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Final Report: Australian Soil Health Summit

Queensland Department of Agriculture and Fisheries

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Avocados Australia

REPORT ON REVIEW OF AVOCADO SOIL HEALTH

Part of project AV17005

Brisbane, 08 – 09 November 2022

Renata Grunennvaldt, Simon Newett and Bridie Carr

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9. Simon Newett (SN)
10. Tony Pattison (TP)
11. Brigette Ryan (BR)
12. Denis Roe (DR)
13. Graeme Thomas (GLT)
14. Neil Wilson (NW)

From left: Denis Roe, Alan Blight, Lisa Fyffe, Stephen Jeffers, Anthony Beutel, Liz Dann, Brigette Ryan, Tony Pattison, Tim Kemp, Simon Newett, Neil Wilson, Bridie Carr, Renata Grunennvaldt

DOMESTIC SURVEY RESULTS – DISCUSSION POINTS

Please refer to the Domestic soil health survey results *in the BPR for a detailed report of the results.*

The notes below report on the discussion of survey results at the summit.

What do you think about the rank of priority where 72% answered that soil health is a top-level priority? Do you think this actually represents the practices that you have seen in the avocado industry?

Most believe it is, but it can also be related to peoples' definition of soil health. Comments were around orchard floor management, especially the use of mulch.

There is a bias with the survey given it was a soil health survey – meaning only people interested in this topic were going to complete it.

There were several 'number one' priorities – managing orchard floor seems to be the most important.

AlB - Water holding capacity, micro-organisms etc are important.

TK – What are the effects of herbicides on soil microbiology?

SJ – What are the long-term effects of fungicide and herbicide use and how do they affect soil carbon?

The copper conundrum

In avocado production, we have to apply regular copper fungicide sprays to manage fruit rots, but this copper accumulates in the soil and has a potential negative effect on soil life.

Organic matter holds copper and appears to 'fix' copper thus reducing its negative effect on soil microflora. This was borne out by a comment from SJ who said that he created an induced copper deficiency by applying too much compost. However, SJ asked 'Are we preventing the achievement of high organic matter (OM) levels by applications of mineral N and Cu?'

BR – the highest soil levels of Cu she has seen are 77ppm, averages are around 40ppm.

The literature review showed that only one study investigated the effect of copper in the soil. The paper shows that more worms were observed in the native forest, adjacent to orchards, than in orchards where copper fungicide was applied.

Organic matter

Note: Organic Carbon % x 1.7 = Organic Matter %

Soil type will dictate how high soil OM is able to go.

If OM is less than 1% then there are serious issues.

OM levels are typically lower in tropical regions than in temperate climates.

However, NW said that in the Amazon, native practices which include the use of biochar can result in very high OM levels.

OM can reach 15% in the NQ rainforest but in excessively cultivated sugarcane fields in the same region it can drop to below 1%.

What is an aspirational OM level for avocados? Avocados, being a permanent crop (soil is not tilled) should have a higher aspirational level than cultivated crops.

It is very difficult to build up OM in a sandy soil.

SJ felt that there needs to be more emphasis on root exudates as a source of soil carbon.

SJ said that mineral N applications to the soil burns up soil carbon. He is more interested in the appearance of the tree. He wants any N applied to be taken up and converted into protein and not to exist as free N in the soil.

Biochar is a habitat for soil microfauna and microflora.

AnB incorporates brown coal and compost before planting – a shovelful mixed in the hole prior to planting.

Mulching is a 'must'.

The soil biome should have a fungal rather than a bacterial dominance.

DR said that woody mulch promotes a fungal dominant biome, whilst grassy mulch favours a bacterial dominant biome.

LF questioned the survey respondents' definition of mulching.

Grass should be allowed to dry out before applying as a mulch.

There was discussion around what is and isn't good mulch material.

Rhodes grass is great mulch – allow to grow long to get stalky woody material rather than cutting whilst lush, this provides mulch with a higher level of cellulose. Turn it to hay before applying as mulch.

Quality concerns were raised around council waste product. AnB had to scrape one lot off he put out given it sealed and water couldn't penetrate. AlB uses council waste, and it works well for him on his 'beach sand'.

Introducing biology into the soil

TK uses a lot of different products.

There was a general agreement that the approach should be to 'feed the biology' already in the soil, rather than to 'introduce biology' to the soil.

There is a product called EndoPrime® that claims to introduce mycorrhizae to the soil.

DR and NW both mentioned that many products do not have the levels of microorganisms in them that they claim to contain.

NW said that is very, very hard to manufacture and successfully introduce biology into the soil – it just doesn't make sense biologically.

Chloride toxicity can be confused with manganese deficiency.

LITERATURE REVIEW – DISCUSSION POINTS

Please refer to Soil health literature review *authored by Dr Renata Grunennvaldt which can be accessed in the BPR.*

The notes below report on the discussion of the literature review at the summit.

TK and others congratulated RG for the review. TK would like to see the literature review promoted/marketed to growers.

DR said that he was pleased to be reminded about the topic, it refreshed his memory on the topic.

The complexity of the topic was highlighted – soil health is a huge area!

TP raised the conflict between on the one hand promoting the use of beneficial mycorrhizae but on the other hand using fungicides.

AlB said it contained new information on salinity.

SJ said that one of the gaps in the review was the effect of pesticides and other chemicals on soil health.

ED, on the topic of sustaining beneficial fungi on fruit to help combat pathological fungi such as anthracnose, said that it would be possible in an environment such as SJ's farm on the Sunshine Coast but it wouldn't work in the harsh dry environment of the Perth area for example.

TK said that a hot dry 40°C day kills off beneficial organisms.

TP spoke about the impacts of herbicides on soil biology in bananas. A one-off application doesn't have much effect, but repeated applications does. Also, using a rotation of different herbicides doesn't help.

RG mentioned that she couldn't find any peer-reviewed papers on the food web.

TK said he can't find much information on calcium in the soil.

