)</td>
<td>mm (measured immediately above lignotuber)</td>
<td>At harvest</td>
</tr>
<tr>
<td></td>
<td>Stem diameter (at 5mm from base)</td>
<td>mm (measured 5mm from base or ground level)</td>
<td>At harvest</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>mm (measured from base to growing tip)</td>
<td>2 month intervals</td>
</tr>
<tr>
<td></td>
<td>Canopy width</td>
<td>mm (measure on north – south axis)</td>
<td>2 month intervals</td>
</tr>
<tr>
<td></td>
<td>Lignotuber diameter</td>
<td>mm (measured at widest point)</td>
<td>At harvest</td>
</tr>
<tr>
<td></td>
<td>Number of laterals</td>
<td>Count (all laterals originating from main stem or a dominant stem)</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Root mass</td>
<td>Count of lateral and plunging roots based on orientation</td>
<td>At harvest</td>
</tr>
<tr>
<td>Tree form</td>
<td>Crown shape</td>
<td>Categorical 1(round) 2 (oval) 3 (conical) 4 (rounded to conical)</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Canopy balance</td>
<td>Scale 1 (balanced) 2 (unbalanced)</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Branching pattern</td>
<td>Scale 1 (good radial balance) 2 (slight imbalance) 3 (severe imbalance)</td>
<td>Final week</td>
</tr>
<tr>
<td>Stem form</td>
<td>Angle of branch attachment</td>
<td>(º) Average of 3 angles taken from 1st 2nd and 3rd portions of the tree</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Habit</td>
<td>Categorical 1 (single), 2 (bifurcated) , 3 (multi-stemmed)</td>
<td>2 month intervals</td>
</tr>
<tr>
<td></td>
<td>Number of forks</td>
<td>0 (none) 1 (one fork) 2 (two or more)</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Angle of stem attach (forked trees only)</td>
<td>(if bifurcated) degrees –where?</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Clear Leader or shared dominance?</td>
<td>Count of forked or multi-trunked specimens without a clear leader</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Stem Straightness (single stems only)</td>
<td>Scale of 1 (very poor) to 6 (excellent)</td>
<td>Final week</td>
</tr>
<tr>
<td>Health/vigor</td>
<td>Condition</td>
<td>Scale 1 (dead/dying) to 5 (no apparent problems)</td>
<td>2 week intervals</td>
</tr>
<tr>
<td></td>
<td>Deaths – survival</td>
<td>Count</td>
<td>At harvest</td>
</tr>
<tr>
<td></td>
<td>Foliage Density</td>
<td>Scale 1 (light) to 3 (dense)</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Dieback exhibited</td>
<td>Yes/no (if yes in what region of the tree)</td>
<td>Final Week</td>
</tr>
<tr>
<td></td>
<td>Tip death</td>
<td>Yes/no</td>
<td>Week 20</td>
</tr>
<tr>
<td></td>
<td>Branch abscission</td>
<td>Yes/no</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Change of leader</td>
<td>Yes/no (if yes at what height)</td>
<td>Final week</td>
</tr>
<tr>
<td></td>
<td>Lignotuber shoot initiation</td>
<td>Yes/no (if yes how many?)</td>
<td>At harvest</td>
</tr>
<tr>
<td></td>
<td>Foliar nutrient concentrations</td>
<td>%w/w, mg/kg</td>
<td>Week 16</td>
</tr>
</tbody>
</table>
Data Analysis

Only preliminary data analysis has been conducted to date. Two way analysis of variance has been undertaken to establish significant difference \( (p \leq 0.05) \) between provenances and the necessity for further analysis (log transformation of data, pairwise comparisons and least significant difference tests). Categorical data appearing mostly as percentages was subject to arcsine square root transformation prior to initial statistical analysis. Three deaths were recorded during the trial and were removed from the data set prior to analysis. Tables 2-5 display the means for each provenance and the relative ranking of each (if applicable). P-values that have been generated in analysis of variance are given for most of the assessments reported in this paper.

Readers are warned to view results with caution as neither variation within the provenances nor variation between blocks (accounting for site differences and nuisance variables) have been taken considered in this early stage of data analysis.

Results and Discussion

Growth Rate

Table 2. Growth rate. Preliminary results

<table>
<thead>
<tr>
<th>Rank</th>
<th>Mean</th>
<th>Rank</th>
<th>Mean</th>
<th>Rank</th>
<th>Mean</th>
<th>Rank</th>
<th>Mean</th>
<th>Rank</th>
<th>Mean</th>
<th>Rank</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
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<td>3</td>
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Although the findings recorded in Table 2 are at a preliminary stage of statistical analysis, the most vigorous provenances are clearly identifiable. Significant differences between provenances have been found for stem fresh weight \( (P < 0.05:P = 0.005) \), fresh weight of roots \( (P < 0.05:P = 0.000) \), stem diameter 1 \( (P < 0.05:P = 0.006) \), height \( (P < 0.05:P = 0.000) \), lignotuber diameter \( (P < 0.05:P = 0.004) \) and the number of lateral branches present \( (P < 0.05:P = 0.001) \). Provenances 4 (\textit{C. maculata} Bodalla SF site 2), 8 (\textit{C. maculata} Wingello) and 6 (\textit{C. variegata} – Richmond Range SF) appear to exhibit stronger rates of growth than the other provenances. These three ecotypes are ranked between first and fourth for every measure. Conversely, provenance number 3 (\textit{C. maculata} Mumbula SF) is ranked seventh or eighth for 87.5% of measurements – demonstrating its weakness in comparison to the other ecotypes.
Of the 160 trees grown only three deaths were recorded all belonging to provenance number 1 (C. maculata Bodalla SF site 2) with 15% of the population not surviving, differing significantly from the other ecotypes (P < 0.05: P = 0.032). A number of low values were however recorded for fresh weights, heights and stem diameters suggesting that trees were struggling to survive in provenances 3 (C. maculata Mumbula SF) and 7 (C. maculata Curryall SF) also. Provenance 4 (C. maculata Bodalla SF site 1) ranked highest for mean condition rating closely followed by Provenance 8 (C. maculata Wingello), with mean values of 4.05 and 3.8 respectively. Apical death was recorded as significantly different between provenances (P < 0.05: P = 0.001) with 90% of C. henryi (Provenance 5) specimens injured. Significant differences were also found between provenances (P < 0.05: P = 0.019) for a change in leader as identified in the stem but were not recorded for foliage density, die back, or limb drop.

