Global Urban Forest

Soil Health • Tree Health

Veale Gardens/ Walyu Yarta - (Park 21) Plant Health Care (P.H.C) Project - 2015-2018

"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. "

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Attention: Kent Williams Snr Cons – Parks Water and Environment Infrastructure Management

Contents

Executive Summary:

A four-year case study in remediating tree decline in Veale Gardens/Walyu Yarta

(Park 21), Adelaide Park Lands.

Urban Forestry is currently experiencing unprecedented growth around the globe. By emulating a healthy natural system, urban forestry endeavours to provide multiple benefits including improving human health, increasing ecological sustainability, mitigating storm water and sequestering carbon. However, one of the most important goals of modern Urban Forestry is mitigating the Urban Heat Island Effect (UHIE) through the natural process of transpiration. This cooling effect from evapotranspiration comes from both plants and soil. Healthy plants and soil produce a microclimate that reduces air temperatures day and night during extreme heat conditions. This microclimate productivity is essential to the viability of cities and urbanised areas around the globe. Extreme temperatures and the constraints of urbanisation have a relatively unknown effect on plant and soil health and present an ongoing issue to the effective use and sustainability of urban forests as mitigation tools. The complexities that drive urban forestry's ability to provide sustainable ecosystem functions are currently under-defined and over-simplified.

The current standard approach to define tree health in Arboriculture is based on a Visual Tree Assessment (VTA). This approach uses few objective measures and instead relies on a complex set of observed tree health indicators that vary widely depending on the applicator's education and experience. This small range of measures does little to define overall tree health and rarely considers below ground factors such as soil health.

This scenario presents a major opportunity to improve the current standards in tree assessment in managing the urban forest. Global Urban Forest (G.U.F) have been investigating and remediating tree decline in urban environments for over a decade. The common denominators of tree decline are extreme weather events and poor soil health. These are interlinked and compounding and often lead to tree decline events. Despite the importance of soil health in tree decline, it is rarely considered nor currently defined in horticulture.

In this case study, soil health is defined as a framework of physical structure, biological activity and soil chemistry. All of which are inter-related, so increasing soil biological activity can improve soil chemical and physical parameters and vice versa. Measuring all three components provides a detailed understanding to apply evidence-based management practices to improve soil fertility in the Urban Forest.

This study utilised a variety of advanced techniques, methodologies and unique equipment to determine plant and soil health, remediate the issues and capture shifts in critical parameters. This study aimed to draw attention to the importance of soil health, how it is linked intrinsically to plant health and how it drives overall Urban Forest health and function.

In brief the outcomes of the four-year case study were:

- Application of organic amendments increased soil organic matter and increased the availability of macro and micro nutrients including: Nitrogen, Potassium, Phosphorous, Calcium, etc.
- Soil biology can be increased rapidly with the combination of products such as compost, mulch and liquid biological soil amendments such as Actively Aerated Compost Tea.
- Soil biological activity could be measured easily and affordably using the Our-Sci Carbon Mineralization Sensor
- The Plant Health Care treatments used in this study reduced soil compaction compared to an untreated control.
- Relative chlorophyll content and Visual Tree Assessments both showed tree health increasing over the four years of the case study, but the chlorophyll measurements were more consistent
- Photosynthesis measurements were effective in identifying severe tree stress, but were too complex to be useful as an everyday management tool
- Urban forest soil health can be damaged by long term compounding extreme heat conditions that leads to tree decline events.
- Improving soil health can arrest tree decline if implemented within a key threshold timeline.
- The use of recycled water and its impacts on soil health need to be monitored over time

Based on these results it is clear that soil health is crucial to tree health and long-term viability. Therefore, tree health assessments need to be improved to include additional, objective parameters such as relative chlorophyll and soil health indicators. The development of data-driven tree health assessments would provide Urban Forest managers with the tools they need to understand the effects of extreme climate events and management decisions. These tools can further provide managers with the ability to accurately assess the efficacy of remediation methods in urban forestry. This document lays out the process of developing such a data-driven process and provides insights into the lessons learned in the development process.

Section 1: Introduction

1.1: Statement of the Problem

In 2015, City of Adelaide parks management staff noticed a severe tree decline event affecting a large portion of the northwest corner of Veale Gardens/Walyu Yarta (Park 21) Adelaide Park Lands, one of Adelaide's most premier and historic open space parks.

In October 2015, Matthew Daniel, Director of Global Urban Forest Pty Ltd (formerly Director of Tree Preservation Australia), conducted site inspections and soil testing at various sites throughout Adelaide. These investigations uncovered various plant and soil health issues around the Adelaide Park Lands from a variety of stressors (Box 1). Common stressors across the sites were compaction, poor soil nutrition and biological activity, water quality and encroachment of the tree protection zone (Fig. 1, 2). It is common in Urban Forestry that plant and soil health stressors originate from management, environmental conditions and urbanisation impacts. Veale Gardens was an example of this and chosen by the City of Adelaide as a site to investigate advanced management principles.

Box 1: Excerpt from initial site investigation Tree Preservation Australia report in 2015

The Veale Gardens report by TPA reveals several primary manageable factors. Indicators differing in magnitude and impact regarding surveyed trees across the various sites and can reasonably be considered as indicative of wider conditions in their respective areas, and they include:

a. Severe compaction

b. Poor and incompatible soil microbiology

c. Irregular and unbalanced soil nutrient levels

d. Potentially marginal irrigation water quality

e. Insufficient drainage considerations for tree roots

f. Encroachment and imposition of grey infrastructure on tree root zone proximity

Site assessment of many of trees placed them in the 'poor' category with structural issues and a sobering message delivered by the analytical data for soil nutrient and biological levels. These trees will require an intensive level of intervention for extended longevity and resilience to environmental extremes including pest and disease tolerance. Annual repeat recording of soil and tree health data is essential with at least quarterly inspections, to monitor some basic parameters which influence program delivery and timing. External factors will always need to be considered requiring some pre-emptive but most reactionary management. To reduce most of these harsh impacts to soil and tree health, a remediation program is advised for 2016, 2017 & 2018.

(The colour code is Good_Acceptable_Marginal Poor Extreme.)

Site ➡ / Condition ⬇	Rundle Mall	Victoria Drive	Veale Gardens	Rymill Park/Lake	Palmer Gardens
Compaction					
Soil Microbiology					
Soil Nutrient Levels					
Irrigation and water quality					
Drainage					
TPZ Encroachment					

Figure 1. Visual indication of data interpretation of various sites from the 2015 investigations. The main issues at Veale Gardens/Waylu Yarta were compaction, soil nutrient and biological levels, water quality and Tree Protection Zone (TPZ) encroachment restricting root to shoot ratio development.

Figure 2. Tree Protection Zone (TPZ) incursions. A) Impacts from creek works; B) Footpath sealing works.

The Veale Gardens/Walyu Yarta Plant Health Care (PHC) Project 2015-2018, was developed as an extensive study into rapid tree decline throughout the park, led by Matthew Daniel. The study was designed to take a holistic approach of measuring multiple tree and soil health factors extensively on an annual basis. Over a four-year period, the response of 30 trees, each showing signs of decline, to Plant Health Care (PHC) remediation applications were tracked.

To understand tree health holistically and implement remediation methods, it is essential to include measurable tree and soil parameters. This study developed a detailed set of baseline soil and photosynthetic analytics that can be used and applied in practical terms by current Urban Forest management and provide future managers with benchmark data of methodology supported by measurables to better understand Urban Forest productivity. Four years of data from 2015 up to October 2018 identified the progress of soil remediation works at Veale Gardens/Walyu Yarta (Park 21). The soil analysed by independent laboratories consists of two major categories: soil chemistry (Environmental Analysis Laboratories (EAL) and soil microbiology (Agpath). Soil physical components such as compaction and moisture were measured in the field with specialised equipment. To determine the tree health response a hand-held photosynthesis meter and meta data collection tool called MultispeQ was used https://www.photosynq.org/instruments

Figure 3. Image of 30 trees of a variety of species, chosen for the PHC project 2015-2018.

1.2: Impacts of Historic Climate Change and Management at the Research Site

Urban Forest canopy cover takes decades to establish a functional level of essential service. The impacts of extreme weather events on soil health in Urban Forestry are relatively unknown but must not be underestimated. The effect of extreme weather events such as drought on soil health that compounds into tree decline is an ongoing issue to address in Urban Forestry. The effects of extreme weather events on the Veale Gardens/Walyu Yarta study site can be seen in Figure 4. Soil health is more than just moisture content. The complexities of soil must be managed more effectively in Urban Forestry because this fundamental component of growing trees determines how long the natural assets will be viable and productive.

Figure 4. The colour coded composite of aerial photography of the NW corner of Veale Gardens/ Walyu Yarta (Park 21) over a period of 50 years. Arrows indicate impacts of drought periods over time and implementation of GAP water. Photos courtesy of Kent Williams.

Millennium Drought Eastern Australian States– 1997-2010. South Australia experienced between 2005-2010	
GAP – Glenelg to Adelaide Park Lands Recycled Water Project - Irrigation 2010 -2017	
GAP water supply disruption period – Dec – Jan 2018	

1.3: A Whole System – Plant and Soil Function

Plant and soil health must be defined and managed in Urban Forestry. It is not currently defined adequately throughout many industries including the Urban Forest industry. This project aims to assist in providing a practical framework to achieve a better understanding of soil health and define it in functional terms in relation to our urban environment, and then how that relates to providing a measurable essential service from individual trees. To understand this complexity the whole system including photosynthesis, plants and soil needs to be investigated.