On the topic of silicon, potassium silicate is more likely to work in low OM soils because high OM may tie it up.

SJ said that there are inconsistent results from silicon, but the overall trend is positive.

Si does help strengthen cell walls (as does Ca).

Carbon farming – LF has her fam registered for carbon credits – the process took three years to complete and is supposed to attract a premium of $4 per tray of fruit.

TK said that carbon farming is too complex for the average farmer to access.

The carbon farming space is a potential area for growers to be supported in. For example, with tree removal and the cost of mulching. Carbon neutral premiums are possible through marketing.

The new AS18000 (national tree crop intensification program) project may be looking into carbon systems.

SUSTAINING SOIL'S SERVICES – DR TONY PATTISON, RESEARCHER

Please refer to Tony's PPT available on the BPR for more detail.

Guest speaker – Tony Pattison

Tony is a Principal Nematologist highly regarded both nationally and internationally in the soil health discipline. Tony has pioneered a range of innovative technologies that have greatly assisted the quantification of microorganisms within the soil that are able to interact with horticultural crops, and his theories and ideas were shared and discussed by the summit group.

Tony believes we are lacking the knowledge of how to connect farm management practices with soil biological interactions to provide healthy soils.

Soil health looks at how the chemical, physical and biological properties of the soil come together and interact. It is the organic matter component that connects these three components and drives soil health. It's organic matter, which turns the inert piece of dirt into something that is living and interactive. Everything that's happening in the soil is biologically driven.

Microbial biomass in the natural environment can be double that of cultivated soil, especially if the latter is a monoculture. When we talk about soil biology, there are millions of different organisms in the soil ranging from bacteria to other micro-organisms, nematodes, mites, worms, and insects. They all interact with the soil.

What do we want to know when it comes to biological activities? Basically, how much is there (the quantity), how many different types of organisms are there (biodiversity) and what do they do? This information is measured in different ways.

Measurement of soil biological activity has evolved over the last 10-15 years and is still evolving. Historically it was observational, then it moved into more biochemical practices, looking into enzymes and respiration. Now what's taking off is molecular sequencing to really understand what's there, in what abundance, and then even looking at the gene level.

Some constraints that hold back both production and biological activity are physical - low water holding capacity, low nutrient retention, acidity, compaction, poor aeration, salinity etc. In many cases, pests and diseases are simply consequences of poor soil structure.

In North Queensland within the banana system, work was done looking into soil quality. A survey was conducted that selected sites with commercial banana crops, sugarcane, natural rainforest and wild bananas (native species). Soil samples were taken throughout the year.

Banana and sugarcane soils had less microbial biomass and this is the result of management practices.

Wild banana sample biomass was equivalent to the rainforest and semi-natural samples.

There is a different nematode community in the cultivated vs. the natural environment. Rainforests have a much lower population of plant parasitic nematodes compared with cultivated soils, but a higher population of beneficial nematodes.

In cultivated banana plantations the levels of *Fusarium oxysporum* (a pathogen) are very high, but the probability of *F. oxysporum* decreases if you increase the biomass in the soil.

Measuring biomass gives an indication of the probability of disease.

Diversity is important.

Tony is looking at how nutrients are re-cycled in different soil systems.

A DNA analysis shows that there are more de-nitrifying bacteria in cultivated soils than non-cultivated soils.

Tony said at last count there were 255 'organic' products on sale to growers. Most biological products for sale that are added to the soil will last less than 3 months (except for nitrogen rhizobia). The soil has its own existing ecology (biome) that has developed for that environment. The soil environment is usually a foreign environment for the introduced micro-organisms which must compete with the physical conditions and existing soil microbiology to survive.

Shifting the soil pH to about 7 will maximise biological interactions.

Copiotrophic organisms are fast-growing (found in environments rich in nutrients, especially carbon)

Oligotrophic organisms are slow growing (found in environments low in nutrients and oxygen, e.g. in leached soils).

High nitrogen applications result in higher levels of soil bacteria. High nitrogen decreases the plant's defences.

Measuring the different types of nematodes in your soil gives a good indication of soil health, but it is difficult to develop a commercial test for this.

Groundcover is important. Disease symptoms were more severe in bare soils.

What can growers do? Add compost? Let weeds grow?

Mulches are better than nothing. Live ground cover is good but at what point does it compete with the commercial crop? The practice used in banana farming is to establish the banana plants before establishing ground covers. 2,500 ha of the 4,000 ha of bananas planted in Australia now use ground cover.

Tony and his team are looking at what is being applied to the banana crop and what effect it is having in the soil. The team know that phosphorus and a single application of Basta®, has very little impact. Nitrogen has some effect. Ground cover has a major effect.

It was observed that increasing the amount of nitrogen (going from 0 to 500 kilograms per year) decreased the number of fungivorous nematodes (beneficial nematodes that eat fungi) and increased the number of total plant parasitic nematodes.

It was pointed out that avocados are very shallow rooted and suffer from weed competition therefore the net benefit of using living groundcovers in avocado orchards may be questionable.

It was suggested that groundcovers be experimented with in avocado orchards by establishing them in the interrow then allowing them to grow closer and closer to the tree trunks and monitoring the effect on the avocado trees.

'Farming the interrow' might be a better proposition for avocado orchards. Initially you will get annoying weeds then these will start disappearing and low growing species will take their place – usually after about 18 months.

DR said that if you are going to use compost then it needs to be very good compost.

SJ said that his healthiest avocado tree is growing in the vegetable garden where no herbicides are used.

Grower mindset is difficult to change – e.g. Tony says that it is hard to convince banana growers in the Philippines to adopt the use of ground covers.

TK asked about the use of companion planting – should you use woody species or grassy species, or a combination of both?