### Stem structure

<table>
<thead>
<tr>
<th>Provenance</th>
<th>Single (%)</th>
<th>Bifurcated (%)</th>
<th>Multi-Trunked (%)</th>
<th>Percentage of trees with a fork or forks in stem/s (basal or above)</th>
<th>Percentage of bifurcated or multi-stemmed trees without a clear leader (shared-dominance)</th>
<th>Percentage of single stemmed trees with above average to excellent form (stem straightness)</th>
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<td>20</td>
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</tbody>
</table>

Table 3 Health. Preliminary Results

Of the 160 trees grown only three deaths were recorded all belonging to provenance number 1 (C. maculata Bodalla SF site 2) with 15% of the population not surviving, differing significantly from the other ecotypes (P < 0.05: P = 0.032). A number of low values were however recorded for fresh weights, heights and stem diameters suggesting that trees were struggling to survive in provenances 3 (C. maculata Mumbula SF) and 7 (C. maculata Curryall SF) also. Provenance 4 (C. maculata Bodalla SF site 1) ranked highest for mean condition rating closely followed by Provenance 8 (C. maculata Wingello), with mean values of 4.05 and 3.8 respectively. Apical death was recorded as significantly different between provenances (P < 0.05: P = 0.001) with 90% of C. henryi (Provenance 5) specimens injured. Significant differences were also found between provenances (P < 0.05: P = 0.019) for a change in leader as identified in the stem but were not recorded for foliage density, die back, or limb drop.
Table 4 Stem Structure. Preliminary results

The proportion of single stemmed trees was significant (P < 0.05: P = 0.000) with Provenance 6 (Corymbia variegata) recorded as a single stemmed tree 80% of the time. Additionally, the same provenance was ranked above average to excellent (score 4 or above on a scale of 1 –6) in terms of stem straightness for 75% of assessments - 35% of the trees were recorded as exhibiting excellent stem form (6/6). Significant differences were not recorded between provenances for percentages of bifurcated or multi-stemmed specimens, additional forking of stems or for shared dominance in forked or multi-stemmed trees.

Tree Form

<table>
<thead>
<tr>
<th>Crown Shape (%)</th>
<th>Canopy Balance (%)</th>
<th>Branching Pattern (%) (Good Radial Balance)</th>
<th>Angle of Branch Attachment</th>
<th>Growth Habit (%)</th>
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</thead>
<tbody>
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<td>8</td>
<td>30</td>
<td>25</td>
<td>30</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 5. Tree Form. Preliminary results

Most measures of tree form did not reveal significant differences between provenances in two-way analysis of variance. This can most likely be attributed to the nature of the data (categorical) and its method of collection (subjective assessment). The only differences in measures of tree form applied to trees with an upright growth habit (P < 0.05: P = 0.000). Corymbia variegata exhibited a strongly upright form in 90% of situations and specimens of Corymbia maculata (Provenance 8 Wingello) 80% upright in growth habit. Similarly there were no weeping trees recorded in provenances 6 (C. variegata) and 3 (C. maculata Mumbula SF). Data concerning radial distribution of branches, canopy balance and mean angle of branch attachment did not uncover any significant differences between Spotted Gum ecotypes.

Conclusion

While preliminary results regarding stem structure and tree form do not suggest that variation between provenances is significant, promising results for vigour (tree growth) and vitality (tree health) have emerged. Corymbia maculata provenances 4 (Bodalla SF site 2) and 8 (Wingello), and the species Corymbia variegata (provenance 6) have consistently ranked higher than other provenances in statistically significant traits measured. Conversely, provenances 3 (Corymbia maculata Mumbula SF) and 7 (Corymbia maculata Curryall SF) have been the poorest performers in many aspects of this trial. Whether these patterns of performance will remain fixed after complete statistical analysis of data is currently unknown. It is hoped however that by the completion date of these research project (March 2002) superior ecotypes of the Spotted Gum group can be recommended to the tree grower industry.
References


Forestry Commission of NSW 1985 *Notes on the silviculture of major NSW forest types*, Sydney: Forestry Commission of NSW.


Mazanec, R. 1999 Thirteen year results from a Spotted Gum provenance trial in the Wellington catchment of Western Australia *Australian Forestry*: 62 (4) 315-319.

STREET TREES INFLUENCE ON SOIL MOISTURE, URBAN DWELLINGS AND PAVEMENTS AND WALKLEY HEIGHTS AS A UNISA-TREENET RESEARCH SITE

Aaron O’Malley & Donald Cameron - University of South Australia, School of GMC.

Abstract
This paper discusses research currently being undertaken by the University of South Australia, on the influence of trees on soil moisture, urban dwellings and pavements. Moisture depletion in the urban environment more specifically the influence of street trees on this moisture loss results in surface and sub-soil movements under house foundations. This is a worldwide problem. Moisture changes caused by environmental changes, which occur when creating urban areas, and tree related desiccation may cause bending of footings and pavements and cracking of houses. With the trend towards smaller-sized blocks in urban areas, the problem has intensified.

The initial study, now in its final stages, investigated the influence of five species of established street trees on soil moisture (and suction) changes and surface movements in the City of Salisbury. The second study, which has only just begun examines the influence of immature street trees on soil moisture changes in the early years of a new subdivision. The current study is located at Walkley Heights and the soil is expected to show large movements, due to the area’s extremely reactive clays, planting of street trees on both sides of the road and the small block sizes.

The overall research objectives are to provide information on soil moisture changes, clay desiccation and species water use, which may be used by engineers to design footings that account for the extra movements caused by tree related desiccation in the urban environment.

1. INTRODUCTION
1.1 The Research Problem
Street trees are provided by Local Government Authorities to improve the landscape, enhance the environment and ultimately to increase land values. Apart from their aesthetic value, trees also provide valuable habitat for fauna and extend the urban wildlife corridor, thereby protecting and enhancing biodiversity. Trees however, may present a nuisance if they become too large for the streetscape, lose branches in storms or their roots uplift pavements.

Trees may indirectly damage pavements and dwellings in urban environments, through the extraction of moisture from unsaturated clay soils, causing deep drying effects (eg. Biddle 1983). Tree-related desiccation causes greater ground movements during the drier months than would be expected without the presence of trees (e.g. Richards et al. 1983 and McInnes 1986).

If the shrinkage settlements are significant, pavements and houses may deflect, resulting in unsightly and perhaps structural damage arising from desiccation. If the settlements are large and unanticipated, footings of houses may be adversely affected.
Highly reactive, clay soils are found over much of the Adelaide area and its
surrounds, which are prone to large settlements upon drying. These settlements are
significantly increased by soil moisture drying due to street trees.

Currently, civil engineers try to minimise the risk of soil shrinkage settlements by
excluding trees or, more recently, by designing footings to cater for anticipated soil
movement. Design rules have been based on the proximity of the trees to the
proposed structure (D:H) relative to the heights of the trees. The first such rules
originated in Great Britain (Ward 1953). Such design criteria are based on simplistic
empiricism, as very little information is available on the relative water usage of
different tree species in an urban environment. Without this information, footings are
either being over designed, adding substantially to building costs, or under designed,
resulting in footing failures as the trees reach maturity.

Generally, houses over ten years old have not been designed to cater for the soil
drying effects of trees and are therefore at greater risk than new houses. In addition,
the footing design rules assume that trees are planted after construction. Little is
known of the effects of trees, which are well established prior to building
construction. In fact, the design rules do not address this situation.

With the introduction of the new Local Government Act in January 2000, a greater
emphasis has been placed on Councils’ responsibilities in regard to street trees. Local
Government has a responsibility to provide amenities, which balance the soft
elements (trees and shrubs) with other elements of the street and reserve
environments. Yet provisions for trees are clearly enunciated in the Australian Model
Code for Urban Development, which many Councils have adopted in their
Development Plans. Therefore, the planting of trees on reactive clay soils cannot be
avoided.