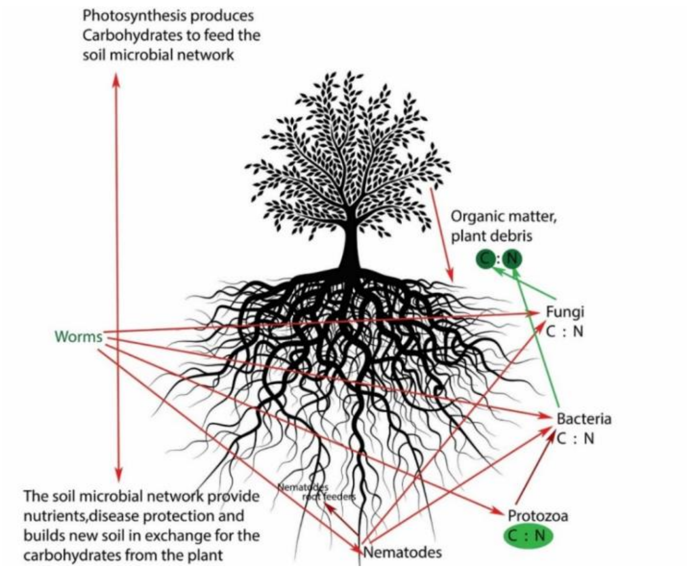

Figure 5 Key components of the whole system: Photosynthesis and energy distribution to soil biology by the plant to develop symbiotic relationship with soil microbiology. These symbiotic relationships between plant and microbes must not be underestimated. Diagram courtesy of Matthew Daniel *Global Urban Forest* 2011.

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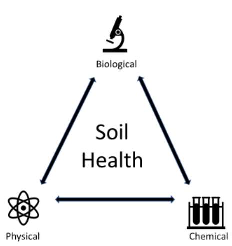
1.4: Defining Soil Health

Soil Health can be defined "as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans"(*https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/*).



Chemical – *understand total, available and exchangeable nutrient pools in soil in relation to the requirements of supporting plant material*
Physical – *measure and understand physical soil structure and water holding capacity*
Biological – *understand and measure the soil microbiome, a balanced set of functioning bacteria, fungi, protozoa, nematodes and mycorrhizae that develop symbiotic relationships with plants*

1.5: Relationship Between Soil Health and Climate Change in Urban Forestry

Localised extreme weather events caused by climate change, are occurring, being observed on the ground, experienced and documented all over the globe. A common and consistent driving factor associated with these extreme weather events is heat. To mitigate this heat in cities or highly urbanised areas, Urban Forests are being designed, installed and developed around the planet. This is a direct response to urbanised areas getting hotter and described as the Urban Heat Island Effect (UHIE). The concept of mitigating UHIE with vegetative growth to reduce the temperature relies on the plant and soil functioning effectively. It is often assumed soil health is a given and water is the only consideration regarding soil health. Water is a key component, essential to soil health and soil health is critical to plant health, although soil health is more than just water availability.

The effects to Soil Health from heat waves and drought, both short and long have a residual sinister potential to cause tree decline years after the extreme event has occurred. The Millennium Drought and SA Government response in transitioning to GAP water to maintain the Adelaide Park Lands is an example of this and investigated in this study. This intensive study of Veale Gardens/Waylu Yarta aims to understand the change in ecosystem function from a plant and soil health perspective. Through a process of:

- Defining soil health
- Measuring the components – developing baselines and monitor changes overtime
- Intervening with PHC focused soil management principles and practices that address chemistry, physical structure and biology
- Develop an understanding of how the soil health adjustment have occurred, and if successful, how to continue proactive management of the improved conditions.

An Urban Forest is a sum of its parts, all plants in both public and private realms make up the Urban Forest as a whole. Canopy cover in an Urban Forest provides a potential capacity to mitigate heat with microclimate production. This microclimate supported and stimulated by evapotranspiration, comes from soil and plants.

A result of drought is reduced plant and soil health. It would be fair to say that most would assume this poor plant and soil health resulting from drought could be visualised as “brown grass and trees”. If you ask those same people what caused the “browning off” the response is commonly “Lack of water”. The assumption that the reintroduction of water into the system after a drought resolves any risk to environmental decline, is oversimplified and short-sighted.

These types of extreme droughts that trigger a collapse in ecosystem productivity do not exclude the Urban Forest. The Millennium Drought in Australia that developed into the 2000’s and declared over in 2010 is one such drought. In Adelaide, South Australia the Millennium Drought between 2005 and 2010 became the period in which a compounding amount of plant and soil stressors culminated into a tree decline event in Veale Gardens/ Waylu Yarta, although the effects continued years after the drought had finished and soil moisture returned, because soil health had been damaged in the park.

It is important to consider the long term and compounding effects of severe drought to the Urban Forest ecosystem and how that relates to soil health.

Section 2: Plant Health Care and Evaluating Tree and Soil Response

2.1: Plant Health Care (PHC) Applications

In 2016, a soil remediation plant health care plan was designed for 30 trees in the northwest corner of Veale Gardens/Walyu Yarta. This plan included a mixture of compost, mulch, compost tea and microbial stimulants applied from 2016 – 2018 (Table 1). The first step was to calculate individual Tree Protection Zones (TPZ) and remove grass (sod) from within the treatment areas (Figure 6). One healthy tree, Tree #31, was left untreated and used as a healthy control tree throughout the course of the project.

Table 1. Soil Remediation PHC – Applications - Total Application volumes – 30 x trees

Year of Application	Application input	Application rates
2016	Compost – AS 4454 2012 - compliant	100 mm per tree
2016	Mulch – ACC Green Waste – tub grinding	150 mm per tree
2017 & 2018	Actively Aerated Compost Tea – AACT – Liquid drench and soil probe	Approx. 252,000 Litres applied between 30 trees
2017 & 2018	Microbial stimulants	Approx. 336,000 Litres applied between 30 trees

Figure 6. An example of the individual tree preparation area. The grass was removed, and a layer of compost and mulch applied then liquid amendments applied via drench and soil injection method.

Compost Application

100mm of compost material was applied to each designated TPZ. Compost was recommended because it's a good source of plant nutrients and organic carbon, which provides an important food source for soil microorganisms early in the remediation process. Unfortunately, the standards for producing compost (Australian Standard AS 4454 – 2012 Compost, Soil Conditioners and Mulch) do not put an emphasis on quality, such that compost quality varies widely. Increasing the minimum standards for compost to promote material that is fit for soil remediation, meaning it can improve soil biological, chemical and physical status in soil would help improve compost quality. See appendix 1 for the nutrient content of the compost used in this case study.

Mulch Application

150 mm of course green waste mulch material was supplied by the ACC Green waste facility and was applied to each trees unique Tree Protection Zone (TPZ) area.

Actively Aerated Compost Tea (AACT)

AACT is a liquid soil amendment produced with specialised equipment that contains bacteria, fungi, protozoa, nematodes and soluble nutrients sourced from high-quality compost.

Over a 24-hr period the liquid amendment is brewed with food additives to grow bacteria and fungi and aerated with dissolved oxygen to grow the aerobic organisms derived from the compost inoculum. The outcome is a liquid product containing a concentrate of beneficial microorganisms including bacteria, fungi, protozoa and nematodes. Figure 7 shows the processes used by G.U.F. for producing and applying AACT.

Figure 7. A.) G.U.F - PHC - preparation centre at the Adelaide Nursery; B.) G.U.F – AACT 3 x 1000L mobile brew operation; C.) AACT - microbe brewer oxygenating the 1000 L liquid solution to provide conditions for beneficial aerobatic microbes to increase; D) G.U.F – PHC application Vehicle.

Microbial Stimulants

Microbial stimulants are organic liquid amendments that provide a strong food source for soil microbes. The types of products used are for specific microbial groups and are high quality and laboratory tested for their specific stimulant efficacy. Microbial stimulants consist of products such as:

- Kelp
- Fish Hydrolysate
- Humic Acid
- Molasses

Microbial Inoculums

Microbial inoculums provide dormant spores of species of Mycorrhizae and were applied as part of each batch of AACT, then drenched onto the tree rootzone area covered by compost and mulch.

2.2 Measuring Photosynthesis - Canopy Function Data

The photosynthesis data collected in this study was collected using a sophisticated but inexpensive hand-held photosynthesis meter called the MultispeQ which was connected to the PhotosynQ open data platform (Fig. 8). PhotosynQ is a collaborative online plant research platform, which enables users to create, share and collaborate worldwide to analyze detailed sophisticated environmental scientific information. The PhotosynQ project was developed at Michigan State University in the Kramer Laboratory. The device and platform allow for intensive data collection to unlock nature's secrets and develop a greater understanding of how the natural world functions in its innumerable complexities.