Conclusions:

- Healthy soils are the foundation to sustaining agriculture production
- Soil organisms transform soils and play crucial roles in sustaining soils services
- Farm management practices influence soil health services, either directly or indirectly

SHORT PRESENTATIONS

SALINITY – GRAEME THOMAS, CONSULTANT

Salinity is an issue of growing concern in the Australian avocado industry. Mainly in WA, CQ and Tristate during drought, also now in NQ where there are 50 hectares of avocados receiving recycled water.

Chloride leaf levels have reached 0.9% in CQ, and up to 1.5% in WA at which point the leaves fall off.

Rootstocks have an influence, for example West Indian rootstocks (e.g. Velvick) are more tolerant of salinity compared with Mexican which are the most susceptible.

The mode of action & symptoms of sodium and chloride are different in the plant.

Sodium (Na)

Sodium accumulates in the roots first, e.g. with Na at 42 mg/kg in the soil, root Na is about 0.7% but leaf Na is about 0.01%.

In Manjimup, WA, with a soil Na of 560 mg/kg, leaf Na can still be 0.01%.

Leaf analysis is not a good indicator of Na toxicity. The % of the soil's exchange capacity occupied by Na is a more useful indicator. Soil Na should represent less than 3% of the exchange capacity. However if this level gets too high it can be displaced by the application of other cations, e.g. Ca, Mg and K.

Chloride (Cl)

Unlike sodium, chloride does not accumulate in the roots. Healthy roots can exclude Cl uptake to a certain extent, but Phytophthora affected roots cannot.

However when it is taken up, it moves straight into the transpiration stream and get deposited in the leaf where the water is transpired into the atmosphere leaving the Cl behind. Build-up of Cl in the leaf will lead to tip burn, then leaf margin burn and then early leaf fall.

Leaf levels are a good indicator of Cl levels.

High chloride levels can be mitigated by:

- Precise irrigation
- Irrigation flushing
- Use of nitrate N instead of ammonium N* (an increase in the concentration of nitrate in the irrigation solution reduced the Cl content in the leaves and enhanced the ability of the avocado plant to use increasing concentrations of saline water).

** South African Avocado Growers' Association Yearbook 1987. 10:47-48. Proceedings of the First World Avocado Congress* ***"Nitrate nutrition as a tool to reduce chloride toxicity in avocado"****. Y Bar[1], U KKafkafi[2] and E Lahav[3]*
[1] Regional Experiment Station, Akko; [2] Dept of Soil Science, Faculty of Agriculture, Rehovot; [3] Dept of Fruit Trees, Agric Res Org, Bet Dagan, Israel
https://avocadosource.com/wac1/wac1_p047.pdf

Case study: In WA irrigation water contained 470 mg/L (recommended upper limit for avocados is <80 mg/L). Grower was advised against using this water but went ahead. Leaf Cl level reached 1.18% (recommended leaf level for avocado in Australia is <0.25%). Orchard failed.

Tony Whiley did an experiment where he entirely defoliated a tree in autumn, this reduced the subsequent yield to 25% of that achieved in the untouched trees. Thus, loss of leaf (from Cl burn) will reduce yield in proportion to the % of leaf canopy that is lost.

Recommendations in situations where there are high Cl levels:

- Periodic flushing outside the wet season. The higher the leaf chloride, the more frequent the flushing needs to be.
- Do not allow any water stress.
- Maintain good root phosphorous acid levels (roots not affected by Phytophthora root rot are better able to reduce chloride uptake).
- Apply only the nitrate form of nitrogen fertilisers

Graeme reminded the group that healthy roots can exclude Cl uptake to a certain extent, but Phytophthora affected roots cannot. Another good reason to manage Phytophthora well and keep the phosphorous acid levels high in the feeder roots.

ED thinks that leaf burn (from high Cl) may predispose trees to leaf blight. ED agrees that you mustn't let trees get moisture stressed, especially in spring when the effects of increasing temperature and flowering increase water demand.

CASE STUDY OF SOIL HEALTH PRACTICES AT SIMPSON FARMS – BRIGETTE RYAN, AGRONOMIST

Brigette's definition of soil health is an active growing medium which is full of life and organic matter which can sustain plant growth through the supply of nutrients. As growers she believes that we must sustain the soil, continue to replace what is removed and strive to always improve it.

For Simpson Farms the soil health journey started many years ago with regular mill mud applications across the properties as it was a cheap and a highly available source of nutrients and organic matter. However, the Bundaberg 2011 and 2013 floods played havoc with tree and soil health across the their orchards as well as many other farms in the region.

In 2013 after the floods there was a significant decline in tree health, in addition the high volumes of rain runoff swept away topsoil and organic matter from under the trees. This was a trigger to bring back tree health by improving soil health.

Major tree height reduction and staghorning took place, which left a large amount of wood that had to be disposed of or used. This was the point at which Simpson Farms started their composting site as it was the answer to using up the prunings and creating a product that added organic matter back to their soils.

In 2013 Simpson Farms commissioned the compost site on an unused 1.3 ha area. The objective was to develop a waste management system where prunings from the orchard could be composted and returned to the orchard to improve soil health.

Targets for the compost included moisture, C:N ratio, temperature, and microbial levels. A variety of ingredients were tested including filter press, manure, sugar cane mulch and woodchip.

The site has the capacity to produce 2,000m^3 of compost per year.

After getting the site certified and becoming fully operational, the compost made on the farm was a rich source of OM, microbes, and nutrients, which was then put out under the trees.

In 2017 the avocado processing facility was built, and its by-products provided new ingredients for the compost. The large amount of by-products included avocado skin, flesh and seed which were now included as ingredients in the composting process. Converting components into humus was a key goal.

There has been a good increase in soil organic matter with a noticeable dark organic layer forming on the soil surface. Total soil carbon has increased from about 1.2% (2% OM) to about 3% (5% OM).

Even though there were obvious improvements in soil health and tree health, it was noticed that the compost wasn't resulting in an increased volume of roots or root growth, and worm levels were still low.

The desired root growth was only going to be achieved through the application of mulch. At this time the costs of inputs for the compost were increasing making it uneconomical.