Cameron (2001) stated in his recent paper that the most useful data for future footing
designs will come from studies of desiccation in urban environments. This project has
followed that suggestion and has placed effort into field trials in the Adelaide urban
environment.

1.2 Reactive Soils (Unsaturated Clays)

Reactive soils have a tendency to swell during wet periods and shrink during the
summer-autumn months. Trees are able to draw moisture from the soil to relatively
high levels of soil desiccation or suction. Settlement occurs when the soil volume
decreases and trees assist this movement by further extraction of water, which may
lead to flexure of footings and likely cracking of masonry houses (Holland 1979).

Moisture-reactive clay sites are classified in accordance with Australian Standard AS
2870 as "Slight", "Moderately", "Highly" or "Extremely" reactive, depending on the
amount of the design ground surface movement expected in a 50 year climate cycle in
an urban environment (without trees). The site classification assumes reasonable site
maintenance practices are adhered to throughout the life of the dwelling. New home
owners are supplied with CSIRO information sheet No. 10-91, which advises
homeowners on foundation maintenance and footing performance. This pamphlet
includes site classifications, care of duty, soil shrinkage, garden planting, drainage and
how to avoid damage to the house.

Environmental conditions of an area play an important role in the behaviour of soils.
Climate dictates the design level of soil moisture changes at a site and therefore the
site classification (Aitchison & Holmes 1953). Annual variations in intensity of rainfall and evaporation, depth of ground water table and site drainage patterns will influence both the extent and the pattern of ground movements on a reactive site. Additionally, soil profiles at a site can vary markedly, leading to differences in movement across a site, even though it may experience a uniform change in soil moisture condition. The complication of a high water table is relatively rare in the reactive soil areas of Adelaide.

On a well-drained and uniformly reactive site, the environmental changes arising from urbanization lead to initial dishing of the ground under a house and, in years to come, a doming distortion is likely to develop. As the soils beneath the edges of a house undergo almost seasonal variation in moisture condition, dishing is most noticeable over the winter-spring period, while doming is most distinct during summer-autumn. Civil engineers design footings to counter these movements in order to avoid large deflections of the structure.

1.3 Suction and Suction Changes

Driscoll (1983) and others have shown that moisture fluctuates seasonally in an open field and is more stable towards the centre of large pavements (or for that matter, ground slabs). Further soil drying by trees usually occurs in the summer months. While seasonal moisture changes are evident away from trees, the moisture changes are much reduced near the trees and the moisture profile is generally drier.

The state of desiccation of reactive soils can best be expressed by soil suction. Soil suction is the negative pressure of the pore water, expressed on a logarithmic scale pF, where pF is the logarithm to the base 10 of the suction head in centimetres. Soil suction is related to the moisture content of a soil, but the relationship changes with each and every soil type. A linear relationship is usually assumed between suction and moisture content. High suction infers a low moisture content or dry soil. The usual range of soil suctions in the field in a semi-arid climate is 3 to 5 pF (100 kPa to 10 MPa); with 3 pF being a wet soil and 5 pF a dry soil.

Soil suction has also been equated to the wilting point of trees. It has been inferred from studies of soil suction profiles (Cameron 2001) the maximum suction that can be imposed by the roots of some eucalypts on the underlying soils is 4 to 4.5 pF (1 - 3.2 MPa), which is similar to the range reported by McKeen (1992). If the soil happens to get drier (especially near the ground surface over summer-autumn), the tree is unable to extract any further water from the soil. This limit is the trees wilting point. Moreover, wilting point suctions (total suction) for a tree and a site should be referenced to the soil salinity. These ranges are species dependent and presently based on very limited data.

1.4 Avoiding Damage from Tree-Related Desiccation of Soil

Two methods are used to decrease the likelihood of house damage to soil moisture changes:

1. Permitting minimum footing depths (no tree effects considered) and trying to ensure sufficient separation between the tree and building to prevent damage (AS 2870);
2. Increasing footing depths to permit tree planting designs, based on estimates of additional soil suction change due to the vegetation (Footings Group, IE AustSA)
Method 2 is based on very limited data and does not consider the influence of species.

1.4.1 Method 1: Recommended Safe Distances of Trees from Houses, D:H

It is easier for footing designers to abide by safe distances of separation than to design for trees. The proximity of trees to structures is the minimum horizontal distance, D, between the base of the tree and the building perimeter, to the height of the tree, H, (D:H). Separation distances equivalent to the height of the tree is used widely today to avoid damage to houses caused by clay shrinkage from tree-related desiccation. Ward in 1953 designed the D:H=1 rule, in which an “effective” root spread equal to the height of the tree should be assumed, and therefore adhered to. With the current Australia-wide trend towards smaller housing lots, the prescribed safe distances could lead to a treeless urban environment. It is considered aesthetically unacceptable in the urban environment to employ this design rule (Flora 1978).

Australian Standard AS 2870, provides recommendations for the appropriate safe distance of trees to buildings. Ravina (1983) suggests that separating trees and buildings by a minimum distance of about half the tree height could eliminate 75% of reported house damage cases in Britain. The current AS2870 proximity ratios are more stringent.

According to the guidelines in AS 2870, any tree could potentially damage buildings at distances of separation between three quarters and one and a half times the height of the tree, depending on the reactivity of the site. Species effects are ignored, as there is insufficient information on species interaction with soil water. Furthermore, variations within a species are inevitable due to the different climates and environments around Australia in which they grow (e.g. the Queensland Box grows to heights between 34 to 40m in Queensland, 10 to 25m in Melbourne, whereas in Adelaide this species is usually less than 15m).

1.4.2 Method 2: Footing Depths and Designs

This method is currently based on very limited data and does not consider the influence of species. Increasing footing depths is risky as estimates are based on the estimates of additional soil suction change due to vegetation. The available data on water extraction and wilting point suction values for specific tree species is insignificant at the present to develop more reliable engineering rules for either the proximity of trees to houses on the increased footing designs. The information and research used to estimate these depths needed to be developed and researched further, in order to improve design rules for footings. The costs of increasing footing depths are of great concern and produce difficulties for engineers, developers and the homeowner.

Although there is a good deal of information available in soil water extraction, evapotranspiration and stomatal behaviour of a large number of plants species in agriculture and forestry, similar information for ornamental plant species used in urban areas is very limited. Data on the role of trees in extracting water from the soil and the desiccation that results (i.e. suction profiles) are also very limited, particularly for trees in an urban environment. Some recent work was reported by Cameron (2001), in which the effects of trees were inferred from soil moisture studies around damaged houses.

Large mature trees can extract water from depths of up to 4m and even to depths of 6m where a stand of trees is competing for the soil moisture. The soil can not be dried
at depth in the soil profile any lower then the wilting point suction. Near the surface, the wilting point may be exceeded with intensive evaporation over the summer months, however soils at depth rarely exceed the wilting point suction (i.e. $\leq 4.5\, \text{pF}$).

