SOIL HEALTH, TREE HEALTH

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VEALE GARDENS/WALYU YARTA - (PARK 21) - PART 4

This case study examines the application of advanced tree management techniques to rehabilitate a population of trees experiencing decline in Urban Forestry. These management techniques focus on enhancing soil health by improving soil physical structure, chemistry and biology. The efficacy of this approach was evaluated using innovative sensing technologies to better understand the links between soil health and tree health and to quantify the productivity of trees in Urban Forestry.

Following up to PART 3 of this Case Study, which ran in *The Australian Arbor Age* Jun/Jul 2019 issue, we are now proceeding with the evaluation of the results in terms of photosynthesis analysis, visual tree assessments and comparing recent salinity studies to come to a conclusion of our case study.

Veale Gardens Photosynthesis Analysis

Multivariate analysis was conducted for each individual tree to account for environmental covariates such as light intensity and time of day and generate adjusted means for each sampling date. Based on the results of this analysis, relative chlorophyll content generally increased over the three years of this study. This trend was also true for the untreated control (tree 31) with relative chlorophyll increasing from 29 in October 2015 to 55 in February 2018.

Matthew Daniel inserting MultispeQ Beta into CO2 chamber.

Similar analysis of other MultispeQ parameters (Phi2, PhiNPQ, and PhiNO) did not show any consistent trends and there was a high degree of variability, most likely caused by the sampling regime used to collect the data (data not shown). To address this issue, a narrower analysis was done by combining all the trees of the same genus and analysing them together (Fig. 26). Only the genera' which included at least three trees were included in this analysis. Three of the four genus showed a consistent increase in relative chlorophyll throughout the study period, with only *Fraxinus* trees not increasing noticeably over time. In contrast, there were no clear time-related trends for the other MultispeQ parameters, with Phi2 generally remaining level and PhiNPQ and PhiNO offsetting each other (if PhiNPQ increased, then PhiNO decreased).

This pattern is expected since these three parameters equal the destination of all captured light by photosystem II, and therefore the sum of these three parameters will always equal 1.

The only genus that did not show an increase in relative chlorophyll was *Fraxinus*, which is also the genus of the control (untreated) tree.

To determine if the untreated tree was behaving differently from the treated trees, all the MultispeQ data were combined from February 10, February 20, and March 10, 2018 into a single dataset. This dataset was chosen because it used a common MultispeQ version (V1.0) and had many data points for the untreated control tree has well as other trees in the park. A separate multivariate analysis considering light intensity, time of day and ambient temperature was conducted to generate adjusted means of MultispeQ parameters for each tree (Fig. 27).

There appears to be a pattern of PhiNPQ and leaf temperature differential decreasing and PhiNO increasing as the tree numbers increased. To test the causes of this trend, correlation analysis of the adjusted means compared with the average light intensity and time of day was conducted (Table 4). While Phi2, PhiNPQ, PhiNO and leaf temperature differential were all correlated with light intensity, there was a much stronger correlation between time of day and PhiNPQ, PhiNO and leaf temperature differential (Fig 28).

These results suggest two phenomena:

1. Over the course of a given day, the trees ability to regulate incoming light (PhiNPQ) diminishes
2. The multivariate analysis was not able to account successfully for all the effects of light intensity and time of day on photosynthesis parameters.

The former outcome results in higher levels of PhiNO, which can lead to photodamage, and hotter leaf temperatures and mean that the trees are noticeably more stressed in the afternoon than in the morning, regardless of light intensity. This is important to note, as it may suggest that future photosynthesis measurements should be taken later in the day, if possible, to see if more stressed trees show greater differences in photosynthesis ▶