As time progressed and spreading equipment became more efficient and economical, they saw the benefit of allocating more budget to a mulching program.

Currently, the business aims to mulch every block across the property every year.

Bales are purchased from multiple suppliers and managed on-site through allocated dump sites for travel efficiency and economics.

From the past decade of compost applications and mulch, their soil health has improved along with a good population of worms now being present. Soil structure has also improved through worm holes and soil aggregates.

Across 200 blocks in 2022 soil organic matter has averaged 4.5%. Total carbon has increased to about 6% (10% OM) on some blocks.

Maintaining these levels and building OM up in the orchard blocks that still have low levels is a key priority. This year they have made additional mill mud applications to help build up organic matter levels on blocks which have been consistently low through the past couple of years. Application levels of around 20t/ha are used. Mill mud does have a high moisture content therefore turning the piles whilst in storage may also be required for drying out and for ease of spreading.

Importance is placed on getting the mill mud analysed so that the levels of nutrients applied as mill mud can be included in the annual nutrient application budget.

Another process is to continue utilising the wood from prunings each year. All blocks which have been pruned are mulched (they use a Cat mulcher and a John Deere 8370RT mulcher FA Forestry mulcher) depending on the size of the prunings, it could take up to three passes to get the wood to a size they are happy with. This chip is then swept back under the trees using a hay rake. Under the trees, they don't mind a variety of different sized chips as it can also help provide air pockets once the mulch is applied.

Soil testing is conducted for every block each year. They have also been undertaking grid farm soil sampling for the last couple of years. This is also part of their soil health journey to create well-balanced and consistent soil.

This year they purchased their own variable rate spreader, this will help tailor this program and reduce the overall quantity of mineral fertilisers applied to the soil by not applying where it is not needed.

Summary

- Ideally, layer compost and mulch
- Compost site still producing low volumes
- Continue to monitor OM levels
- Variable rate fertiliser applications and apply gypsum as required
- Seasol® and soil microbial products

To sum everything up, they use multiple tools to continue improving their soil in the most economical and efficient way.

ORGANIC AVOCADO PRODUCTION – DENIS ROE, CONSULTANT

Denis presented information based on his experience converting a substantial area of conventional avocado orchard to certified organic production whilst working for Westfalia Estates near Tzaneen in South Africa. The organic blocks had to be certified by an independent accredited auditor.

Denis said that converting conventional avocado blocks to organic requires a radical mind-shift and re-training, you need to forget what you learnt about conventional plant nutrition (mineral NPK) and focus on the soil using carbon-based additives to follow the *"Feed the soil - to feed the microbes – to feed the crop"* approach.

To make it pay they had to receive a premium of 30% on the sale price for the certified organic avocados.

Denis emphasised that the best avocado blocks had to be chosen to convert to organic production to have any chance of being able to yield an economical crop. You need to start with good soil & strong healthy trees. You would have little chance of converting poor performing orchard into financially viable organic blocks.

They aimed to get soil organic matter levels up to 10% and one of the major steps was to produce good quality compost. They used the *controlled thermophilic microbial aerobic method* which involves getting the balance of ingredients right and carefully managing the temperature and moisture levels throughout the process. The major ingredients were woody material, green material and some compost from a previous batch (10%). A special machine was built to straddle the rows of composting material in order to turn it and add water. Sometimes avocado sludge from the processing plant was used as the source of moisture and it was also a useful way to get rid of this waste product. 10,000m^3 compost was made each year. Through the thermophilic stage which last a couple of weeks, turning sometimes had to be done twice a day. Temperatures need to be kept below about 65°C. To illustrate the high temperatures reached they would sometimes wrap a chicken in aluminium foil and place it inside the compost, it was cooked within a few hours.

In year one about 1m^3 compost was applied per tree, in year two, ½ m^3 was applied per tree. All the material had disappeared from beneath the tree within three years.

After about three years of treating the block in an organic manner, most of the insect attacks subsided (no insecticides could be applied) and/or were controlled by beneficials. The compost, mulching and more tolerant rootstocks helped manage Phytophthora root rot. *Bacillus subtilis* and *Trichoderma* spp were applied to help suppress root rot but no measurable response could be demonstrated.

Gypsum and lime could be applied but only if these were mined products. Copper fungicides were permitted to be applied, European customers allowed no more than 6kg of copper to be applied per hectare per year.

After 10 years of production, the organic blocks were converted back to conventional practices given that financial returns could no longer justify organic management practices (prices for organic avocados dropped due to an oversupply). They were getting a yield of 11-12 tonne per hectare from the organic production, but around 18 tonne per hectare from conventional. Fruit quality was comparable.

ASSESSING SOIL HEALTH USING DNA-BASED MEASUREMENT OF MICROBIAL DIVERSITY – DR NEIL WILSON, RESEARCHER, METAGEN AUSTRALIA

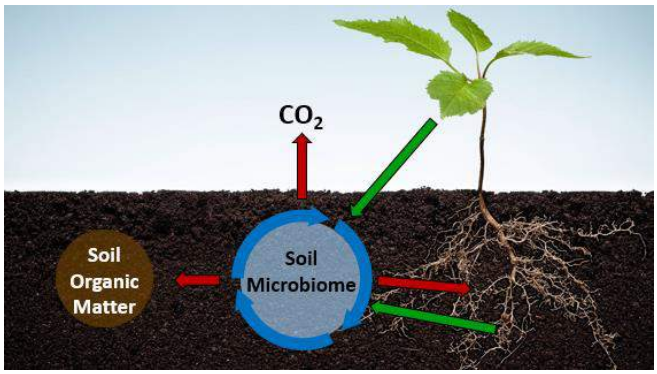
Please refer to Neil's PPT available on the BPR for more detail.

Neil works at Metagen Australia, 'The Soil Health Company' based out of Toowoomba. His mission in the company is to work out ways to better measure soil biology with the grand aim to better understand what's happening in the soil and thus be in a better position to more effectively manipulate the soil microbiome for better results.