### 1.5 Soil suction and soil movements

All clay soils experience seasonal suction variations, causing seasonal soil movements. In Adelaide these seasonal movements have been observed to a depth of about 2 m. The movement decreases with depth and there is a time lag between the surface and deeper movements (Aitchison & Holmes 1957). In a housing development, it is recognised by AS 2870 that urbanization causes environmental changes, which can lead to greater depths of movement and a moderation of seasonal effects. Adelaide’s semi-arid climate dictates that house footings should be designed on the basis of a design suction change from wet to dry at the surface of 1.2 pF varying linearly to 0 pF at a depth of 4 m.

Despite there not being a prescriptive Standard for designing for the effects of trees, engineers have been pressed by the community to accommodate the extra soil drying that may arise from trees. Knowledge of the in situ soil suction changes around trees is essential to reliably estimate the ground movement in expansive clay soils. Once the magnitude and pattern of the ground movement is known, footings can be structurally designed to mitigate adverse effects and to facilitate an acceptable performance of the structures they support. At present, additional suction changes are provided in guidelines by the Footings Group (IEAust SA), which do not recognize either any influence from tree species or the concept of wilting point. Suctions supposedly generated by trees using the Footings Group approach tend to be higher than equivalent suction at the wilting point.

### 2. RESULTS FROM THE MATURE STREET TREES PROJECT

In this project five streets were monitored over a minimum period of one year. Each street contained mature tree plantings consisting of both Australian native and exotic species (*Eucalyptus leucoxylon*, *Eucalyptus sideroxylon*, *Angophora costata*, *Jacaranda mimosifolia* and *Celtis australis*).

To measure the influence of street trees and the movements of clay soil in urban areas, a number of instruments and approaches were used. In this project, a neutron moisture meter (NMM) was employed to measure volumetric soil moisture contents, and soil samples were taken at various stages in the project to back up the NMM soil moisture profiles. Level surveys were conducted to monitor surface movements of the street and nature strip, while a Wescor dew point hygrometer was used to measure leaf water potential (LWP) on site. LWP is useful as a measure of the stress and water uptake by trees. In addition a one year long survey of wildlife along the streets has been launched to investigate the value to biodiversity of the various tree species.

#### 2.1 Neutron Moisture Meter Count Ratios and Suctions

The NMM is a probe that can be placed down boreholes to monitor soil moisture. It works by emitting neutrons and a detector within the probe measures the number of neutrons returned after collisions largely with hydrogen atoms in the soil. As hydrogen is associated with water molecules, the more collisions the higher the count and therefore the greater the water content in the soil. A count ratio is made for each measurement by dividing the raw count to the standard count.
All the soil suctions reported in this paper are total suctions measured in the laboratory on recovered soil samples with a Wescor dew point hygrometer.

Figure 1: Soil suction profile and NMM Count Ratio profile, *Celtis australis*

Figure 2: Soil suction profile and NMM count ratio profile, *Eucalyptus leucoxylon*

Figure 1 displays the suction and NMM data for Wolsten Road, Para Hills, which is planted with the nettle tree species (*Celtis australis*). The Wolsten Rd. graphs show a distinct difference between the soil moisture suction profiles across the site at the time of establishment. The suction profile below the nature strip (“between trees”) shows a dry soil profile to considerable depth (suction \(\cong 4.3 \text{ pF}\)), while the suction profile away from the trees (D:H = 1.4) is quite wet. The other graph in Figure 1 is the depth profile for the NMM count ratios at the same site. It shows a similar trend to the suction graph; the driest place is between the trees, and the “pavement” and “away” profiles are wetter than the between the tree profile.
Figure 2 corresponds to the suction profiles for Saxon Street, Pooraka, which is planted with blue gums (*Eucalyptus leucoxylon*). A similar trend is observed to the Wolsten Rd. data; the driest place is between the trees, and the “pavement” and “away” profiles are wetter than the between the tree profile. The blue gums appear to generate a slightly higher soil suction (wilting point suction) than the nettle trees, having a value of approximately 4.35 pF. The “away” curve indicates dry soil between 1 and 2.5 m, however the soil becomes noticeably wetter with depth and there would appear to be evidence of decreasing suction with depth, possibly suggesting a groundwater table not much deeper than 4 m.

The cyclic nature of soil moisture changes well away from the trees at Wolsten Rd is shown in Figure 3. Soil suction samples were taken in May and October 2000 and April 2001. The greatest moisture changes are in the top 2.5m, between October and April (wet-dry). These soil moisture fluctuations are usual for soil moisture change profiles in the absence of trees. Figure 4 illustrates the constant depletion of moisture near trees as compared to the “wet” soil moisture profile away from the trees in Figure 3.

![Wolsten Rd., Seasonal](image)

**Figure 3: Soil Suction Profile “Away”, *Celtis australis***

Figure 4 provides the NMM count ratio depth profiles over a one year period for both the nettle tree (Wolsten Rd) and the SA blue gums, “between trees”. The graphs show the seasonal changes of NMM count ratios from summer-autumn and winter-spring. It is evident that there was little difference between soil suction profiles for the wetter and drier months, although the higher suctions can be found during the summer months. This is due to the stand of trees extracting water all year round, depleting the soil moisture and therefore making it considerably dry throughout the year.
2.2 Soil Suction Change and Ground Movement

Levelling surveys were used to monitor soil movements. Survey marks consisting of ramset nails were positioned across the road surface, near the trees and away from the trees. The levels show the ground movements across the pavements and near and away from the trees.

Soil suction changes can also be used to estimate the ground movements arising from the various properties (soil reactivity) in the soil profile. How much a movement can be attributed to the trees requires some judgement.

Figure 5 represents the influence of trees on the soil moisture desiccation by comparing the soil suction profiles under the pavements and away from the trees, relative to the profile below the trees.

Figure 5 has been constructed by assuming the soil throughout the site is uniformly reactive. A soil shrinkage index of 3%/pF was assumed, which would have the site
classified on the H-E boundary. The site depicted is Wolsten Rd., Para Hills (May 2000). As the site classification for this area is probably H-D, the estimate of the shrinkage index may be a little high. Note that movement estimates are directly proportional to the shrinkage index.

Figure 5 can be used to estimate the relative soil movements due to the influence of species. On extremely reactive sites, trees can have a large influence of up to 50% of the total soil movement (Biddle 1983). In this case however, the total soil movement due to the tree extracting water at depth is approximately 25%. These movements, although not large, can cause significant damage to houses (especially older houses), footings and pavements.

![Figure 5: Soil Movements Due To The Influence Of Street Tree](image)

### 2.3 Leaf Water Potential and Species Water Relations

Leaf water potential is the potential of the tree to extract water from the soil; it is measured in MegaPascals (MPa), and is a negative value as a negative potential (suction) is needed to drive the water through the plant. The atmosphere through humidity provides the pulling power (negative pressure) to move water from the soil through the plants xylem to the foliage. Water moves from regions of higher potential to regions of lower potential.