Figure 26

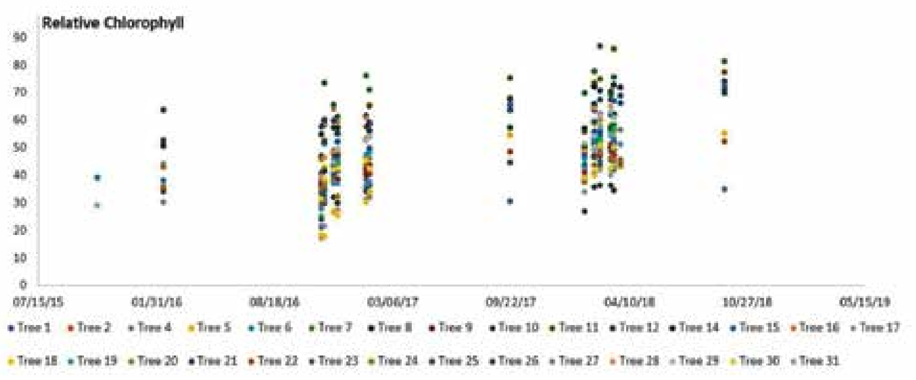


Figure 27

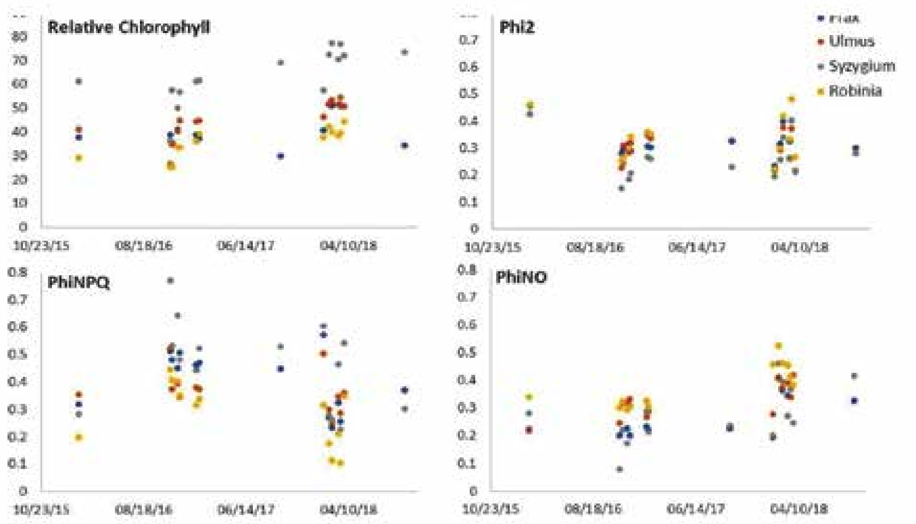


Figure 26: Relative chlorophyll for all trees from October 2015 until September 2018. Tree 31 did not receive any treatment, while all the other trees received treatment.

Figure 27: Photosynthesis parameters by tree species by date. Multivariate analysis was used to adjust species means at each sampling date, accounting for light intensity and time of day, both of which affect field-based photosynthesis measurements.

Table 4: Pearson correlation coefficients between adjusted means of MultispeQ parameters and the environmental covariates light intensity (PAR) and time of day.

Table 4

	PAR	Time (hours)
Relative Chlorophyll	0.080	0.073
Phi2	0.501[b]	0.237
PhiNPQ	-0.600[c]	-0.795[c]
PhiNO	0.472[a]	0.813[c]
LTD	0.499[b]	0.815[c]

[a]significant at $p \leq 0.05$
[b]significant at $p \leq 0.01$
[c]significant at $p \leq 0.001$