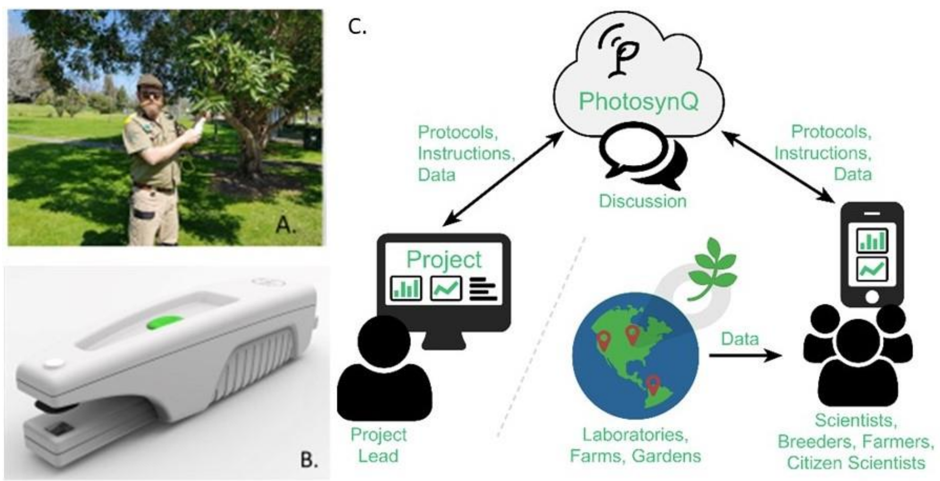


Figure 8. Tree photosynthesis data was collected using advanced environmental sensors: A) Matthew Daniel collecting Photosynthesis data with the MultspeQ V1.0; B) The MultispeQ V1.0 sensor, which links to a mobile phone via a PhotosynQ app; and C) the PhotosynQ cloud-based open source data collection platform.

In 2015, Matthew Daniel of Global Urban Forest Pty Ltd was invited by the PhotosynQ team to beta test the platform and join the Experts Program. This initial small group hailed from diverse fields of science and industry which included agricultural research scientists from Malawi (East Africa), science educators from Ukraine, Great Barrier Reef marine science researchers from Australia and plant scientists from across the USA. Each member of the initial 'Experts Program' were supplied with a 3D printed MultispeQ prototype to conduct research in their chosen fields and support the development of the MultispeQ version 1.0. Matthew Daniel's focus was the Arboriculture and Urban Forest industry. He developed the Tree Health Calculator 1.0 project to better understand the link between soil health and canopy function.

MultisepQ, photosynthesis data was collected from 2015 – 2018, intensively during the PHC # 1 and # 2 program mobilizations. The primary photosynthesis parameters that were measured with the MultispeQ are as follows:

- **SPAD** – Relative chlorophyll content, measures leaf" greenness"
- **Phi2** - Quantum yield of Photosystem II. This measurement is essentially the percentage of incoming light (excited electrons) that go into Photosystem II. Photosystem II is where most light energy is converted into food.
- **PhiNPQ** - Estimate of non-photochemical quenching. The amount of incoming light that is regulated away from photosynthetic processes to reduce damage to the plant.
- **PhiNO** - Ratio of incoming light that is lost via non-regulated processes. PhiNO is the combination of several unregulated processes whose by-products can inhibit photosynthesis or be harmful to the plant.
- **LEF** - Linear Electron Flux. The total flow of electrons from antennae complexes (were light is captured) into Photosystem II, taking the leaf absorptivity into account. Calculated as LEF = Phi2 x PAR x 0.42

2.3: Measuring Soil Compaction and Moisture Content

Soil compaction was measured using a penetrometer (Fig 9A). Penetrometers measure the force of pushing a spike into the soil and then note the depth at which the pressure is recorded. For example, 600 psi @ 5 cm would indicate high soil compaction at a shallow depth that would restrict healthy tree root growth.

Soil moisture was measured using a moisture probe that provides moisture content as volumetric water content percentage (Fig. 9B). Moisture was recorded at three depths - 10 cm, 20cm, 40 cm.

Figure 9. Measuring soil physical status: A) Using a penetrometer to determine soil compaction; B) measuring soil moisture with a moisture probe.

2.4: Laboratory Analysis of Soil Samples

Soil samples were collected from a subset of 8 trees every year starting in 2015. Soil samples were collected from each tree in 2016, 2017 and 2018 to determine the shift in soil chemistry and allow for adjustments in the PHC program applications. These samples were then sent to Environmental Analysis Laboratories, Southern Cross University, Lismore NSW for analysis.

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The chemistry assessments conducted were to understand three essential components of soil nutrients:

1. Total Nutrients
2. Available Nutrients
3. Exchangeable Nutrients

2.5: Measuring Soil Respiration

Soil respiration was measured for a subset of 8 trees using a Carbon Mineralization Sensor developed by Dr. Dan TerAvest of Our Sci, LLC, a start-up from Michigan, USA. This method adds water to an air-dry soil sample and measures the resulting "burst" of CO_2 after 24 hours by using a syringe to push air over a pass-through CO_2 sensor (Fig 10). This methodology can be easily conducted by Urban Forest tree survey professionals in soil health investigations and can assist in the specification of input materials such as composts and mulches.

Figure 10. The Our Sci C Mineralization sensor (left) connects to an android-based app (right)

Section 3: Results

3.1 Soil Chemistry

Independent laboratory assessment of eight trees was conducted throughout the 3 years of the project. In 2015, Trees #6 and #31 were the focus with Tree #31 providing healthy a control throughout the PHC intervention period.

Soil chemistry is complex and shifts in one nutrient will affect other nutrient concentrations. In the initial investigations in 2015 and 2016 there were multiple issues associated with the chemistry at Veale Gardens ranging from nutrient deficiencies to nutrient toxicities based on desired levels.

Trees receiving PHC treatment displayed large increases in chemical properties compared with the untreated baseline (Fig. 11). For example, the amount of total C, total N, exchangeable Mg, and exchangeable K increased by an average of two or three-fold (100 – 230%) in trees receiving treatment while in the baseline the increases were 8%, 44%, 20%, and 21%, respectively. Available P increased by a factor of ten 2 years after treatment, but only increased 33% in the untreated baseline. There was also an increase in plant available N over time compared with the baseline tree in treated trees (Fig. 12).

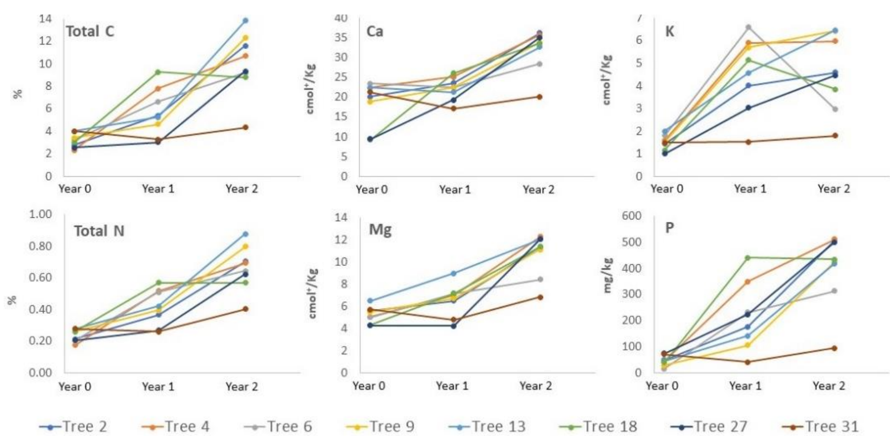


Figure 11. Soil chemical properties by year, total C and N, exchangeable Ca, Mg and K, and available P. Tree 31 did not receive any treatment, while the other seven trees all received treatment. Year 0 = samples in 2015 and 2016, prior to treatment; year 1 = 2017; and year 3 = 2018.

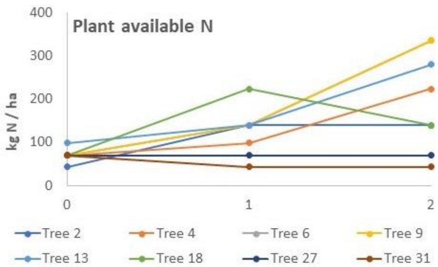


Figure 12. Plant available N by year. Tree 31 did not receive any treatment, while the other seven trees all received treatment. Year 0 = samples in 2015 and 2016, prior to treatment; year 1 = 2017; and year 3 = 2018.

In an ever-changing soil environment, it is important to understand all these nutrient pools and not just available soluble nutrient that is a common soil agronomic method. The shift in soil chemistry of the trees treated can be explained in some cases although it is important to understand this is a snap shot in time and additional adjustments will occur seasonally and over time. Another important factor is the interaction between soil biology and soil chemistry which is difficult to quantify.