Leaf water potential does not however measure the water use of trees. It may indicate the potential of the species to extract water from the soil. The lowest potential (highest suction) is measured during the afternoon period as the trees wilt (or stress). Leaves lose greater amounts of water due to adverse positions of the sun and environmental conditions (O’Malley 2001). Leaf water potential is measured in-situ (in the field) using a Wescor leaf hygrometer. This is the same equipment used for soil suctions in the laboratory, but with different chambers for the field environment, more suited to leaves. It is a non-destructive method that does not damage the trees leaves.
Jacaranda and the blue gums range of potential in pF was 4.2 - 4.35 pF. Although they have the same pF ranges, the two species had different peaks and troughs in LWP throughout the year. The jacaranda tree became more stressed at the start of the dry period (peak February), while the blue gums potential followed a linear path to its peak of 4.35 pF in April 2001.

Figure 6 illustrates the data for *Jacaranda mimosifolia* on Gould St., Para Hills and *Eucalyptus leucoxylon* on Saxon St., Pooraka. The leaf water potentials in the plot are the average of three leaves and their LWP values for the month. The highest potentials are during the winter months (June to October 00) as there is more moisture in the soil and therefore it is easier to extract water from the soil. In the drier, summer months (November-May) there is a shift in the trees LWP. The LWP becomes lower as there is limited water in the soil and the tree has to apply a higher suction to extract water from the soil. These high suction values during the drier periods may be directly related to urban desiccation, the cause of clay shrinkage, which causes pavements to crack, and houses to deflect. Higher suctions correspond to greater desiccation and hence greater soil movements in urban areas.

There was little difference observed in water relations between the tree species over the course of the project. Daily and weekly differences in water relations measured in LWP, but were found to be insignificant over a long-term trend. No difference was observed between the native and exotic tree species. The jacaranda species tended to have higher LWP during wetter periods and the native species had lower LWP (higher suction) during the summer months. The native trees are better suited to dry climates and the exotic jacaranda and nettle trees are more suited to wetter temperate climates.

### 2.4 Wildlife Study and Value of Biodiversity

A wildlife study looking at the importance of street tree species for urban biodiversity began in August 2001. It is a joint project between the UniSA, and City of Salisbury run through the councils Urban Forest Biodiversity Program. The surveys will be conducted for a period of one year, so all seasons can be encompassed. Surveys will concentrate on the movement of birds in and around the five tree species. The results will be used by the local council and urban forest groups to determine if there are any significant differences of fauna activity between the species. The role of native to non-native species will be investigated to determine if the native eucalypt species attract or are home to a higher or lower number of bird and fauna species. The role
and usage of the tree species can be used to gauge the importance of the mature trees in the urban environment.

3. A STUDY OF IMMATURE STREET TREES IN A NEW SUBDIVISION-WALKLEY HEIGHTS

The mature street trees project has led to the current project at Walkley Heights, looking at the influence of younger trees on soil moisture depletion, their establishment in a new development and long term monitoring of soil moisture and soil movements. This stage of the research is aimed at answering the question, how much soil moisture change and ground movement is attributable to street trees.

The Walkley Heights project is in its early stages, with trees planted in August 2001 and the installation of boreholes at the sites beginning in late August. It will be conducted along the same lines as the previous project with NMM monitoring, levelling surveys (road and houses), soil sampling (suctions) and leaf water potential measurements. Tree species that are being investigated are *Jacaranda mimosifolia*, *Ulmus parvifolia*, *Pyrus* species, *Koelreuteria paniculata*, *Eucalyptus torquata*, *Eucalyptus leucoxylon*, *Lophostemon conferta* and *Eucalyptus cladocalyx subsp. nana*. (underlined species represent the main sites in the study, while the other species will have LWP measurements only. All the species are immature trees with heights of 2 m, apart from the stand of mature dwarf sugar gums, which are 7-8 m in height.

3.1 Objective

The objectives of the project over and above the mature tree study is to examine the potential nuisance that trees may cause to urban buildings knowing the background soil movements.

3.2 Expected Outcomes:

Trees need to be evaluated in urban areas so Local Government Authorities can strike a balance between amenity and nuisance factors in developing management strategies. In Adelaide’s semi-arid climate, reasonably drought-resistant species of trees are required, which will not extract excessive moisture from shrinkable clay soils. To this end, it is expected that the project will establish a methodology for Local Government Authorities for appraising trees in asset management programs in terms of:

- Water demand;
- Potential movement and damage to buildings and infrastructure by mature trees, existing prior to construction;
- Potential movement and damage to buildings and infrastructure by trees, planted after construction;
- Develop information on tree species for civil engineers to incorporate in footing design rules to improve the reliability of performance of building footings in a treed environment;
- Develop information on tree species for civil engineers to improve on site assessments of causes of damage to buildings

The last two points will be developed from the information and knowledge gained from the two research projects.
3.3 Walkley Heights

The Walkley Heights project is expected to show greater soil moisture changes, soil movements and higher suction profiles than the mature trees project in Para Hills and Pooraka, due to the area’s extremely reactive clays, small block sizes and the semi-arid climate. Soil movements on the subdivision’s main leading road, creating ripple effect along the road, and some residents have reported movements in their houses. The area’s roads are approximately two years old.

4. SUMMARY

Due to Adelaide’s reactive soils and the prevailing diverse climate, homes will be threatened by underlining soil movements. Engineering designs have minimised the risk of damage. However, trees present something of an unknown factor to footing designers. The best solution to minimise damage to footings and houses is to either apply the D:H proximity rule or increase footing depths to account for extra soil movements. Both these approaches are used today, but without scientific and direct knowledge of species, extent of desiccation and soil movements, design rules are too simplistic and inefficient.

The best way to tackle this problem is to look at the influence of trees in urban environments, by monitoring ground movements and soil moisture changes and tree responses. The two projects being undertaken by the UniSA are adding valuable knowledge and information on urban species water use, soil desiccation, reactive soil movements and the damage caused to dwellings, footings and pavements. The results from the research project will be used to design footings for extra soil movements and to develop guidelines for urban street tree species taking into account climate, geology, soil reactivity and species.

The research to date has shown that the trees do dry the underlying soil at depth and that significant movements can result.

5. REFERENCES


IS THERE A PLACE FOR AUSTRALIAN TREES IN OUR STREETS?

Neville Bonney, Greening Australia (South Australia)

Much of what I have to offer has been and will be discussed by the various excellent speakers here today.

Speaking of the use of Australian trees in our streets can throw up many thoughts to many different people.

It is not easy when councils have many considerations to take into account, yet it is the residents who have to endure, appreciate the species often chosen by the streetscapers, usually under local council direction.

To speak of Australian trees, can also conjure up many thoughts for the Australian public.

In many areas we still have trouble accepting that they originate in this country. We have a 200 year background where all trees in the new land were described as being scrubby in nature, most lacking form, untidy, mostly all evergreen, and many lacking the flowering beauty of those they had left behind in Europe.

To many Australians, the shackles of our past have not left us and that thinking often remains. With the renewed interest in retaining urban biodiversity, Australian trees and shrubs are once again coming into favour.