Figure 28

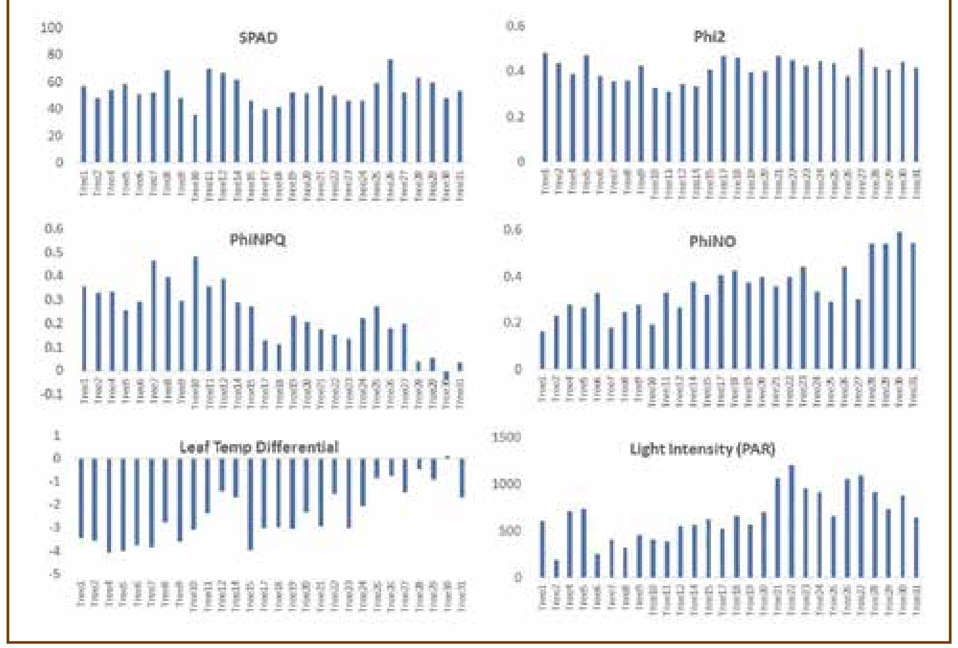
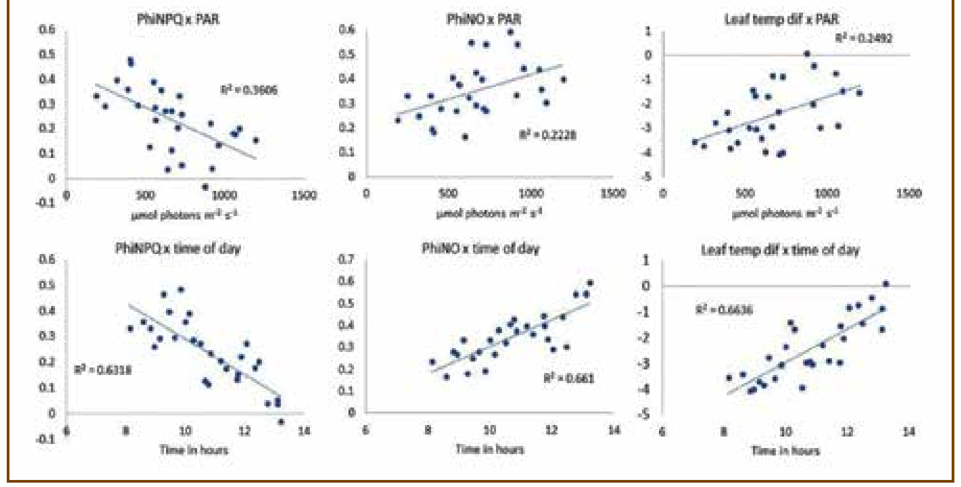


Figure 29



parameters. The latter phenomena could be corrected with a more robust sampling regime, in which each tree was measured at multiple times throughout the day, so that each tree was measured in the morning and in the afternoon.

Finally, it was useful to determine if there was a noticeable difference in tree health between the untreated control (tree 31), which was a healthy control tree in that it did not show signs of decline, and the other *Fraxinus* trees (trees 6, 7, and 15). To do this, results generated in Figure 8 (were used to rank relative chlorophyll content and Phi2 from high to low and then highlighted the position of each of the four *Fraxinus* trees (Fig. 30).

Figure 30

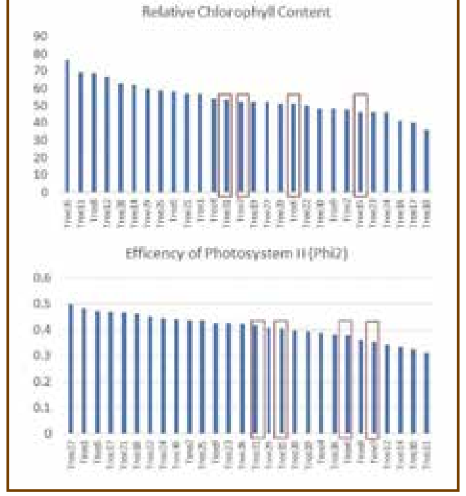


Figure 28: MultispeQ photosynthesis parameters for February - March 2018. Data presented here are adjusted means of multivariate analysis with light intensity, time of day and ambient temperature has covariates.

Figure 29: Correlations between adjusted means of photosynthesis parameters (using multivariate analysis) and environmental covariates (light intensity and time of day).

Figure 30: Ranking of adjusted means for relative chlorophyll content and Phi2, with red boxes identifying the four trees of the Fraxinus genus.