Table 2. The average shift in soil nutrients post PHC # 1 in 2016

Nutrient	Description of change
Potassium	Increase in potassium is most likely due to the increased soil moisture and the liberation from clay particles that the microbiology is interacting with. Elevated potassium has been a response from the soil microbiology and it is recommended to monitor this as further changes occur over time.
Phosphorus	Total Phosphorus has increased from the PHC # 1 program, as the control tree is still deficient in Phosphorus**.** The increase in phosphorus may be the result of the compost and Compost Tea. Will need to investigate if manure was used in the production of the compost. The trees will take up the increased phosphorus over time although there is a limit each growing season. Iron and Zinc levels will need to be monitored in relation to the high Phosphorus levels. The fungal activity may also sequester some of the increased phosphorus.
Carbon/ Organic Matter	Carbon levels have increased significantly due the application of compost and mulch and the increased microbial activity. The significant increase in Carbon in the soil is another example of how soil management can reduce carbon dioxide in the atmosphere substantially. The control tree (Tree #31) has a reduction in soil carbon in comparison.
Nitrogen	Nitrogen levels have increased due to the increase in soil beneficial bacteria and predation of bacteria on protozoa and making Nitrogen available for plant uptake.
Calcium	Total Calcium has increased. The high calcium levels are most likely due to the elevated soil pH and microbial activity. High calcium levels may bond with phosphorus and reduce the calcium, although phosphorus is also high so is not an issue with this nutrient relationship. Calcium is the king of nutrients and essential for new cell growth (stems, leaves and roots) Calcium will also be taken up by fungi so it may not be toxic as the soil biology is increasing and other nutrients are in excess.
Magnesium	Total Magnesium has decreased due to the increase in calcium, calcium: magnesium ratio (C: Mg) A conventional agronomic response to this issue would be to add lime to increase calcium, although Calcium levels are already elevated and once lime has been applied it cannot be removed if it causes issues. Adding lime now is not recommended. Further monitoring is required as microbial growth is also adjusting the chemistry.

Sodium	An important reduction in sodium levels can be explained by the increase in average rainfall over the past two years enabling salt to be leached from the soil profile. It may also be the case that increased humus levels in the soil have bonded with the sodium molecules and reduced the impact of salt damage to soil biology and the plants root systems.
Selenium	Selenium has increased.
Copper	Total copper has increased and decreased within the different trees tested. Copper will affect the microbial growth in soil. Copper increase may be the result of decomposing organic matter as the park is not spayed with copper fungicides such as an orchard. Toxic copper levels can affect uptake of Iron, Nitrogen, Phosphorus and Zinc, although all these nutrients are also elevated. Elevated Zinc levels reduce copper uptake in plants, so this contradiction is unusual. Toxic copper levels will also reduce root activity. Copper is generally low in alkaline soils, so this is also unusual as the pH is around 8. As the fungi levels are increasing the elevated Copper levels appear to not be affecting fungal growth but may be a means of explaining the lack of Mycorrhizal infection of the roots tested. Investigate recycled water mulch and compost further.
Sulphur	Sulphur has increased with the trees treated. This is most likely from the compost or mulch as sulphur did not come from PHC # 1 liquid treatments. Sulphur is a secondary macronutrient in soil and important to plant function in desired levels. The sulphur levels appear to have increased and cannot be explained other than possibly from air pollution absorbed into the mulch or compost.
Chromium	Chromium is elevated in the samples in 2016 and can affect plant growth, photosynthesis and a variety of uptake in nutrients. Elevated levels of chromium are dangerous to humans if inhaled or ingested. Chromium can be reduced by fungal activity such as Mycorrhizae. Chromium and Mycorrhizae will need to be monitored further to determine future status in relation to rates of mycorrhizal infection.

Table 2 provides an in-depth analysis of the shifts in soil chemistry in 2016. In 2017, soil chemical parameters were shifting in many directions (Table 3). However, there appears to be a clear shift in total nutrient status between the treated trees and the untreated control tree. To date, these shifting patterns are positive and further monitoring is required to establish if it will result in more sustainable soil health for the trees treated at Veale Gardens/Waylu Yarta (Park 21).

Further analysis is required to determine the extent of the issues presented although as the soil physical status and soil microbiology improves so will the chemistry. The use of recycled water and mulch may present further issues in understanding the variation of soil chemistry results and requires further investigation to determine the long-term effects and management outcomes. Further analysis and soil testing are required to determine true patterns.

The PHC treatments used in this study did not have a noticeable impact on soil pH, which remained elevated (> 7.5) in all of the tested trees, regardless of treatment (Fig. 13).

Table 3. Comparative shift in soil chemical parameters between treated trees and the untreated control in 2017.

Nutrient	**Treated Trees**	**Untreated Control Tree**
Potassium	Significant increase	No change
Phosphorus	Significant increase	Decreased
Nitrogen	Significant increase	Decreased
Sulphur	Significant increase	No change
Sodium	Significant decrease	Decreased
Carbon	Significant increase	Decreased

In summary, there were noticeable positive shifts in soil chemistry in the treated trees, suggesting that PHC # 1 and # 2 increased soil nutrition, which should lead to greater nutrient uptake in treated trees and better tree health outcomes. The reduction in sodium (salt) from the recycled water is most likely a result of rainfall leaching, although increased soil carbon and humus from organic amendments and the resulting increase in microbial activity provides a buffer to sodium related issues because it is attracted to the humic and fulvic acid molecules.

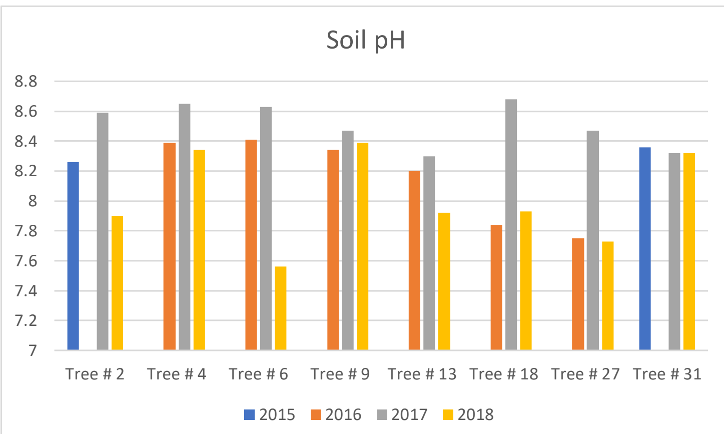


Figure 13. - Soil pH is elevated. A healthy range for this soil type of Clay Loam is ph. 6.5

3.2 Increased Root Zone Activity Due to Improved Soil Fertility

The root zone area of each tree had the sod removed prior to the application of compost and mulch. The addition of organic materials and liquid amendments stimulated a significant amount of new healthy root growth and activity. This new root development was observed growing beneath the mulch layer and can be declared as new root mass (Fig.14), which increases the trees Root: Shoot ratio significantly.

Figure 14. Undisturbed soil surface with fine fibrous root material visually observed at the soil surface. Note that the 250 mm layer of carbon mulch material has almost fully decomposed leaving a healthy humus material and new soil.

3.3 Soil Biology

Soil biological activity is very sensitive to soil moisture content, compaction and soil chemistry. For this reason, there was a high degree of variability in the soil biological activity data. However, despite this variability, there were some very positive shifts in biological activity compared to the baseline (prior to PHC treatment) to note. In 2017, after the first application treatments, the soil biology of the treated trees increased 1741% compared with the increase of 273% of the control tree.

The amount of total and active fungi and bacteria did not consistently increase over the three years of monitoring results (Fig. 15). On the other hand, there was a noticeable increase in protozoa under the treated trees over time compared with the non-treated baseline (Fig. 16).

While the laboratory analysis may have been a mixed bag of results, the visual indicators of soil microbial activity were astonishing. In January 2017 there was a fungal bloom and production of fruiting bodies (mushrooms) during the summer months and on consecutive days above 38 degrees Celsius. This is an unusual yet positive event and can only be explained because of the rapid increase to fungal activity caused by the intensive PHC works (Fig. 17,18).

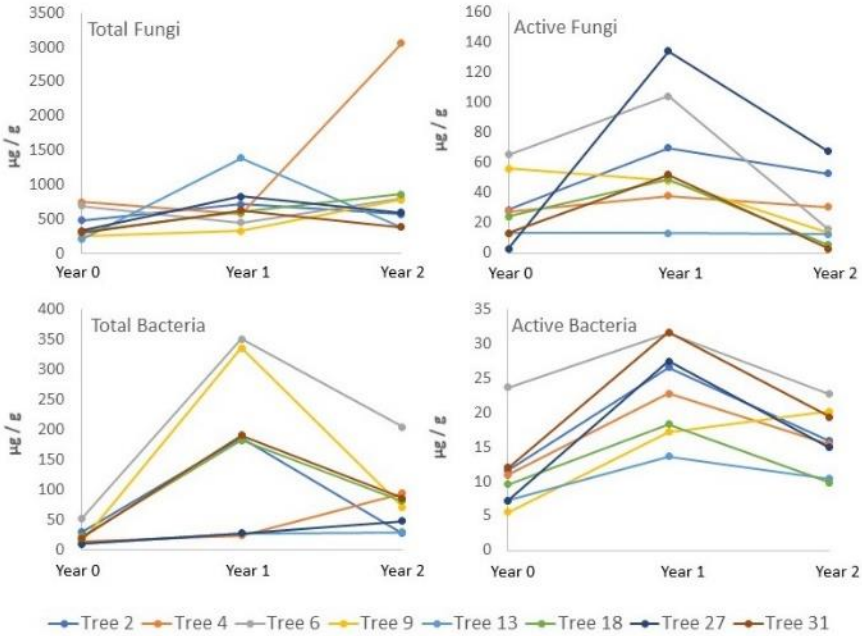


Figure 15. Total and active fungi and bacteria by year. Tree 31 did not receive any treatment, while the other seven trees all received treatment. Year 0 = samples in 2015 and 2016, prior to treatment; year 1 = 2017; and year 3 = 2018.