In my journey around this country and in particular South Australia, I see many excellent examples of treescaping. I also see problems in the future with the planting of some particular species.

So what are some of the perceived problems? Do some councils have a policy of changing streets say every 25 years, or are they changed because of necessity?

What is the right tree for any particular area? If only that species was planted, a monoculture of streetscaping would soon appear. Is that what we want? Mixed species would seem more popular throughout suburbs.

So let us look at some suitable species.

What is the criteria for councils when selecting particular trees? I don’t know. Historically, it was usually what the nursery person suggested.

As we move into a new century, there is marked improvement. Most councils have their own nurseries, trained horticulturalists, environmental staff etc. who are well trained in many aspects of tree culture.

The advent of the Treenet group here in Adelaide can only see improvements in the future.

In a recent TREENET Report compiled by D. Lawry and J. Gardner, some interesting statistics were brought to light in relation to a series of responses by Local Councils. The survey indicated that there was an equal number of Australian native species planted as street trees to the number of exotic species.
On the list of those Australian species planted, some really don’t have a future, unless grown for on 10 – 15 years. They are what many of us involved in the tree business would call ‘short term only’ or ‘problems ahead’. There are so many environmental conditions to consider when choosing the right tree for the right position and future TREENET information gathered will address this.

For example: coastal and high wind areas should see plantings in groups so that crowns of trees merge together when they mature. We need to get away from formal plantings in these areas. The choice of trees for coastal and high wind areas should have a high percentage of trees with fine or needle like foliage e.g. *Allocasuarina* which in turn filter the wind or slow it down. Don’t try and stop the wind totally with broad foliage species.

The growing interest in local biodiversity and the retention where possible of existing trees, is giving credence to the planting of Australian native species. The use of understorey shrubs, grasses, sedges etc. to compliment street trees, is a huge improvement visually.

So what are some of the problems associated with the use of Australian trees and shrubs?

Pruning many native species, particularly shrubs etc., is an advantage: knowledge is required on certain species of the amount that can be cut back. For example, the Myrtaceae family – callistemons and melaleucas really benefit from hard pruning, yet those of the Proteaceae – grevilleas, banksias need light pruning only. Most of these plants will not respond with new growth of old wood, so understanding this factor of other plant families also needs to be known.

When choosing trees, often the potential size indicated is far from correct. Size of trees is often gained by botanical recordings in their natural range. If we take them from their natural range, soils, rainfall, then put them into a new environment, often a higher natural rainfall, an additional watering program in their initial years, and excellent weed control programs, then the trees can and will double their natural size. The message here is when you select a tree, double the size and see whether that still fits into your program.

Another area for improvement is not to choose certain species that with pruning, create an umbrella shape. For example: hakeas and particular eucalypts like the *Eucalyptus platypus* group, will and do blow over. It is best that these type of Australian species not be put on future lists as potential street trees, or if used, then in mass plantings or groups closer together.

Another area that needs to be addressed, is to have an holistic approach to street scaping, more than just street trees. Some councils, to their credit, are making some progress and they are to be commended. We all need to accept and try and work in harmony with existing landscapes or create streetscapes that have an Australian landscape about them.

How many streets do we drive along and see the biggest kaleidoscope of mismatches with trees and shrubs you could expect to find? If n or should we. Many older plantings now have historical and heritage value and we need to accept them as they are and to perhaps learn from them.
My message is to streetscapers of the future, particularly in newer suburbs is to use linkages of say, parklands etc. and create a more natural theme. It can work well, it does work well and some excellent examples can be found in Eastern Australian cities and towns. Don’t be ashamed that you are using Australian native trees and shrubs – be proud of it. Be more innovative in your approach.

So, is there a continued place for Australian trees in our streetscapes? Yes, of course there is. There are many treasures out there still to be used to compliment those we use already. There are many cultivars and hybrids destined to make their way into streetscaping in the years ahead.

For example, in low rainfall areas, the following have excellent potential to be trialled.

- *Myoporum platycarpum*
- *Pittosporum phylliraeoides*
- *Geijera species*
- *Acacia stenophylla*
- and many other dry land *Acacias*

In high rainfall areas:

- *Callistemon Cultivars*
- *Persoonias*
- Small eucalypts to name a few.

Not to forget the excellent range of grasses, sedges, *Lomandra* species from the iron grass group and *Dianella* species from the Liliaceae are excellent in use as understorey streetscaping.

At the end of the day, does it matter what we plant as long as residents are happy and the tree or shrub meets the objective of the council and its maintenance costs are not too large.

When choosing that tree or shrub, we must know its history, its potential change once in cultivation, it adaptability to soils, rainfall, its final size and potential age and most importantly, what maintenance will it require, during the course of a year for local council.

With this in mind, there are great opportunities ahead for streetscapers. Don’t be afraid to implement changes, as mentioned earlier, be bold and innovative.

Remember, as streetscapers, you are also the artist. You are creating a picture for many of us to enjoy. The beauty does not have to be in the flower, it can be in its form, foliage or bark.

With this in mind, Australian trees and shrubs do have a place in our streets and parks and hopefully, in the early part of this century we will see a lot more.
THE TREENET WEB SITE – USING THE INTERNET TO SHARE STREET TREE INFORMATION

Sean Donaghy

SUMMARY
The role of the TREENET web-site is to provide information about TREENET, allow people to share ideas and experience, and to act as a way to input and output trial site data and information.

The TREENET system is still very much in its development phase, and as such is a work-in-progress. It has, however, progressed to the point where we are seeking input from prospective end-users about: (a) the features they would like to see and (b) how they plan to use the system. This phase of development is vitally important, as it allows us to mould the system to suit the end-user.

In this presentation I will discuss five main topics:

Why use the Internet? A general discussion of the technologies involved and how they can be used to achieve TREENET’s aims.

What is on-line so far? A quick tour of the web site.

Trial Site Data Uploads How to send us trial site data.

What is proposed? A discussion of some of the ideas we’ve been working with, some of which we propose to implement in the coming months (modified according to feedback from prospective users).

Feedback How prospective users of TREENET can give us feedback and how important this period of discussion is to the TREENET project.

And, finally:

The future possibilities for TREENET as an on-line resource Where the technology is heading, what it means for TREENET, and what we might see in the years to come.
TREES ROOT NETWORKS : A VITAL INGREDIENT OF TREENET

G M Moore, Burnley College, University of Melbourne

INTRODUCTION

The knowledge of the tree below the ground has expanded dramatically over the past two decades (Perry, 1982; Yau, 1991; Moore, 1995; Watson and Neely, 1994). The era in which those managing urban landscapes could ignore the management of tree root systems, because they were “out of sight and out of mind”, has long passed. So too should the era when people assumed that large trees in urban sites had large tap roots, and that root systems could not be managed to meet the demands placed upon trees.