Figure 31: Average Visual Tree Assessment by date for treated and untreated trees.

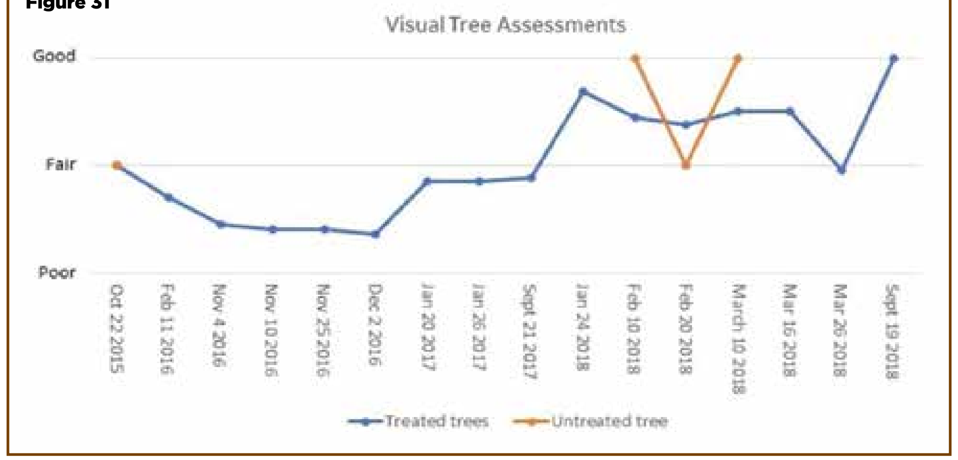
As expected, the healthy control tree had the highest relative chlorophyll content and the greatest Phi2 of all the *Fraxinus* trees. Ideally, tracking the healthy control tree more frequently throughout the experimental period to see if the gap between the healthy tree and declining trees were reduced over time. Relative chlorophyll and Phi2 were used as an illustration because they were the least affected by time of day or light intensity and were therefore the best parameters for comparing trees against each other.

The lack of any trend over time of the photosynthesis parameters (Phi2, PhiNPQ, and PhiNO) suggest that they are not good indicators of tree health, especially considering the care that needs to be taken to develop robust sampling regimes to account for confounding factors like light intensity and time of day. Secondly, while relative chlorophyll content increased throughout the course of the study, that trend was true for the untreated tree and the rest of the trees, and so the cause of the increase appears unrelated to tree management. However, a key caveat here is that with only one control tree, it is hard to draw any firm conclusions.

Visual Tree Assessments

In conjunction with the traditional and novel data collections approaches that have been previously detailed, tree health was also assessed using Visual Tree Assessment (VTA). Figure 31 presents the average VTA score for treated and untreated trees over the course of this case study. Generally, tree health increased over time for all trees, which is similar to the relative chlorophyll content data presented in the previous section. However, the VTA data can be quite inconsistent, due to the subjectivity of the process. For example, on March 16, 2018 half of the trees were rated as good and half as fair, but 10 days later the average rating was only fair. There results suggest that measuring chlorophyll content is at least as good as VTA for assessing tree health and is probably better because it is more objective than VTA.

Figure 31



Comparing recent salinity studies at Veale Gardens

In this section we compare some key soil salinity results from the Veale Gardens/ Walyu Yarta PHC Project with a study that was recently published in the peer-reviewed journal *Sustainability*. This publication "Soil Salinity Mapping of Urban Greenery Using Remote Sensing and Proximal Sensing Techniques; The Case of Veale Gardens within the Adelaide Park Lands" used remote sensing to predict soil salinity issues in the Veale Gardens parkland (Nouri, et al., *Sustainability* 2018, 10(8), 2826; https://doi.org/10.3390/su10082826).

Throughout the G.U.F. investigation and subsequent reporting for the Veale Gardens/Walyu Yarta PHC Project 2015 - 2018, soil salinity was difficult to define in Urban Environments, specifically in relation to guideline range. This is an important short- and long-term factor to understand and define in any circumstance. However, as Veale Gardens Walyu Yarta is now utilising recycled water to irrigate its Park Lands, and because the effects of recycled water on soils is not well understood, having accurate and consistent guidelines is doubly important.