The understanding of how soil organic matter (SOM) is formed has changed. The original theory was that SOM comes from matter that is the product of the breakdown of plant material, but it has been found that the vast majority (~80%) of SOM is microbial in origin. It may have come from plant

material, but it has turned into microbial biomass before being turned into SOM. This then means that the soil microbiome is the interface between the plant and SOM accumulation or production. Managing the soil microbiome is therefore the key to building soil fertility. Growers can influence the soil microbiome by providing the soil with organic amendments which can affect the efficiency of the biome - for example influencing them to produce less CO_2 but more SOM.

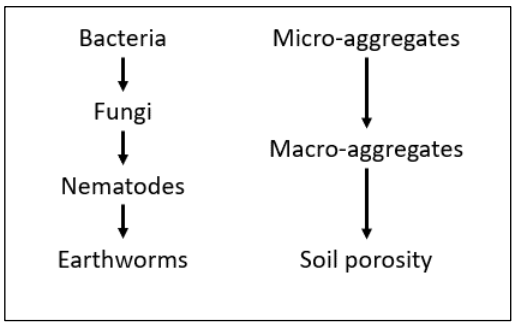
The way this can be done is still not clear, it is an area of active research. The theory behind clever microbiome engineering is that if the right consortia of microbes can be encouraged it can reduce the amount of carbon lost to the atmosphere and improve the amount of organic matter in the soil.



Microbes play a central role in the cycling of critical plant nutrients. For example a healthy biome that is high in biomass and diversity can recycle nitrogen better with less lost to leaching, converting more nitrogen into organic nitrogen compounds in the soil microenvironment. The combination of nitrogen cycling, and nitrogen fixation can really reduce the requirement for adding nitrogen to the system if it's harnessed in the right way. Neil has done some work with sugarcane growers who are now growing really good sugarcane crops on 30% or 40% of the industry standard levels of nitrogen. Similar successes have also been achieved by some wheat growers.

The same can also be said for plant available phosphorus being more readily available with higher levels of microbial activity (phosphatase being present), Neil has some banana grower clients that have not had to apply any phosphorous for 25 years.

Microbes play key roles in building soil structure and reducing erosion:



Microbes are excellent at suppressing plant diseases.

The microbial 'signatures' of healthy soils include Actinomycetes (bacteria) and *Mortierella* spp (fungi).

Microbially-mediated disease suppression has many mechanisms:

- Competitive exclusion (colonise the plant environment instead of diseases)
- Induction of plant defences

- Direct antagonism
- Parasitism
- Predation
- Symbiosis

Healthy and diverse soil microbiomes have a high potential to suppress plant diseases. This raises the question of how this can be manipulated and engineered in a meaningful and directed way to benefit production systems. We are still at the beginning of this journey!

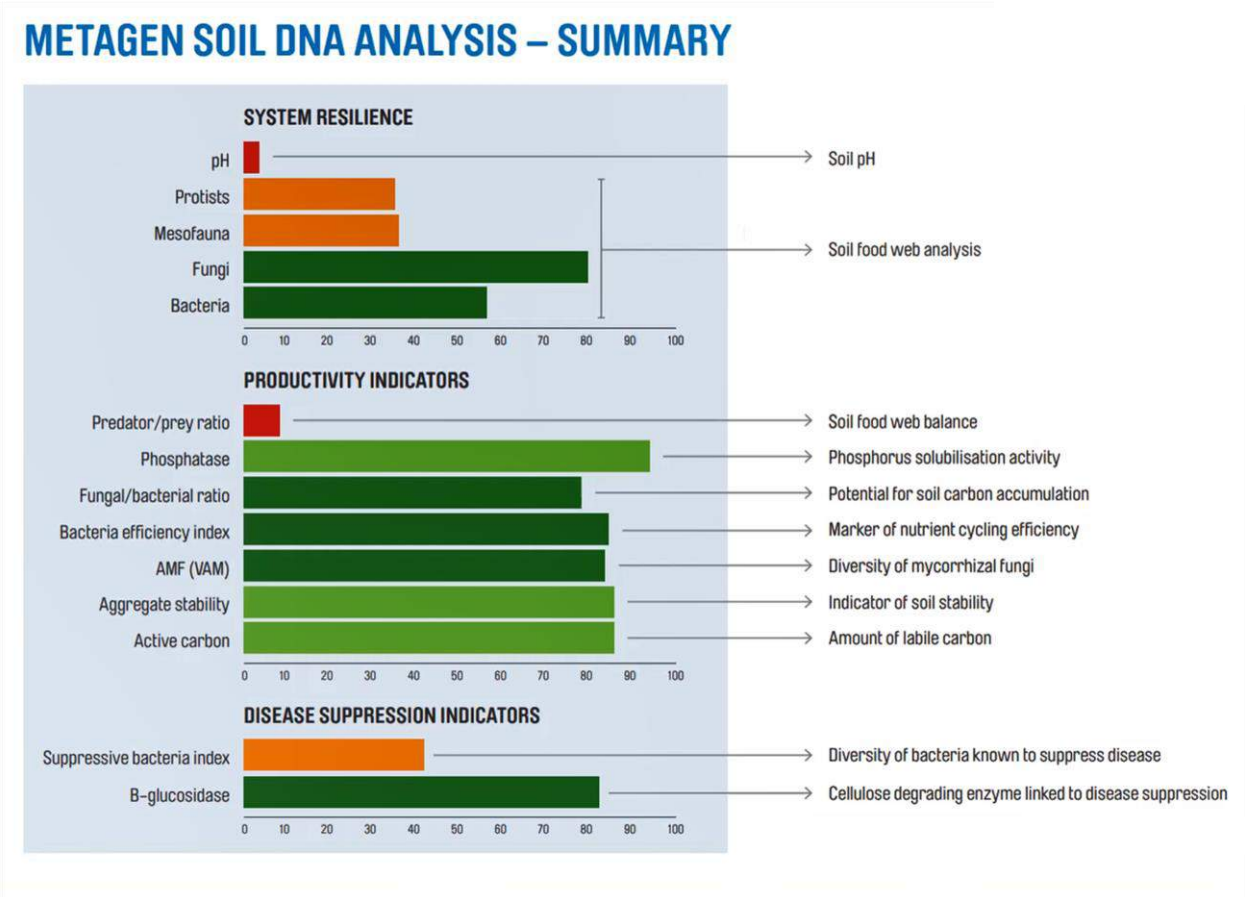
Why measure diversity in the soil microbiome? Diversity gives more functionality. This means that soils with diverse microbiomes are better able to deliver important ecosystem services such as:

- Nutrient cycling
- Plant growth promotion
- Disease suppression
- Building soil structure

Metagen offers a soil testing service that measures the biome diversity and therefore provides an indication of soil health. The tests are being improved all the time.

The results are broken into groups:

- System resilience – the health of the system
- Productivity indicators – keeping the plant fed and happy
- Disease suppression indicators – keep the plant happy



Neil described key results of some Metagen case studies and the use of testing soil health:

Cane on cane, legume cover crop and mixed species cover crop case study

- The mixed species cover crop had the best carbon and phosphorus cycling (buckwheat is a producer of phosphatase itself, mixed species also had higher enzyme activity)
- Legume cover crop had the best bacterial diversity but the lowest active carbon (nitrogen release related)
- Cane on cane had the best predator diversity (likely due to soil moisture)
- The mixed species cover crop had the best mycorrhizal diversity (sunflower was used which is a known host of mycorrhizal)

Continuous cropping, monoculture + heavy cultivation in sweet potato production

- Decrease in labile carbon
- Reduced soil structure
- Decreased biodiversity (from soil disturbance + monoculture)
- Decreased enzyme activity (caused by lower microbial diversity and activity)

Avocado case study (treated vs untreated) with Metagen products

- A decrease in phytophthora root rot abundance
- An increase in mycorrhizae
- Increase in microscopic earthworms
- Increase in canopy volume

Questions /short discussion points:

- Putting nitrogen out with the carbon source is probably a good thing to do. Think of it like a balanced diet, if you're thinking about stimulating the indigenous microflora in the soil, soil is not a plant, it's not photosynthetic and cannot make its own food.
- Tests range from somewhere between $100 and $300. Metagen are about to revamp their testings and have been doing a lot of research on how they can introduce new measures to provide better recommendations out of the tests. Early next year, they'll be releasing a second version of the test to include a lot more chemistry information as well as biological information that allows them to make more predictions. Hoping to get to the point where you can look at the microbial test with a nutritional program and given the level of phosphates present you can apply 30% less P for example.

RESEARCH SNAPSHOT: SOIL HEALTH AND TREE HEALTH - DR LIZ DANN & AKILA PRABHAKARAN, RESEARCHERS UQ

Liz presented work on soil amendment trials.

Tree health was scored on a 1 to 10 scale (1 being healthy and 10 dead – Liz rarely gives a tree a rating of 1), and Substrate Induced Respiration (SIR) was determined as a measure of soil microbial activity. The key message she had was that results were highly variable.

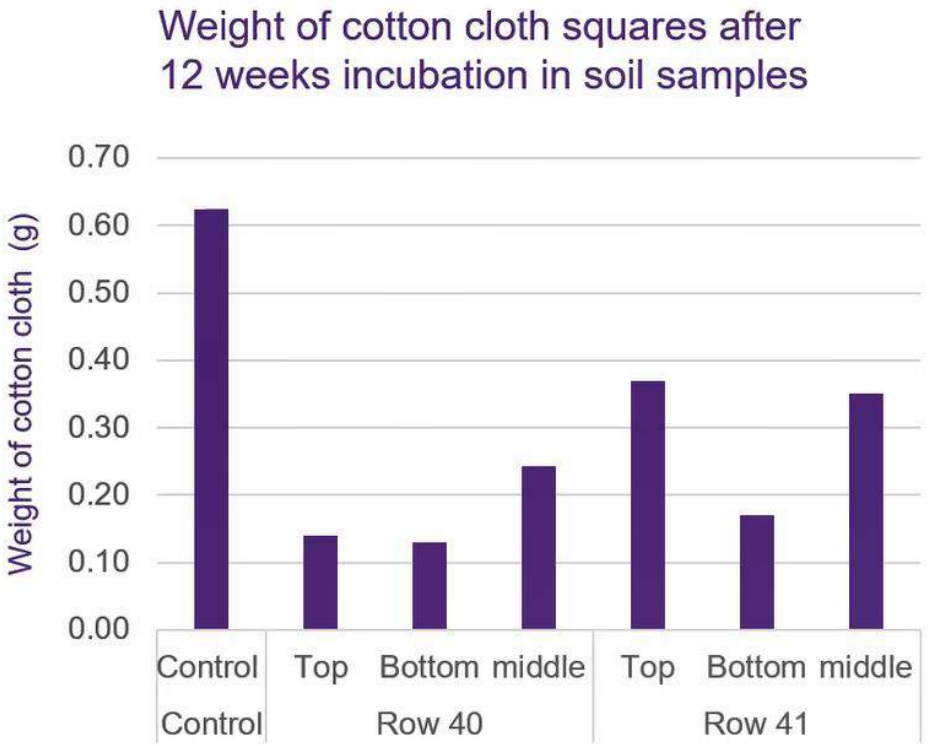
In two trials conducted in South West WA, Liz saw a positive effect of soil fungicide drench treatments (metalaxyl + S3 (an unregistered product)) on tree health and made the comment she has no evidence to suggest that the use of soil applied fungicides are having a negative effect on soil health.