In most urban situations, trees are planted into disturbed soil profiles, which have been substantially altered by past human activity (Smith and Moore, 1997). Such profiles need to be identified (Table 1) and appropriate management strategies implemented if trees are to establish and survive at acceptable rates in such environments. This may require a re-evaluation of the approach to the specification of the planting hole (Figure 1), and communication with urban planners, landscape designers and architects that will provide better information than that which has been traditionally available.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 SCALPIC</td>
<td>Cut land surfaces in which natural topographic contours are broken and ‘rock structure’ occurs near the surface.</td>
</tr>
<tr>
<td>2 GARBIC</td>
<td>Organic solid waste and or a large concentration of methane occurs in the soil atmosphere to within 1 to 2 m of the soil surface, for example a sanitary land fill.</td>
</tr>
<tr>
<td>3 URBIC</td>
<td>Miscellaneous urban fill with manufactured inorganic artefacts (for example bricks, glass and concrete) in the upper profile.</td>
</tr>
<tr>
<td>4 SPOLIC</td>
<td>Locally derived moved earthy soil material, but without artefacts.</td>
</tr>
<tr>
<td>5 DREDGIC</td>
<td>Soils containing dredged materials.</td>
</tr>
</tbody>
</table>

Table 1. A classification of soil types commonly found in urban environments from Smith, 1997.

ROOT SYSTEM MORPHOLOGY

Large trees usually have large root systems to support them. While this may seem axiomatic to horticulturists, its importance is all too rarely appreciated by those from other professions responsible for interacting with tree management in urban sites. Rarely are the issues of adequate soil root volume, or an appropriate area of open surface to the atmosphere necessary for successful tree establishment and growth given attention by such professionals. Even the space around trees planted in streets and the sizes of grids used around them often seem to have been arbitrarily derived.

The network of roots in the root plate is made up of a framework of roots. The largest are the primary or first order roots, which branch to the secondary or second order
roots, these to the tertiary or third order, and so on to the finest of absorbing roots. Fine roots are regularly shed and replaced, in a way that is similar to leaf shedding. Roots become woody and compartmentalise as they age, and it would appear that there are many systems of protection and defence against pests and diseases that are analogous to those that are now understood to exist in the trunk and canopy.

Figure 1.  Recommended design for a typical uncovered individual tree pit or planting hole. The tree could be small container grown stock, semi-advanced or advanced material. Adapted from Craul (1991). And drawn by K.D. Smith for Smith and Moore (1997). Not to scale.

• 75 mm depth mulch, beyond the edge of the hole, overlapping undisturbed soil
• Leave a space between mulch and trunk
• Top of the root ball flush with finished level of the planting hole
• Excavate a sloping, shallow planting hole, 2 to 3 times the width of root the root ball
• Depth of planting hole no deeper than the height of the root ball
• Backfill with site soil, firming progressively
• 75 mm high berm to form a watering basin

However, it is well known that tree root systems tend to be shallow and spreading, rather than restricted and deep (Watson and Neely, 1994; Moore, 1995). Given this knowledge, urban landscapes should be appropriately designed to accommodate this basic biological need. The idea that trees can be planted in deep narrow holes and perform in an acceptable fashion over the usual life expectancy period is unreasonable. What is required is some lateral thinking which sees the space provided as extensive and shallow, and which incorporates the provision of necessary utility services under the trees. Such an approach should see the demands of both the hard and the soft landscape successfully managed.

In recent years the rootball concept, which saw the root mass as relatively narrow and deep has been replaced with the notion that the spreading root system forms a wide but relatively shallow root plate. This concept has been very useful, especially in educating other professionals about the importance of tree root systems in urban situations that involve interaction with the hard landscape. It has also been useful in negotiating with design professionals, planners and other decision makers to provide trees with some of the essential biological requirements mentioned above.

The focus on the root plate, however, has tended to distract people from recognising the importance of the descending roots. These roots, sometimes called sinkers or vertical roots, are an important component of the overall root system morphology. In trees that fall, the root plate is often intact, but the descending roots, which appear to
anchor the root plate, are usually damaged or in some cases missing (Moore, 1995). The focus on descending roots does not mean that the root plate is not important, but rather emphasises that it is the whole root system that is important to tree survival and growth.

The shallow spreading roots that make up the root plate must be properly managed, but so too must the descending roots. These descending roots are easily damaged or destroyed by changes that see rises in the watertable, changes in soil aeration or nutrition or disruption to subterranean water flows. These changes commonly occur when existing trees are impacted upon by construction works, and the creation of substantial foundations for hard landscape. It is also possible that paving over the root systems of pre-existing trees can also cause loss of descending roots. An investigation of the root systems of fifty mature trees of various species that had fallen during strong wind storms, revealed that none had intact descending root systems, and that none had any root material that was still living below a depth of 0.5 metres, and often less (Moore, 1988). In each case the trees appeared healthy and the root plate remained intact, but there was evidence that descending roots had been either damaged or had died. In some instances, rises in water tables due to construction work seemed to cause descending root decline.

THE ROOT:SHOOT INTERACTION

The closeness of the relationship between the canopy of trees and the root system, which supports them cannot be over emphasised. It is well understood that to get a healthy vigorous tree requires a healthy supporting root system. However, what is often not recognised is the intimate relationship between root growth and canopy. For example the defoliation of young *Eucalyptus obliqua* seedlings saw root tip growth cease within twenty-four hours (Moore, 1982). Root tip growth was observed to commence between 24 and 48 hours before epicormic or lignotuberous buds of seedlings began to shoot.

Even more spectacular is the relationship between root and shoot growth in the recovery phase after stress (Figure 2). Clearly the relationship between root growth and successful plant establishment and canopy development is intimate, and in the young seedlings tested, there would appear to be a natural root:shoot ratio, which relates canopy biomass to root biomass (Moore, 1982). Other studies have shown that such relationships are not simple, and that simple rules and ratios for all species do not apply. However, the concept is well worth further research.

Recognising the close relationship between good root biology and successful tree establishment, requires appropriate management of the environment in which roots grow. In most urban situations it should be assumed that the trees will be growing under stress for at least part of the year. The stress may result from high or low levels of water, low soil oxygen or low or high soil nutrient status. In such a situation an understanding of stress biology is important to successful tree management. Trees display various levels of stress resistance to a range of environmental stresses, but the resistance may be due either to stress tolerance or stress avoidance mechanisms. It is important to know which is which when a tree is recognised as having a high level of stress resistance.
Figure 2. Height increment of *Eucalypts obliqua* seedlings for twenty weeks after a period of stress. The stress imposed was to heat the seedlings at 60°C for a period of eight minutes, which is a sub-lethal level of stress. After ten weeks control and stressed seedlings were indistinguishable from each other (after Moore, 1982).

The use of *Eucalyptus* species in urban plantings is increasing rapidly in Australia. Some species have been identified as being suitable for urban use on the basis of their stress resistance, and in particular their capacity to cope with drought. However, species like the River Red Gum (*E. camaldulensis*), which is the most widely distributed eucalypt in Australia, and which occurs in many arid parts of the continent are drought avoiders. This species only grows in places where water supply is constant, or where the extensive root system can tap into subterranean water sources. It has little capacity for stomatal control and so is rarely suitable for restricted and dry urban sites. Despite this biology, it is still often recommended for urban planting, especially by landscape architects attracted to its form and spreading canopy. It would be more sensible to seek plants, which avoid drought through high levels of stomatal control, or which can tolerate drought through the capacity to sustain their metabolic activity in the face of lowered internal water potential. These plants should offer much better prospects for use in urban landscapes.