The range guidelines for soil salinity provided by various authorities are quite wide ranging (Table 5). Far too wide to be useful with such an important and essential soil health component. It is ▶

ELECTRICAL CONDUCTIVITY – EC Ds/m	GUIDELINE PROVIDED BY:
< 0.2	Environmental Analysis Laboratories –EAL - Southern Cross University
<0.5	Soils for Landscape Development – Simon Leake @ Elke Haege
<1.2	AS4419 – 2003 - Soils for landscaping and garden use
0.45 – 0.76	CSIRO 2011, George E. Rayment and David J. Lyons
<2.2	Based on FOA - Soil Salinity Mapping of Urban Greenery Using Remote Sensing and Proximal Sensing Techniques; The Case of Veale Gardens within the Adelaide Park Lands Hamideh Nouri et al.

Table 5: Electrical Conductivity (EC) Guideline Examples appropriate for Urban Forestry.

important to define a clear range of soil salinity to focus on regarding practical management and monitoring of the site. The lowest figure, < 0.2 Ds/m provided by Environmental Analysis Laboratories at Southern Cross University, is the one focused on by the author. This raised concerns as the range used in the aforementioned Nouri et al. study used a much higher range of <2.2 Ds/m.

The Veale Gardens/ Walyu Yarta PHC Project tested soil salinity in eight trees, with tree #31 an untreated control, from 2015 to 2018 (Fig. 32). The sodium levels were highly variable although there was a pattern of sodium levels declining after PHC treatment with organic amendments and stimulants. This may be due to the sodium molecule being attracted to Humic and Fulvic acids produced from biological activity in the remediated soil. Unlike sodium, the electrical conductivity was consistent across each year, with no discernable difference between treated and untreated trees, or any shifts over time (Fig. 33).

The electrical conductivity (EC) results from the G.U.F. soil samples were compared to those from Nouri et. al. by comparing the sampling locations of the Veale Gardens/ Walyu Yarta (Park 21) (Fig. 34B, page 24) and the salinity maps generated by Nouri et. al. (Fig. 34C, page 24). The EC results from Nouri et. al. were higher than the G.U.F. results for seven of the eight trees (Table 6. This suggests that the method used by Nouri et. al. over-estimated EC. Secondly, using the CSIRO guidelines, the results for five of the eight trees sampled show that they have a high salinity rating. Conversely, if using the much higher standard of <2.2 Ds/m suggested by the UN Food and Agriculture Organisation (which is a global standard that does not reflect local conditions) then none of the trees would have a high salinity rating, regardless of the method of determining soil salinity. This ambiguity in the measurements and standards make it difficult for park managers to properly understand the effects of recycled water on their soils.

Tree # 16 – *Quercus Ilex* – Died 2017

During the Veale Gardens PHC program only one of the 30 declining trees died, Tree # 16 (Fig. 35, page 25). As part of the investigation program this tree was evaluated to determine if there was a detectable causative factor. The death of this tree was an unfortunate outcome, although it does highlight that tree decline driven by poor soil health must be considered and managed quickly to reduce early tree mortality.

A pathology assessment of Tree # 16 was conducted due to the rapid desiccation and pronounced death of the tree due to ceased vascular activity between June and September 2017. This tree had been in a severe state of decline for some time. It was discussed in 2015 between Matthew Daniel and Veale Gardens management that the tree had been showing signs of stress for up to a decade. The soil health conditions of this tree were identified as poor due to high soil compaction, toxic soil chemistry and low beneficial soil biology in 2015. The ▶

Figure 32

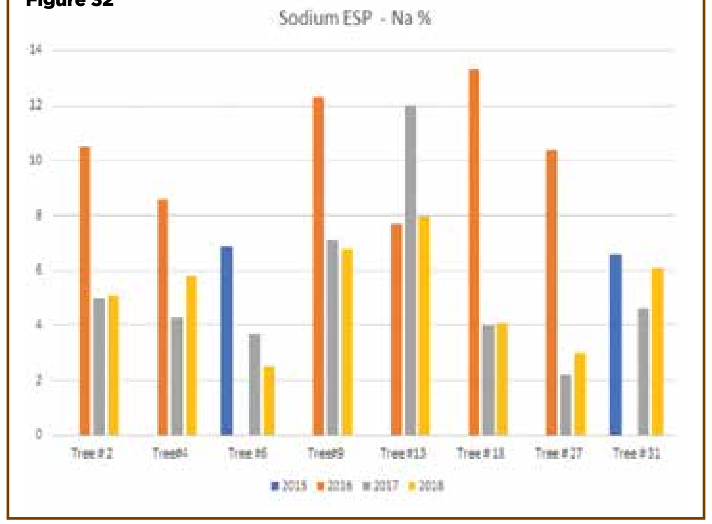


Figure 32: G.U.F. - Exchangeable Sodium (%) by tree and year.

