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

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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 minium 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 minium 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 (eg the Queensland Box grows to heights between 34 to 40m in Queensland, 10 to 25 m in Melbourne, whereas in Adelaide this species is usually less than 15 m).

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 (ie. 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 4 m and even to depths of 6 m 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. ≤ 4.5 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 suctions at the wilting point.

2. RESULTS FROM THE MATURE STREET TREES PROJECT

In this project five streets were monitored over a minium 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.

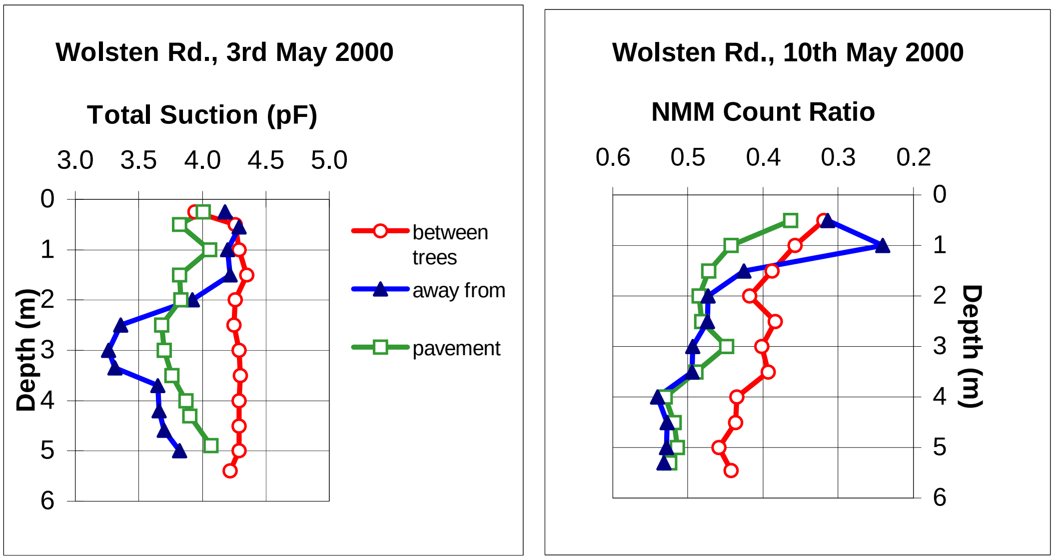


Figure 1: Soil suction profile and NMM Count Ratio profile, *Celtis australis*

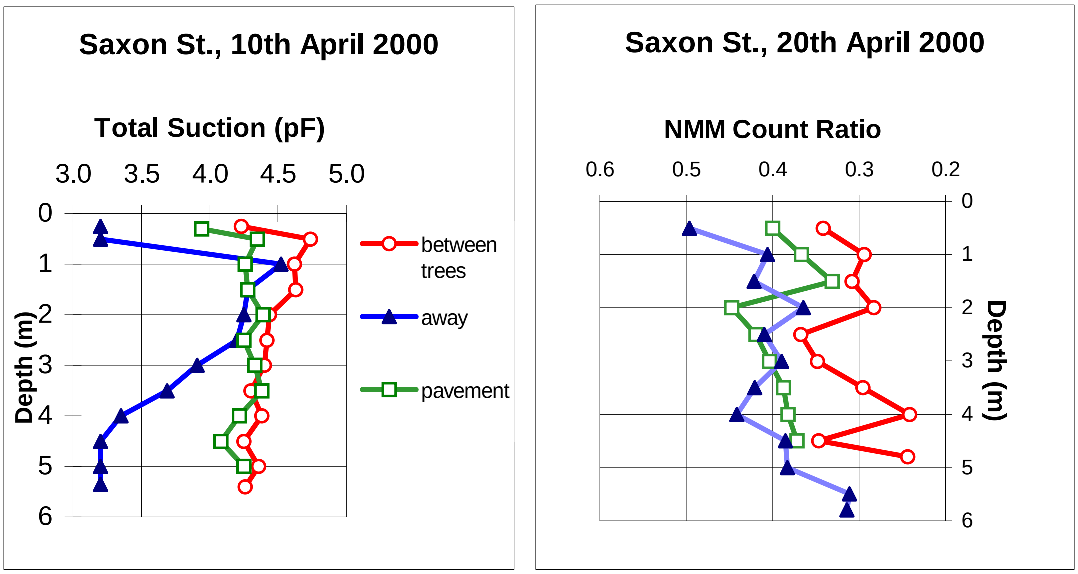


Figure 2: Soil suction profile and NMM count ratio profile, *Eucalyptus leucoxylon*

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 ≅ 4.3 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.