**TREES AND SOILS: A NECESSARY INTERACTION**

Tree roots tend to grow along lines of least resistance (Yau, 1991). As root tips grow and subsequently elongate, they do not grow around soil particles as many people think. Rather the tip is forced through the soil and is constantly abraded by the soil particles. In soils with high bulk density (Smith, 1997), the resistance to root tip growth, elongation and subsequent development is high. In such soils the establishment of an extensive root system can be limited and so it may take many years before the plant can successfully establish and grow in such a soil.

In other situations however, where the natural soil profile has been shattered by earth works for the construction of foundations, pipelines or other hard structures, the soil bulk density is much reduced and so the roots can extend and develop along these
lines of lesser resistance. In such situations the construction processes often provide ideal conditions for root proliferation in the very places that landscape managers would wish to have few, if any, roots at all. In short bad management and poor arboricultural practices are inadvertently providing conditions of low soil penetrative resistance, high soil oxygen levels and enhanced soil water levels in places where root growth is not wanted. If organic matter is added to this list by inappropriate back filling in such situations almost ideal root growth conditions have been provided. It is obvious that such a situation must be properly managed.

The issue of properly managing soils around hard landscape constructions is an issue that should be addressed with some urgency (Moore, 1994; Watson, and Neely, 1995). Too often engineering and landscape specifications are inadequate in protecting hard structures from damage due to the presence of large trees. Many of the management practices required to avoid these situations are simple but rarely practiced (Table 2). It is important that the soil profile around footings, foundations and paving, and along trench lines should be reconstructed by proper back filling, and perhaps heavy compaction. Such an approach should minimise the risks of root proliferation in places where root growth is undesirable.

Table 2. Simple management practices for limiting root damage to hard structures and services (after Moore, 1994).

| * | PROPER INSTALLATION OF PLUMBING, GAS, COMMUNICATION AND ELECTRICAL SERVICES |
| * | PROPER BACKFILLING OF TRENCHES AND FOUNDATIONS THAT RECONSTITUTES THE SOIL PROFILE |
| * | APPRECIATE THE VALUE OF COMPACTION AS A ROOT MANAGEMENT TOOL |
| * | MANIPULATE ROOTS BY THE MANAGEMENT OF SOIL: OXYGEN, WATER, NUTRITION, PENETRATIVE RESISTANCE |
| * | ESTABLISH THE MANAGEMENT OF ROOT STRUCTURE AND DEVELOPMENT AS PART OF SITE MANAGEMENT ROUTINE |
| * | DEVELOP APPROPRIATE SPECIFICATIONS FOR HARD STRUCTURES, WHICH RECOGNISE THE PRESENCE OF TREES, AND WHICH WOULD INCLUDE: PAVING, FOUNDATIONS, SERVICES |
MANAGING TREE ROOT SYSTEMS

Compaction

For most arborists compaction is regarded as a problem that has to be dealt with to improve the quality of trees growing in sub-optimal urban sites. However, compaction can be a useful tool in the management of trees in urban sites. In understanding that trees require good levels of oxygen, moisture, nutrients, and low levels of soil penetrative resistance for healthy root establishment and growth, these can be inverted and used as management tools to discourage tree root development in undesirable places. A competent arborist with a good knowledge of tree root biology should be able to restrict root growth by creating conditions which reduce oxygen, moisture and nutrient levels and increase penetrative resistance. The easiest way of achieving these aims is to heavily compact the soil and to direct moisture and irrigation away from such sites.

This approach to tree root management has some significant implications for management practices in disturbed landscapes and construction sites. Arborists and horticulturists should always be involved in the planning and decision making processes on such sites to ensure that practices which recognise the needs of tree roots systems are implemented. Some of these practices (Table 2) include the use of compaction in back filling around the foundations of hard structures and the proper back filling of service trenches. By doing so root growth in such places will be discouraged, especially if organic matter and moisture is also restricted. On the other hand, every effort should be made to ensure that where tree roots are to establish conditions of appropriate levels of soil aeration, moisture, nutrients and bulk density are provided. In this way, arborists can effectively manage the development and structures of the root systems which trees develop.

Soil Oxygen, Nutrition and Moisture Management

Given that it is possible to manipulate the growth of root systems by altering moisture, oxygen, nutrient or soil density levels, it is important that this approach should be used, and indeed some landscape managers have been managing root systems using some elements of this approach for decades. It has been clear that different irrigation regimes can result in the development of quite different root systems on the same species of tree. Infrequent watering can result in a root system that is sparse and spreading and which exploits a large volume of soil to meet the trees needs, (Fernandez, Moreno, Cabrena, Arrue and Martin-Aranda, 1991). Frequent watering can produce a shallow dense root system that occupies a much smaller volume of soil. It is not a matter of one root system being better than the other, but getting the sort of root system that is intended and for which the environment is managed (Moore, 1991).

If a tree is to be planted in a remote place where irrigation is unavailable and where subsequent management is to be at a low level it is much better that it develop the sparse and spreading root system. If however, the tree is growing in an urbanised area where soil space is limited, then it is better that a shallow dense root system develops. Trees planted along roadsides or in shopping precincts, should have dense shallow root systems and so intensive irrigation systems should be installed as a matter of course. By doing so the risks of disruption to hard structures can be significantly reduced. The tree will remain safe and healthy provided that the canopy is managed.
appropriately, bearing in mind that the root system will be unable to support a large canopy that offers a substantial resistance to the wind.

There are many situations where proper tree root management, using relatively simple techniques, can reduce damage to hard structures and prolong the useful amenity life of an urban tree. In many Australian cities as trees age and become larger, there are serious concerns that tree roots may do serious damage to house foundations, especially if the soil types involved are reactive clays. One of the simplest solutions is to install a low cost irrigation system, which not only keeps the soil moisture content uniform, which reduces the effect of expansion and shrinkage of reactive clays, but can also be used to manage the development of shallow and dense root systems. Such root systems are less likely to cause damage to dwellings. By imposing an appropriate irrigation regime sophisticated root management practices can be imposed.

CONCLUSION

Trees planted in urban sites are usually growing under conditions that are sub-optimal and as a consequence they require appropriate, and sophisticated management if they are to establish and achieve their full potential as amenity trees. It is important that both climatic and edaphic factors are considered as part of these management factors, and that the basic biological requirements of trees below the ground are considered by those responsible for planning and managing created landscapes.

Considerable advances have been made over the past two decades in the understanding of tree root biology and the arboricultural practices and technologies used to manage trees in urban landscapes. However, some of these advances are being threatened by political and other decision making processes, which exclude or minimise horticultural input. Too often aspects of the hard landscape are given priority over the vegetation components and this puts landscapes at considerable risk.

REFERENCES


TREENET ADVISORY BOARD

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Executive Officer: Dr Jennifer Gardner, Waite Arboretum
Affiliated Institutions: University of Melbourne – Burnley
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