Figure 33

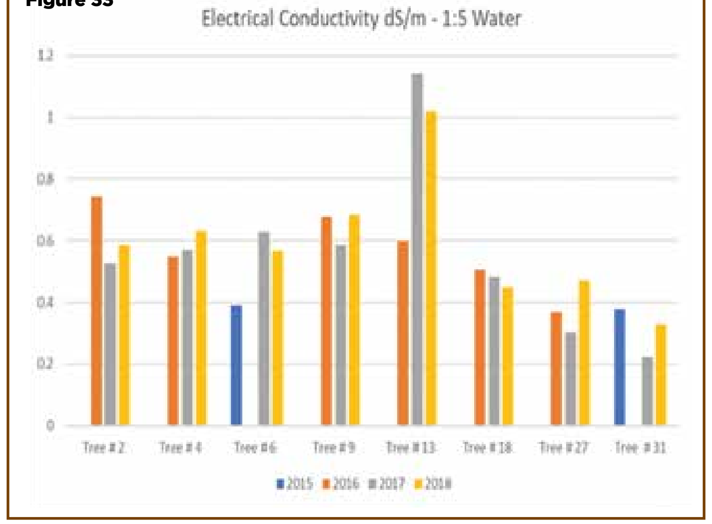


Figure 33: G.U.F. - Electrical conductivity (dS/m) by tree and year.

Figure 34A and 34B, C (on page 24): Comparing the data from the two studies looking at soil salinity.
Figure 34B (on page 24): Blue (treated) and yellow (untreated control) dots in the middle map indicate the G.U.F soil tests sites between 2015-2018.