A trial conducted at Costa's Avoridge orchard in Childers had 10 treatments ranging from woodchip, mushroom compost, mineral mulch, chicken manure, biochar, Ridomil®, molasses, and soil conditioners NRG and Microlife®. This particular trial had trees that were already scoring around 3 to 4 on the tree health score scale at the beginning of the trial so it was unlikely that the results were going to produce a great improvement. Differences would likely be seen when conditions were more challenging and tree stress was high.

There was a possible effect with soil conditioners alone without the addition of microbes (Microlife®), this was a demonstration trial (20 tree) so not replicated.

The quality of compost was raised as being an important consideration that growers should have. Liz gave an example of testing with lupin baiting which showed that one compost was a source of PRR.

Liz described a simple way to test microbial activity in the soil. It involves burying squares of cotton tea towel in the soil and monitoring how long it takes to break down in different situations, treatments, and locations. Denis Rowe's son Brendan did a small trial over a 12-week period and a poster was presented at the soil summit. He found that 12 weeks was sufficient time to get a quick assessment of cellulose breakdown/microbial activity.



Liz asked the question: "Do we really know what lab results mean when it comes testing for soil health?" She did a test sending two samples, one of which had been autoclaved (autoclaving is used to sterilise laboratory and medical equipment) to a laboratory. The laboratory reported the same total microbial biomass result of 37mg/kg for both samples and microbial activity was deemed in the green/good for both samples.

Tony raised the need for multiple indicator measures given biological testing is so 'noisy' so you can have confidence in the result.

There was some discussion about the use of metalaxyl (Ridomil®), DR recommended that it be used for a maximum of two years in a row. Useful to help get trees established – especially in replant land.

DISCUSSION

WHAT ARE PEOPLE USING?

DR – Mulch

TK – After citrus - a fallow with cover crops – couldn't afford to mulch up the citrus trees

SJ – Cost to mulch up a previous tree crop – contractor with a forestry mulcher $2,500/ha.

AlB – Need to encourage microbes that are already present

TP – You need to identify your most limiting factors – different sources of organic matter in different regions. Look at the whole process to see where changes need to be made.

SJ – Plant exudates from the roots are underrated – help plants harvest more sun and CO_2 to get more C into the soil. 'Farm' the interrow. The importance of soil pH is understated.

AnB – The importance of getting irrigation right.

LF – Why aren't more people adopting recommendations? Logistics and cost perhaps.

SJ to BR – How did you get soil OM up so high (12%)? BR – by using mulch and compost.

Important that enough water is irrigated to wet the mulch and as well as the desired depth of soil

Correct method to take a soil sample especially for measuring OM – scrape mulch away – but do you also scrape away the thin layer of black OM on the surface?

One delegate said to dig down to 15cm and sample the soil at 15cm, another said that you sample the soil from the 0 to 20cm zone.

DR – If growing organically it needs to be done properly e.g. compost needs to be very good quality. Also, any run off from the composting site needs to be contained on the site and not allowed to run into local creeks etc.

BR – Is it recommended to include biochar in compost?

SJ – How do you analyse compost? – Use a specialist laboratory, there are not many available.

What is the actual value of compost? NW – as a source of carbon. The microbial content is not of great value because they won't be able to compete with the existing soil microbes.

Soil tests for soil health – what can you use the results for? To test the effects of different practices and to get a better picture of what is going on in the soil

EcoGanic (the people who produce the 'red tip' bananas) use soil health tests to look at trends in soil health e.g. an analysis of the relative abundance of different species of beneficial and pathogenic nematodes.

SHAPING HEALTHY SOILS: THE IMPORTANCE OF SOIL MANAGEMENT PRACTICES FOR PROMOTING ROOT HEALTH AND HIGH FRUIT YIELDS OF AVOCADO – DR DAVID CROWLEY

Please refer to the recording for more detail.

Guest speaker – David Crowley

David is a professor emeritus at the University of California, Riverside, where he worked for 26 years as a research scientist and professor in soil and environmental sciences. David joined the summit group via Zoom to present information on his theories and ideas on the management of avocados for optimisation of soil health and consistent fruit yields, as well as to facilitate a discussion.

David's background:

"My background is in Horticulture and soil microbiology. At the time I joined UCR, Riverside was already an established center for avocado research that was supported by the California avocado commission. After arriving as an assistant professor, I was invited to submit a proposal to see if I could solve the zinc deficiency problem that had been plaguing the industry since 1940. The problem turned out to be a misdiagnosis of iron deficiency as opposed to a zinc problem. I subsequently went on to carry out rootstock selections for salinity tolerance, which led to learning about irrigation technology, and then on to studies of plant growth-promoting bacteria and how that might improve disease resistance and salinity tolerance. In that work, I worked with Dr John Menge and his group on biocontrol using soil inoculation. The last 8 years of my career were looking at the relationship between tree nutrition and fruit yields. That work consisted of a huge field project in which we set up plots on about 20 locations across a transect of California, and involved a team of researchers including Carol Lovatt, Phillipe Rolshausen, Ariel Dinar, and a group of students and postdocs. That project culminated in a set of equations that predict fruit yield potential in relation to all the essential elements. I've now been retired for six years but still interact with growers through a consulting service for fertilizer management."

David provided an overview of soil health (focusing on root health) and the effects of the soil environment on shaping microbial communities and how we can use these management tools to improve fruit yields and the sustainability of our avocado production systems.

The soil characteristics that are important to root growth, tree growth and productivity are well known and form the basis for defining soil health. They also shape the composition and activity of the microbial community that lives in the soil, and which is associated with either root disease or positive root health. This shaping of the microbial community involves both positive and negative feedback loops.

Good tree growth translates into lots of carbon coming in to support this community and when the right conditions are set it runs by itself. But when things go wrong with the soil, avocados are among the most sensitive of all cultivated trees and can be killed in days when subjected to salinity, chloride toxicity and phytophthora.