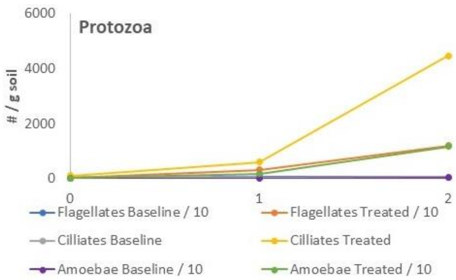


Figure 16. Comparing the mean of the treated trees to the baseline by protozoa class and year. Tree 31 values served as the baseline. Year 0 = samples in 2015 and 2016, prior to treatment; year 1 = 2017; and year 3 = 2018.

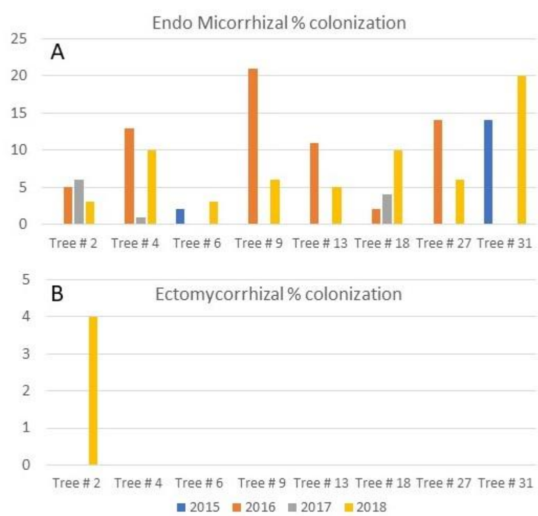
Figure 17. possible *Coprinus niveus* observed during PHC application mobilisations in 2017 and 2018 fungal fruiting body blooms were observed regularly. A diversity of species was observed sometimes in unusually high summer temperatures such as 41 degrees Celsius.

Figure 18. Fruiting Body (Mushroom) activity: A) Possible *Lepiota sp* (saprophytic) if white spored or *Laccaria sp* (mycorrhizal) if pink spored; B) Possible *Mycena sp* if white spored or *Coprinus niveus* if black spored; C) *Fuligio septa* (Dogs vomit) a bacterial feeding slime mould (beneficial) organism indicating the rapid increase in bacterial growth; D) *Coprinus niveus;* E) *Mycena sp* if white spored; F) Visual mycelium activity**,** healthy mycelium with new roots growing through it.

Mycorrhizae

During PHC mobilizations in 2017 and 2018 146 Kg of Mycorrhizae spores were applied between 30 trees. The methodology used for mycorrhizal colonization laboratory assessment is direct microscopy fluoresces staining. Based on this method, Endo-Mycorrhizae colonisation does not appear to have increased, and in some instances, it decreased (Fig. 19A). Ecto- Mycorrhizae colonisation was only observed in Tree 2 (Fig. 19B). This is not of major concern as the sampling methodology is random and the mycorrhizae spores that were applied during PHC # 1 may have been dormant in the soil profile and are yet to infect the increasing root mass that has been observed and documented.

As with the soil biological activity presented above, there was a disconnect between the laboratory data and visual observations made in the field. In this case, Mycorrhizal activity was observed during data collection in September 2017 (Fig. 20).



The presence of mycorrhizal fruiting bodies (mushrooms). observed during the data collection strongly suggest activity is occurring and were not observed in previous visits around the same time of year. The increased soil copper levels and elevated sodium may also be inhibiting mycorrhizal colonisation and growth.

Figure 19. Colonization by A) Endo-Mycorrhiza and B) Ecto-Mycorrhiza by individual tree

Figure 20. *Scleroderma cepa,* ectomycorrhizae fruiting bodies observed at site tree number # 2 although is likely to be from roots of tree # 3 which is *Pinus sp*.

It is important to understand which species of trees have relationships with which mycorrhizae group. As per Figure 20. *Scleroderma cepa* ectomycorrhizal fruiting bodies were observed on tree number # 2. Tree 2 is an *Ulmus sp* and not an *ectomycorrhiza* species. Tree 3 is a *Pinus sp* and it is assumed that the root of this tree was collected as the root systems overlap.

There have been recent statements by some leading experts in the Arboriculture industry that Mycorrhizal inoculums are not effective. This is problematic as mycorrhizal inoculums are a complex soil remediation concept. One component that makes mycorrhizal inoculums different from the use of chemical or organic fertilizers is that they are biological based and require a symbiotic connection with the plant root. Fertilizers provide available nutrients for root uptake or microbial food for microbial stimulation in soil. The Veale Gardens/Walyu Yarta PHC Project has identified that although some mycorrhizal activity was measured there was not a significant increase overall. There are multiple reasons for this in this case study.

- Elevated soil compaction levels
- Highly elevated Copper and sodium levels in soil
- Low root shoot ratios of established trees.
- Extreme heat events

Establishing mycorrhizal connections in some cases has been successful, the nursery industry is an example. Because nursery soil medium and plant roots are accessible, applying spores directly to active root mass is highly effective. Another important reason nursery tree’s develop mycorrhizal associations effectively is the age of the tree.

Applying inoculums to established declining trees is difficult for two main reasons.

- Determining active root zones of trees is subjective
- High soil compaction levels prevent healthy root activity and inoculation of microbial spores
- Extreme heat events reduce soil moisture rapidly and increase soil temperature to levels difficult for beneficial soil microbes to flourish.

The science of soil health focusing on soil microbiomes including mycorrhizae associations is relatively recent and evolving at a rapid rate. Those who have assisted in the development of these biological sciences are highly specialized, dedicated and experienced professionals. It is important for industry to acknowledge their message that mycorrhizal associations are crucial to healthy plant growth although key soil health parameters will limit the effectiveness of developing biological activity (Box 2,3). The use of inoculums such as mycorrhizae should not be discouraged. It is important to inform industry of the required soil health parameters that enable the effective use of mycorrhizal inoculums to provide better outcomes. Knowledge of how to define, investigate and measure soil health will assist industry to use these inputs successfully.

Box 2: Complex associations in nature sampled at a snapshot in time

By: Mary Cole, PhD; MAIA, MAIEA, MSAA, Cert IV Assessment & Training

Any analysis of soil, compost, plant presents what is present or occurring on or in the sampled material at that point of time. it is for this reason that multiple samples are taken whether at one point in time or over multiple times to establish a trend that may be more accurate in identifying a situation/aspect of interest.

Sampling plant roots for mycorrhizae is such a case. So, the roots selected represent the mycorrhizal infestation on that tree or grass? How is the infestation affected by previous management of the soil? Have weather conditions affected that number of propagules seen in the sampled roots?

Mycorrhizal associations have been successful for 450 million years is variability from one or two samplings over a year must be acknowledged.

Mycorrhizal associations are the normal nutrient-absorbing organs from more than 98% of plant species. Mycorrhizae improve plant health sometimes by providing pest resistance, improved environmental stress tolerance and nutrient benefits.

Mycorrhizae stabilise soils, improve water holding capacity of soil and sequester carbon in large amounts.

Site disturbance reduces mycorrhizal efficacy by disrupting the radial hyphal network in the soil.

Sampling is best done at the same time of the year over years so a trend can be established. This way soil remediation alongside a control can show that treatments are benefiting plant health through improved mycorrhizal infestation of the roots.

One sample has no precedence so no comparison can be made. It is just a snapshot in time and may or may not represent the total picture with respect to plant health. The result, however, must form part of a set of results which together show the outcome of an intervention.

Box 3: Using Inoculum

By: Dr Nicholas Malajczuk; Director, MAI (Australia) Pty Ltd

Most plants form a symbiotic relationship with certain fungi (called mycorrhizal fungi) which aid the plant in nutrient uptake particularly phosphorous, as well as warding off disease pathogens.

There are 2 types of mycorrhizas ecto mycorrhizal fungi that are normally associated with forest trees such as pines and produce large fruit bodies. The second type are the endo mycorrhizal fungi which produce microscopic spores and these associate with most agricultural, horticultural, and urban species such as elms, fraxinus and willows.

Infection occurs at the seedling stage and develops on most fine roots as the tree grows. In the forest environment the mass of mycorrhizal fungi is substantial. However, trees in an urban setting may lose a substantial volume of mycorrhizal biomass due to excess of nutrient, water or compaction. Trees may eventually decline and die. Re inoculation of these trees may be possible however the soil parameters need to be changed. Also, the amount of inoculum used may need to be substantial for immediate effects to be observed

Soil Respiration

Soil respiration was measured from a subset of eight trees and cross referenced with laboratory assessments and direct microscopy to determine if it is a viable methodology to use in determining soil biological activity. The advantage of this approach is that it is low-cost, requiring very few tools or laboratory experience to conduct the tests. One disadvantage of the test is that it is non-specific, meaning that it is measuring the CO_2 mineralized by all the micro-organisms in the soil and does not allow the user to differentiate between bacteria, fungi or protozoa.

Soils collected in 2018 were analysed and those results are presented in Figure 21. The lowest soil respiration was recorded in tree #31, which was the untreated control. Therefore, it appears that the addition of compost, mulch, AACT and microbial stimulants did result in an overall increase in soil respiration. Likewise, comparing soil respiration to protozoa from laboratory tests (Fig. 22), there appears to be a correlation between soil respiration and protozoa populations in this case study.

There may be modifications to this method that can allow for more targeted analysis of certain microbial groups. For example, adding a substrate specific to a specific group (e.g. fungi or bacteria) and measuring the CO_2 burst may offer a low-cost way to estimate the activity of soil micro-organisms. These methodologies need to be tested in future case studies.