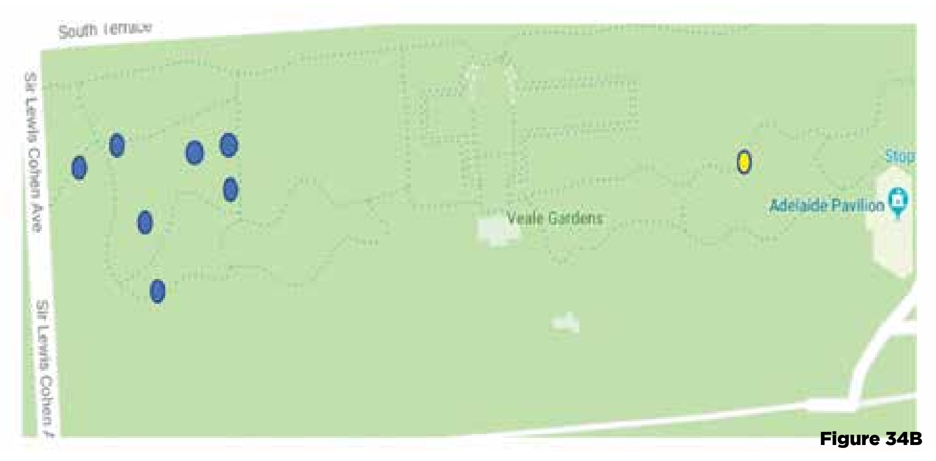


Figure 34B

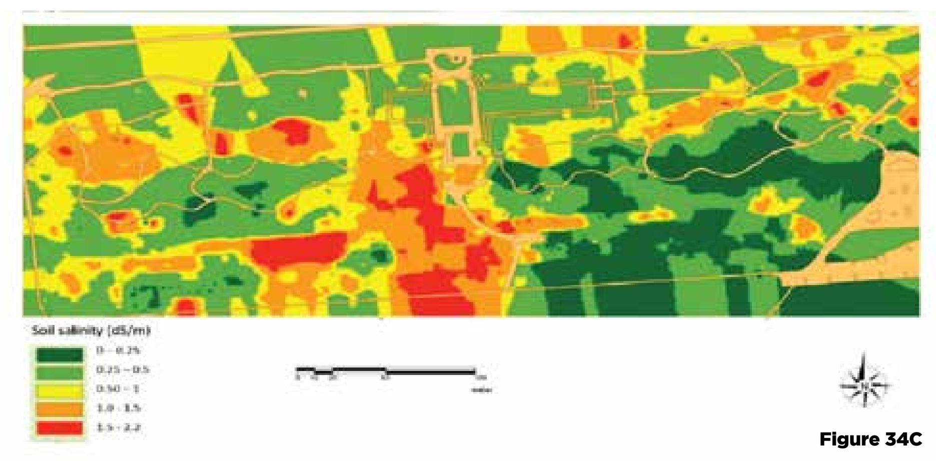


Figure 34C

	NDVI - EC - 2017 – inverse distance weighting interpolation method	G.U.F - EC - 2017 - soil sample laboratory analysis	Range – 20- 40% clay CSIRO 2011 - George E Rayment and David J. Lyons	Soil Salinity Rating CSIRO 2011 - George E Rayment and David J. Lyons
Tree # 2	1.0 - 1.5	>0.5	0.45 – 0.76	High
Tree # 4	0.25 – 0.5	>0.5	0.45 – 0.76	High
Tree # 6	1.0- 1.5	>0.6	0.45 – 0.76	High
Tree # 9	1.0 -1.5	>0.5	0.45 – 0.76	High
Tree # 13	0.25- 0.5	>1.1	0.76 – 1.21	Very High
Tree # 18	0.5 – 1	>0.4	0.19-0.45	Medium
Tree # 27	0.5 - 1	>0.3	0.19-0.45	Medium
Tree # 31	1- 1.5	>0.2	0.19-0.45	Medium

Table 6: The table indicates the major difference in EC measured between the two studies and uses the CSIRO rating system to determine the level of salinity. From these comparison in 2017 Veale Gardens/Walyu Yarta soil salinity is between a rage of medium to very high.

supplied report in 2015 warned of possible pathogen activity due to these conditions and observed poor plant health and vitality.

Since 2015, Adelaide had recorded two years of above average rainfall. This increased moisture coupled with high soil compaction may have led to anaerobic soil conditions forming, favourable to pathogens.

In 2017 Matthew Daniel recommended a pathology investigation be conducted on the tree due to the rapid decline symptoms of complete desiccation (browning off) of the entire canopy. Due to the danger of pathogen activity Matthew Daniel conducted a pathology investigation and sampling of the tree in September as part of the PHC # 2 data collection. Hygiene protocols of equipment used were implemented to reduce the risk of contaminating other natural assets in the area.

Photographs, soil, leaf and root samples were collected and sent to an independent mycologist for pathogen surface sterilisation and plating. The results of the tests revealed:

- *Bacillus sp*
- Pseudomonas sp
- Phoma sp

The *Bacillus* and *Pseudomonas* are beneficial bacterial species and are not of concern. In most situations the presence of *Phoma* or *Phomopsis* group of fungi around trees is unlikely to cause problems to a large woody plant. Although due to the tree being in a state of severe decline for many years, high soil compaction and two seasons of record rain, the combination of these factors is likely to have caused *Phoma sp* to become an opportunistic pathogen and likely the last issue affecting the tree and causing death.

During routine data collection a spike in PhiNPQ was detected in Tree # 16, which was under considerable stress and it appears to have been captured dying in the data (Fig. 36A). Upon further analysis, the spike in PhiNPQ was accompanied by a steep decline in Phi2 and PhiNO (Fig 36B). To confirm these results, we used multivariate analysis to account for light intensity and time of day, the results clearly show a spike in PhiNPQ and decline in other parameters. These results suggest that the tree was unable to use captured light for photosynthesis, and therefore tried to get rid of all of the light energy as 'excess', because the tree was dying. This is a significant outcome as it is proof of concept that this type of methodology could be useful in other areas of Arboriculture tree assessments such as development site monitoring.


Figure 35B


Figure 35C


Figure 35D


Figure 35A

Figure 35A: Tree # 16 – *Quercus Ilex* – 100% desiccated, September 2017 (left) and decaying roots (Fig. 34B, C, D).