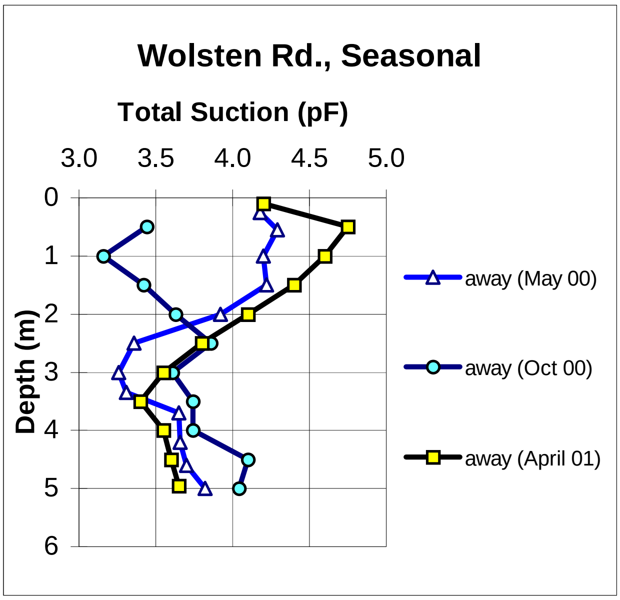
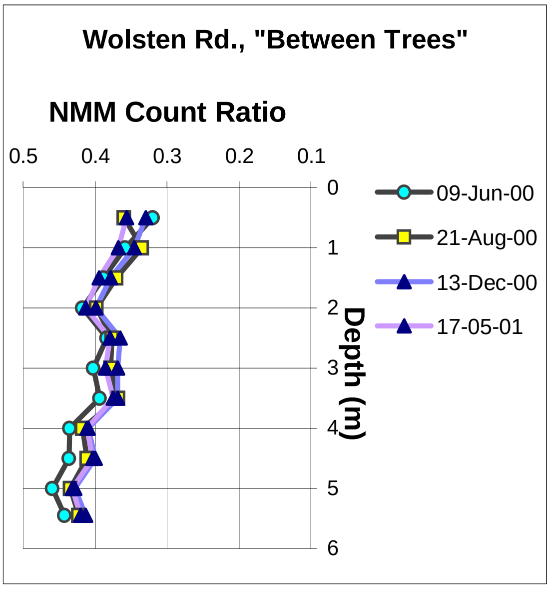


Figure 3: Soil Suction Profile “Away”, *Celtis australis*

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.



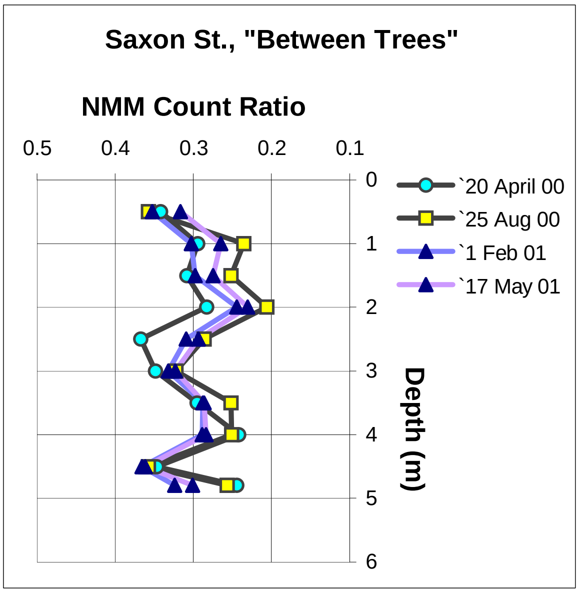


Figure 4: NMM Profiles, "Between Trees" for Wolsten Rd. and Saxon St.

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 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.

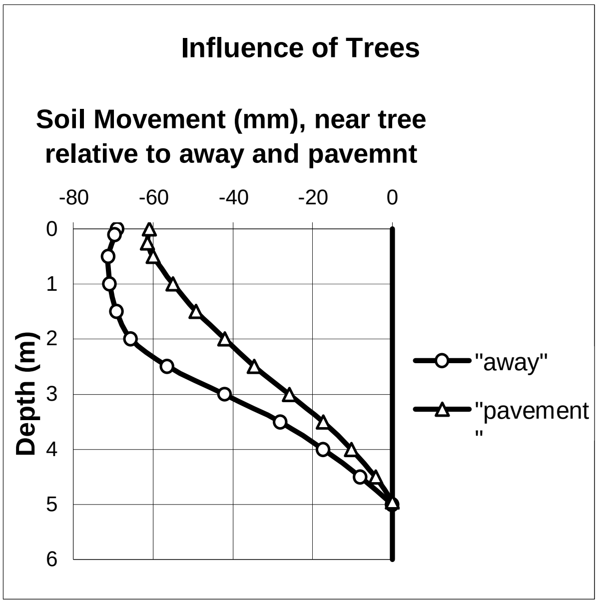


Figure 5: Soil Movements Due To The Influence Of Street Tree

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.

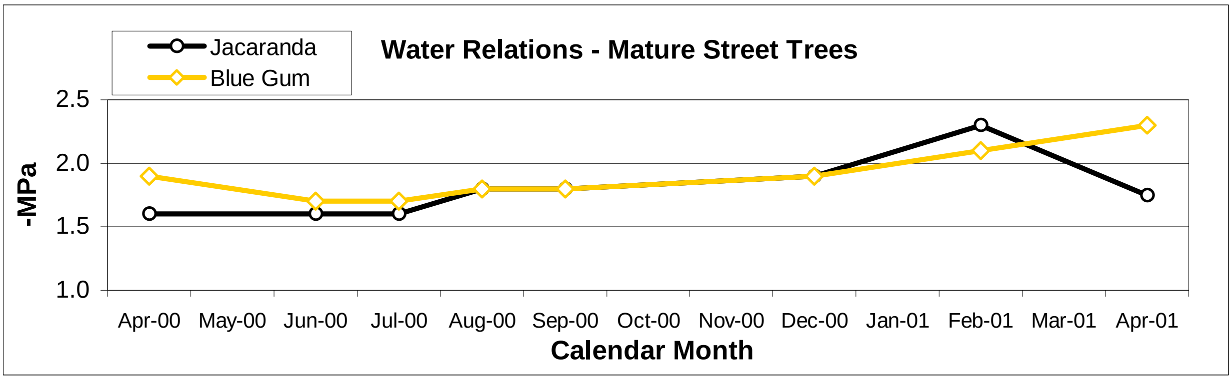


Figure 6: Water Relations for *Jacaranda mimosifolia* and *Eucalyptus leucoxylon* for a one-year period

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.

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