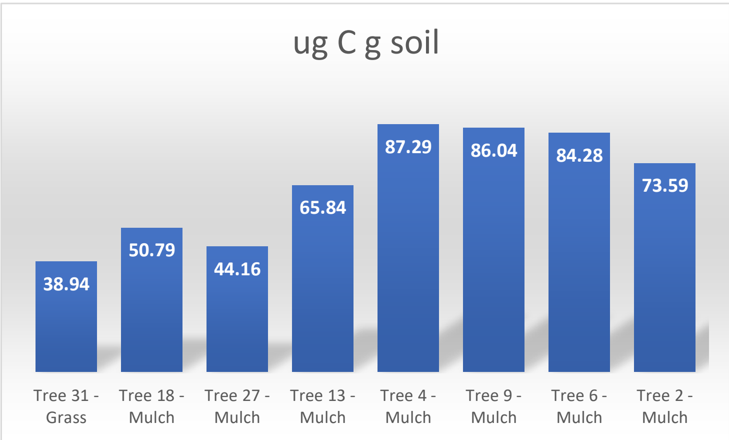


Figure 21. CO_2 respiration by tree using September 2018 soil samples

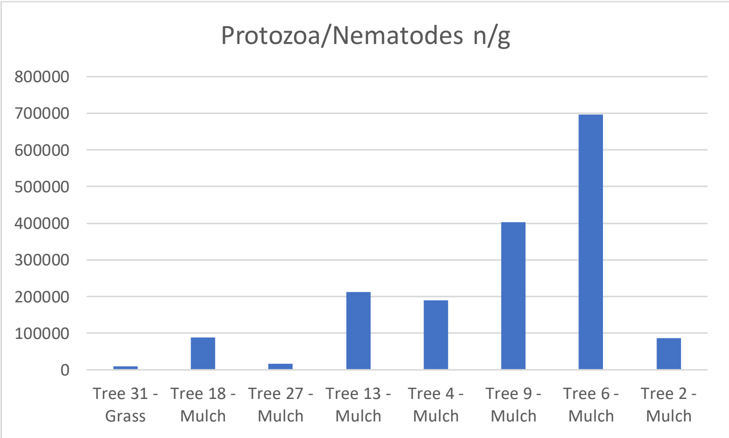


Figure 22. Protozoa / Nematodes (population / g soil) using September 2018 soil samples for laboratory analysis

3.4 Soil Compaction – a physical parameter

In addition to soil chemical and biological parameters, a penetrometer was used to measure soil compaction as an indicator of soil physical structure. Soil compaction decreased over time in all the treated trees that were measured, while compaction remained much higher in the untreated baseline (Fig. 23). Penetrometers are an indication device and the measures can be affected by the users- familiarity with the tool and measurement protocol, making interpretation of penetrometer data subjective. In this case study, all penetrometer measurements were taken by Matthew Daniel, reducing measurement variability. The development of more user-friendly penetrometers that standardize measurement processes and data capture would increase the value of compaction measurements in Urban Forestry.

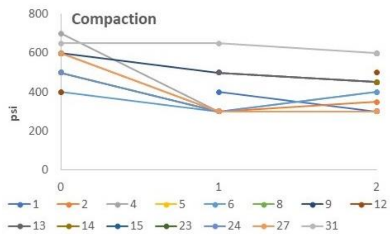


Figure 23. Soil compaction by tree and year. Tree 31 did not receive any treatment, while the other seven trees all received treatment. Year 0 = samples in 2015 and 2016, prior to treatment; year 1 = 2017; and year 3 = 2018

3.5 Wildlife Predation on Soil Microarthropods

Figure 24. An interesting effect of the rapid increase in soil microbiology was the increase in microarthropod predation from birds. This became a valuable free resource of the birds aerating the soil medium. Soil health has assisted ecosystem function.

Local bird life had a noticeable impact on the soil in the TPZ. Ibis appeared to be the most effective soil aerators as they had longer beaks than the local ducks. Hundreds of aeration holes from microarthropod predation by local birdlife was observed in the TPZ of the 30 trees. Worms were observed in the new improved soil conditions and are an indication of increased soil microbiology.

3.6 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 (Fig. 25). 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. 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 analyzing them together (Fig 26). Only the genera' which included at least 3 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 3 parameters equal the destination of all captured light by photosystem II, and therefore the sum of these 3 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 and 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 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). 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 1 control tree, it is hard to draw any firm conclusions.

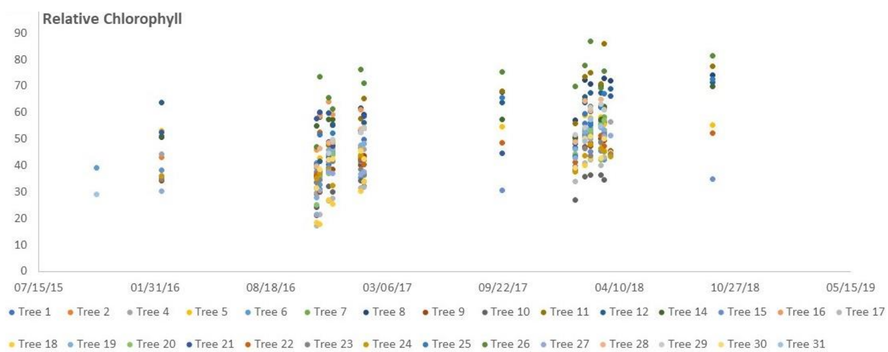


Figure 26. Relative chlorophyll for all trees from October 2015 until September 2018. Tree 31 did not receive any treatment, while all the other trees received treatment.

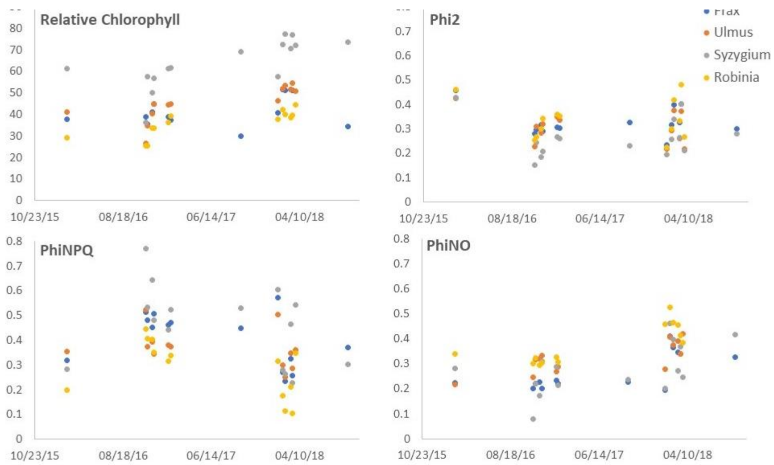


Figure 27. Photosynthesis parameters by tree species by date. Multivariate analysis was used to adjust species means at each sampling date, accounting for light intensity and time of day, both of which affect field-based photosynthesis measurements.

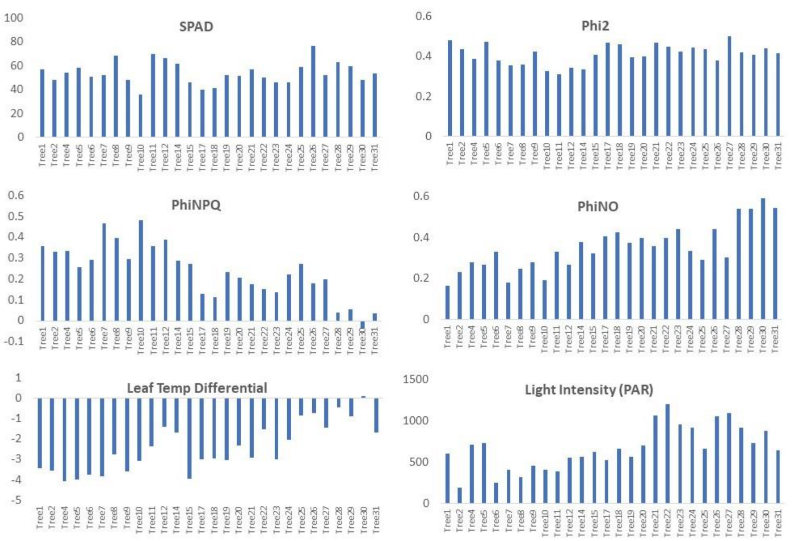


Figure 28. MultispeQ photosynthesis parameters for February – March 2018. Data presented here are adjusted means of multivariate analysis with light intensity, time of day and ambient temperature has covariates.

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

	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 $p \leq 0.001$

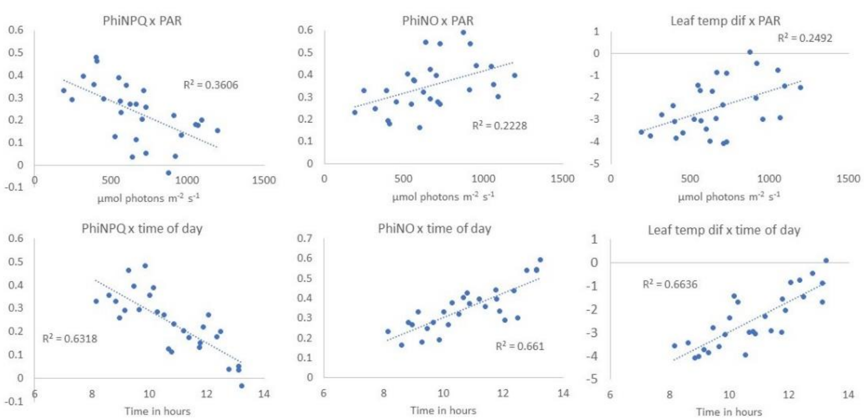


Figure 29. Correlations between adjusted means of photosynthesis parameters (using multivariate analysis) and environmental covariates (light intensity and time of day).