Conclusions

This case study evaluated the impacts of a plant health care prescription on tree and soil health. The PHC plan included applications of compost, mulch, Actively Aerated Compost Tea, and microbial stimulants. To test the efficacy of these applications, a broad range of soil and tree health parameters were measured. ▶

Some of these analyses are traditional (e.g. laboratory analysis of soil samples) and some of these analyses used new, sophisticated technologies (e.g. MultispeQ photosynthesis meter, Our-Sci Carbon Mineralization Meter). Together, the analysis presented in this case study represent a new approach to monitoring tree health in the Urban Forest, which accounts for the complex and interlinked nature of soil health, tree health, and microclimate productivity.

The soil analyses showed that the PHC treatments improved soil chemical, biological and physical parameters, all three of which are required for robust soil health. Soil organic matter and important macro and micro nutrients like Nitrogen, Potassium, Phosphorous, Calcium and Magnesium increased after the PHC treatments. The organic amendments in the PHC also increased protozoa populations and soil respiration in the treated trees compared to the untreated control. Soil compaction decreased over time after the PHC treatments.

A new handheld meter (MultispeQ) was used to measure photosynthesis of all the trees in the project to develop a detailed baseline that can be utilised in the future and applied to other natural assets.

However, the photosynthetic measurements from this instrument were not able to identify differences in tree health or trends over time. This may be due to the complex sampling protocols needed to properly account for environmental factors that affect photosynthesis. On the other hand, the MultispeQ meter was able to detect the severe decline of a tree that was dying. So, while this type of complex tool may not be suited for everyday Urban Forest management, it still has value in identifying serious issues.

The MultispeQ meter also measured relative chlorophyll content, which is a parameter that is not as sensitive to environmental factors and for which cheaper handheld instruments are available. The relative chlorophyll content of all the trees in this project, including the untreated control, increased over time. This suggests that all the trees were recovering from historical stresses. These results were very similar to the Visual Tree Assessments, which also showed a general trend towards healthier trees.

Handheld chlorophyll or NDVI meters are well suited to everyday management as they are less subjective than VTA measurements and are easy to use and interpret.

Regardless of the effectiveness of any given tool used in this case study, the detailed analyses conducted here shows the potential of using more scientific approaches in Urban Forest management. Developing a greater understanding of tree function will improve the management of Urban Forests and secure the investment of urban greening into the future that is underpinned by scientific principles. Furthermore, these approaches will help Urban Forestry to meet its objectives such as mitigating issues such as Urban Heat Island Effect and providing better micro-climate productivity.

A summary of the positive implications of this research to improve the Urban Forestry industry:

- Soil Health drives tree health
- The current standard industry Visual Tree Assessments (VTA) can be improved with science-based methodology and management
- Science-based processes need to account for the soil chemical, biological and physical parameters that drive soil health
- The use of handheld meters can assist in determining tree health and early detection of plant stressors
- Soil compaction can be significantly reduced through increased biological activity
- Measuring soil carbon can be achieved with user-friendly instruments and methodologies that do not require expensive lab testing
- Increasing soil health can assist in remediating the negative effects of recycled water use.

Figure 36: Photosynthesis parameters of all trees.


Carbon respiration – PhotosynQ - MultispeQ (Beta) - CO2 sensor Samples of input materials.

Thanks

Thanks to Dr Mary Cole - Agpath, Graham Lancaster and Brian Smith - Environmental Analysis Laboratories (EAL), Dr Nicholas Malajczuk - Director, MAI (Australia) Pty Ltd.


Compacted soil in turf area.

Disclaimer

Note: Any soil analysis or observation taken and recorded in this report will only ever capture the status of the soil and vegetation on that day. It must be emphasized that changes of sometimes considerable magnitude can be expected in response to normal seasonal and extreme weather responses and some management actions.

This means that outcomes as anticipated with the available evidence collated may be unpredictable, so regular recording of the soil and vegetation using a Soil Health Card or VSA and VTA or TREE HEALTH CALCULATOR 1.0 is essential, with the taking of photos always encouraged to record a history of change. G.U.F warrants that the methods adopted in its programs are largely a practical application of many years of experience in Plant Health Care together with scientifically verified management directives and measures through numerous sensors which are continually improved as new research findings come to hand.

For more information on the Veale Gardens/Walyu Yarta Case Study visit globalurbanforest.com.au AA