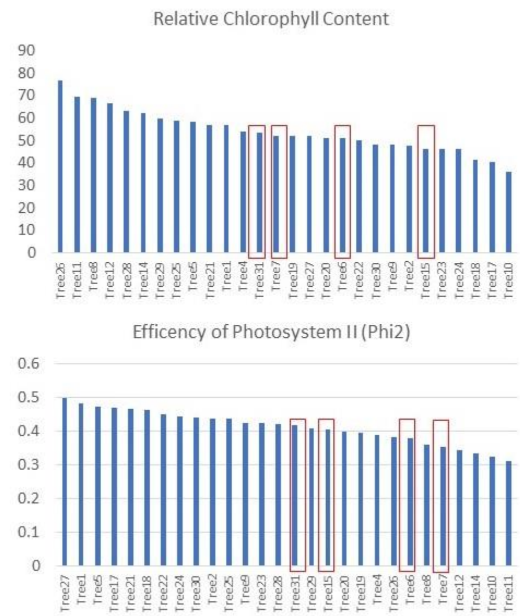


Figure 30. Ranking of adjusted means for relative chlorophyll content and Phi2, with red boxes identifying the 4 trees of the Fraxinus genus.

3.7 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.

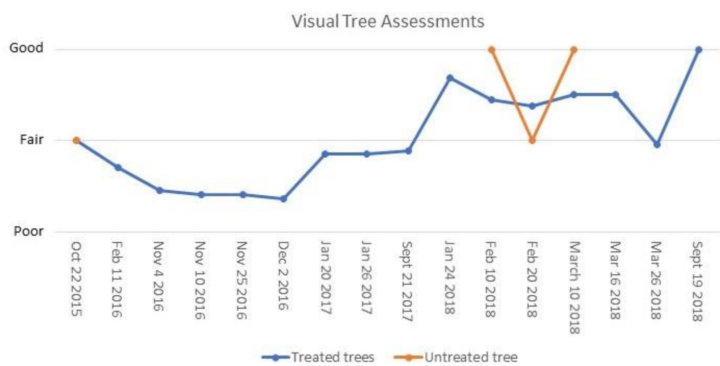


Figure 31. Average Visual Tree Assessment by date for treated and untreated trees.

3.8 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 utilizing recycled water to irrigate its Park Lands, and because the effects of recycled water on soils in 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 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.

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

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.

The Veale Gardens/ Walyu Yarta PHC Project tested soil salinity in 8 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) (Figure 34, Middle) and the salinity maps generated by Nouri et. al. (Fig. 34, Bottom). The EC results from Nouri et. al. were higher than the G.U.F. results for 7 of the 8 trees (Table 6. This suggests that the method used by Nouri et. al. over-estimated EC. Secondly, using the CSIRO guidelines, the results for 5 of the 8 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 Organization (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.

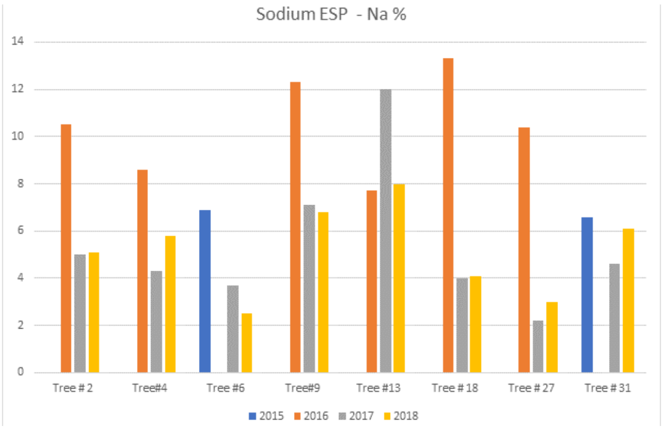


Figure 32. G.U.F. - Exchangeable Sodium (%) by tree and year

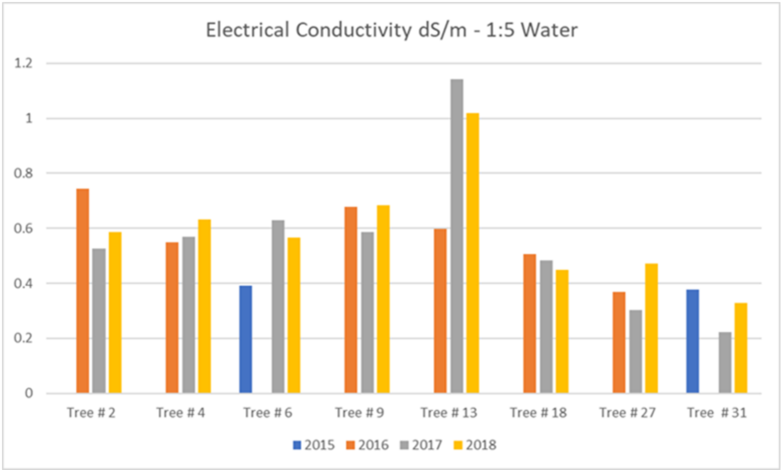


Figure 33. G.U.F. - Electrical conductivity (dS/m) by tree and year

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

Table 6. The below 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.

	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

3.9 Tree # 16 – *Quercus Ilex – Died 2017*

During the Veale Gardens PHC program only one of the 30 declining trees died, Tree # 16 (Fig. 35). 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.

Figure 35. Tree # 16 - *Quercus Ilex* – 100% desiccated, September 2017 (left) and decaying roots.

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 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, C). 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 has '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

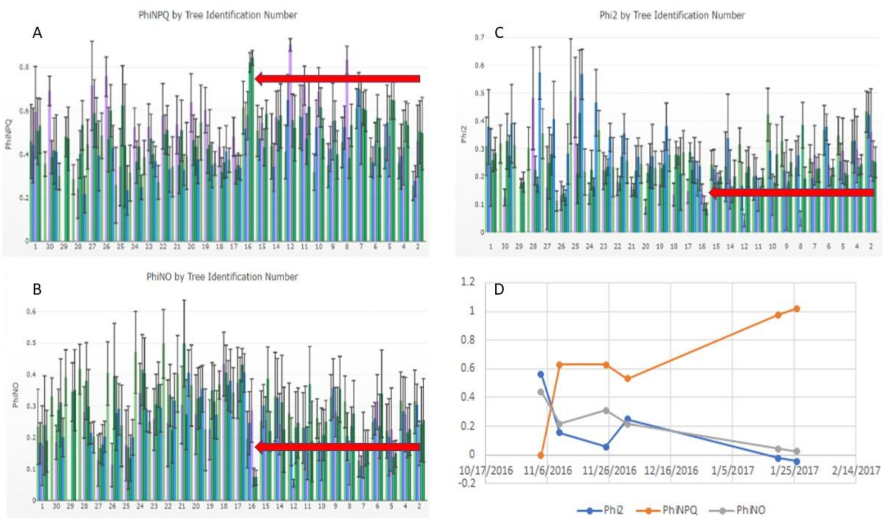


Figure 36. Photosynthesis parameters of all trees. With red arrows indicating tree #16 A) PhiNPQ; B) PhiNO; and C) Phi2. Panel D presents Phi2, PhiNPQ and PhiNO after statistical analysis to account for light intensity and time of day. There is a clear spike in PhiNPQ and drop off in Phi2 and PhiNO.

Section 4: 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

Appendices:

Appendix 1: Example of Compost quality

AS4454-2012 COMPOSTS, SOIL CONDITIONERS AND MULCHES REPORT

1 sample supplied by Jeffries Group on the 14 October, 2016 - Lab Job No. F3947

Analysis requested by Renga Ramasamy.

(412 Hanson Road North, WINGFIELD, SA, 5013)

				Sample 1	Requirement	Requirement	Status
	Product Name:			OC0216F	(Composted Product)	(Mature Compost)	
	Product Type:			Compost			
	Manufacturing Site:			Jeffries			
	Manufactured Date:			4/10/2016			
	Quantity Supplied:			10 kg			
	Test Required:			CA-PACK-011			
	Australian Standard Applicable:			AS4454-2012			
Test Method - Appendix	Nutrient		Units	F3847/1			
B6	pH		na	6.7	>5	>5	Pass
	Electrical Conductivity		dS/m	6.84	<10	<10	Pass
	Soluble Phosphorus in solution	P	mg/L	4.5	≤5 see note 5	≤5 see note 5	--
	Soluble Phosphorus dry mass equivalent	P	mg/kg	23	--	--	--
	Ammonium-N in solution	N	mg/L	180	<200	<100	
	Ammonium-N dry mass equivalent	N	mg/kg	899	--	--	--
I	Moisture Content		%	39	>25 see note 6	>25 see note 6	Pass
C6	Total Organic Carbon		%	28	≥20	≥20	Pass
	Organic Matter		%	47	--	--	--
	Total Nitrogen		%	1.4	≥0.6 see note 7	≥0.6 see note 7	--
	Carbon: Nitrogen Ratio		%	19.7	--	--	--
D5.1.1	Sodium	Na	%	0.23	<1	<1	Pass
	Calcium	Ca	%	2.82	--	--	--
	Magnesium	Mg	%	0.49	--	--	--
	Potassium	K	%	1.02	--	--	--
	Sulfur	S	%	0.17	--	--	--
	Phosphorus	P	%	0.24	≤0.1 see note 5	≤0.1 see note 5	--
D5.1.1	Zinc	Zn	mg/kg	255	<300	<300	Pass
	Iron	Fe	mg/kg	8,006	--	--	--
	Manganese	Mn	mg/kg	284	--	--	--
	Copper	Cu	mg/kg	66	<150	<150	Pass
	Boron	B	mg/kg	35	<100	<100	Pass
	Molybdenum	Mo	mg/kg	1.1	--	--	--
	Selenium	Se	mg/kg	<0.5	<5	<5	Pass
	Cadmium	Cd	mg/kg	0.7	<1	<1	Pass
	Lead	Pb	mg/kg	63	<150	<150	Pass
	Arsenic	As	mg/kg	5.9	<20	<20	Pass
	Chromium	Cr	mg/kg	20	<100	<100	Pass
	Nickel	Ni	mg/kg	9.6	<60	<60	Pass
	Mercury	Hg	mg/kg	<0.1	<1	<1	Pass
3.1(C)	Polychlorinated Biphenyls		mg/kg	<0.5 see note 13	<0.2	<0.2	Pass
	Organochlorines - DDT, DDD, DDE		mg/kg	<0.2	<0.5	<0.5	Pass
	Organochlorines - Other see note 8		mg/kg	<0.02	<0.02	<0.02	Pass
	Salmonella		number/50 g	Absent	Absent	Absent	Pass
	Faecal Coliforms		mpn/g	10	<1,000	<1,000	Pass
G	Particle Size Grading - >16mm Sieve		%	Nil	-- see note 10	-- see note 10	--
	Particle Size Grading - >5mm<16mm Sieve		%	9.4	-- see note 10	-- see note 10	--
	Particle Size Grading - <5mm Sieve		%	90.6	-- see note 10	-- see note 10	--
I	Plastics Light Flexible or film >5mm		%	0.01	≤0.05	≤0.05	Pass
	Stones and Lumps of Clay >5mm		%	1.5	≤5	≤5	Pass
	Glass, metal and rigid plastics > 2mm		%	<0.1	≤0.5	≤0.5	Pass
E	Wettability		minutes	0m 22s	<5	<5	Pass
H	Calcium Carbonate		%	--	--	--	--
B6	Nitrate-N in solution	N	mg/L	0.9	--	--	--
B6	Nitrate-N dry mass equivalent		mg/kg	4.7	≥10 see note 7	≥10 see note 7	Fail
N3.2	Ammonium:Nitrate Ratio		Ratio	193	<3.0	<0.5	Fail
F	Plant Growth Test (Bioassay) - Root Elongation		mm	Nil Growth	60	60	Fail
O	Nitrogen Drawdown Index		NDI	0.03	>0.2	>0.5	Fail
	Oxygen Consumption Rate		mgO2/Kg/min	2.90	--	--	
	Specific Oxygen Uptake Rate		mgO2/gVVS/hour	0.60	<3	≤1	
M	Viable plant Propagules		21 days	Nil	-- see note 14	-- see note 14	Pass

Remarks: All testing was done according to AS4454-2012 and all completed tests have passed except for Nitrate-N in solution, ammonium:nitrate ratio, Plant growth test, Nitrogen drawdown

Figure 36. Compost Chemistry assessment as per AS 4454

Appendix 2: Exploring the use of Environmental Sensors to Determine Input Quality - CO2 Respiration

Soil Biological Activity CO2 Respiration, Measures CO2 concentration in a closed chamber over time. Used to measure soil biological activity in samples of soil or compost either in the field or in the lab. The parameter of interest is the slope of the initial rise in mg C directly after closing the chamber. This protocol measures CO2 at 5 second intervals for ~5 minutes.

CO2 respiration can be linked to biological activity in the soil. Generally, highly compacted soils with low moisture and low biological activity have a corresponding low CO2 respiration. This means healthy root growth is limited to high extent.

Recent Issues with this device have been found and now this methodology has been replaced with the SoilSpeq by Dan Teravest, although the below data provides an interesting outcome that correlates with the authors hypothesis of biological activity in different input materials.

Measuring CO2 respiration of input materials

Measuring CO2 respiration of input materials provides an opportunity to understand the biological activity of different materials for example: better quality compost contains a higher diversity and activity of microorganisms and is reflected in an increased CO2 level. Soils with higher CO2 respiration have higher diversity and activity of microorganisms and function for effectively.

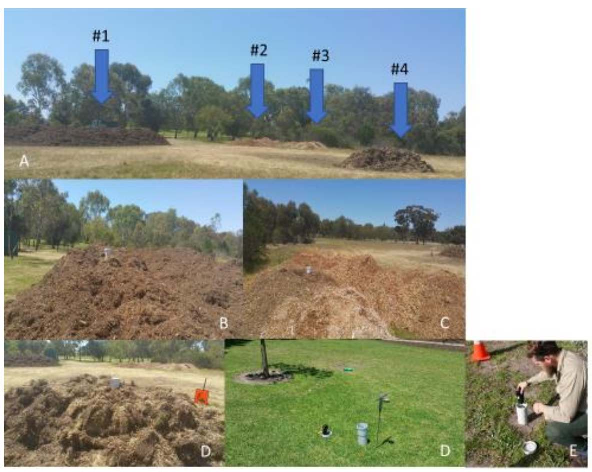


Figure 43. Carbon respiration – PhotosynQ - MultispeQ (Beta) - CO2 sensor Samples of input materials. A) Four piles of input material; B) ACC Green Waste - Tub grindings – processed green waste – broad C/N ratio material ground and then stockpiled - heat temp increases significantly – lots of N degassing; C) Fresh Forest Mulch – tree chipped through wood chipper fresh – weeks, left side of image, Aged – Aged Forest Mulch - – tree chipped through wood chipper aged stockpiled for – months, right side of image; D) Sod Pile – Green – first 10 cm of top soil with grass and roots – microbial activity/moisture; D) Compacted soil in turf area; E) Inserting MultispeQ Beta into CO2 chamber.

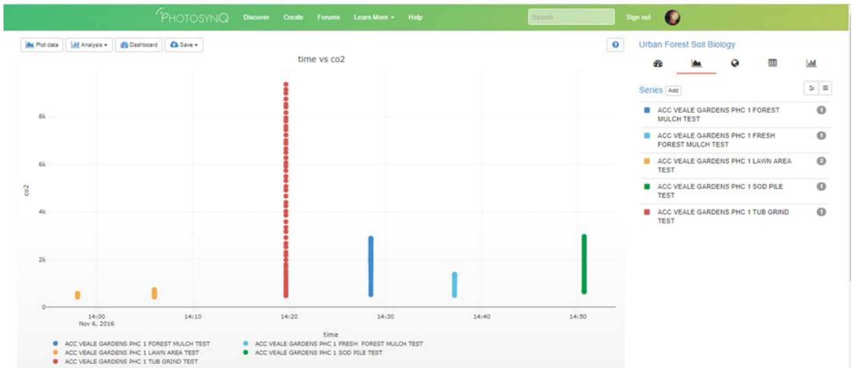


Figure 44. The photosynQ online data visualisation screenshot. Note: compacted soil with estimated low biological activity has produced lowest CO2 production. The (Red) indicates the green waste tub grindings that are still decomposing and procuring the highest CO2 production.

2016 Tree soil sampling - CO2 respiration of soils

Figure 45. Prior to the PHC # 1 program implementation in November 2017 a baseline measure of 12 trees within the 30 trees selected to remediate were collected in February 2016. There is variation in measures which is expected on sites with different soil health condition.

Appendix 3: Veale Gardens PHC program – Individual Trees

Figure 46. Individual Tree Numbers 2016: 1.) *Liquidambar styraciflua; 2.) Ulmus holandica; 3.) Pinus Canariensis; 4.) Ulmus holandica; 5.) Lagunaria Patersonia; 6.) Fraxinus angustifolia; 7.) Fraxinus angustifolia; 8.) Syzygium smithii; 9.) Ulmus Minor; 10.) Acer sp* 11.) *Syzygium smithii.*

Figure 47. Individual Tree # Numbers 2016: 12) *Syzygium smithii;* 13) - *Cupressus arizonica*; 14) - *Laurus Nobilis*; 15) *Fraxinus angustifolia;* 16) – *Quercus Ilex;* 17) - *Robinia pseudo acacia;* 18) *Robinia pseudo acacia;* 19/20) *Ulmus holandica;* 21) – *Lophostemon confertus*

Figure 48. Individual Tree # Numbers 2016: 22) *Lophostemon confertus;* 23/24) *Tillia Cordata;* 25) *Magnolia Grandiflora;* 26) *Syzigium Smithii;* 27) *Quercus palustris;* 28) *Calodendrum capense;* 29) *Ulmus holandica;* 30) *Robinia pseudo acacia;* 31) *Fraxinus angustifolia*

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

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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.