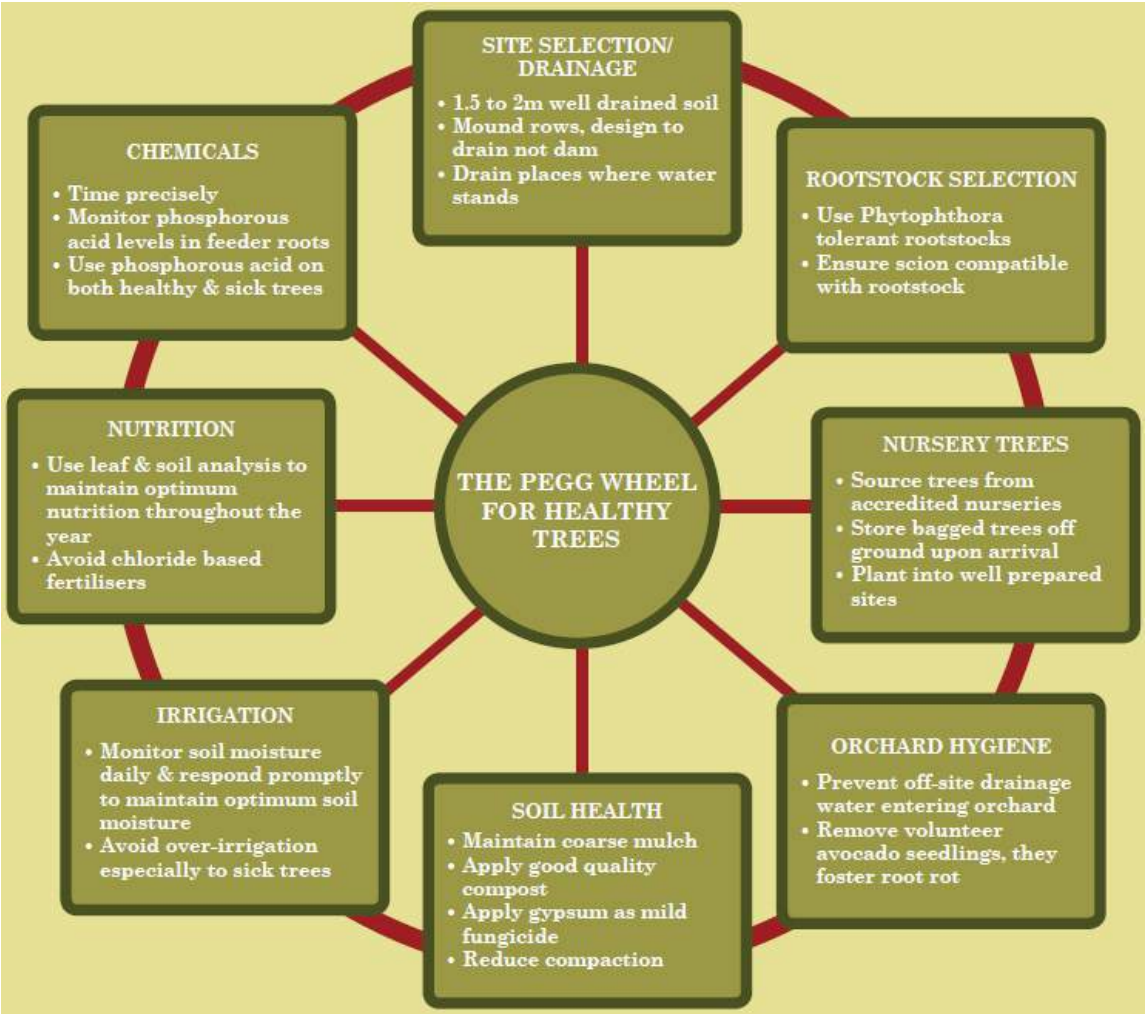
The components of soil health include chemical, physical, and biological properties that are associated with plant root health and the ability to grow and absorb nutrients.

These proprieties can be easily measured; however, we face a challenge on how to exactly measure soil biology. There are still some difficulties in trying to quantify the effects on soil biology, which rely increasingly on molecular biology techniques.

One of the challenges in adapting avocado for food production in different areas is that most environments where avocados are grown today are very different from the original locations where avocados originated. Avocados evolved in the subtropics, where you have volcanic soils that are generally acidic, shallow, and very light in texture. Bulk density is low, aeration is good and there is good porosity. Avocado adapted to this as it evolved. And this is the kind of condition that we would choose as being the most favourable for avocado production. In contrast, Southern Californian soils have very low organic matter. No matter how much organic matter you put on, it degrades very quickly, and generally heavy soils create conditions that are conducive to disease, particularly to phytophthora, but it also affects fruit growth. It's not just the disease, it's the root growth itself that's impacted.

Anything that affects the growth of the roots, also affects the microbial community that colonizes the roots. Avocados co-evolved with their own microbiomes over millions of years. The microbiome was selected for positive feedback giving the avocado tree an enhanced ability to survive and reproduce through the feedback with its microbiome.

When you have a healthy plant, you have a healthy microbiome and the two are a positive feedback loop. As a start look at the soil baseline properties – for example those shown in the Pegg Wheel which was developed to illustrate an integrated approach to manage phytophthora root rot.



Understanding and knowing your soil chemistry, soil structure and clay content is very important in managing the soil and even in selecting it. As soon as avocado are exposed to flooding, salinity, or compaction, things go downhill very quickly.

The soil should contain micro aggregates that are coalesced together, and held together by fungal hyphae, often mycorrhizal. This is what establishes the air space in soils – providing aeration and drainage. This provides a positive feedback loop for soil biology to be able to build the soil structure and inhabit within and around the soil aggregates.

Soil health control variables

There are only a few variables that can be manipulated. One can try to inoculate the soil but longer-term practices that shape the community are going to provide the quantities and types of organic matter (and total soluble organic carbon) that are desirable.

- Adjustment of pH, using elemental sulphur to lower the pH, and using lime to increase it.
- An irrigation regime that ideally maintains the perfect conditions for avocado growth all the time, with 50% soil particles, air 25% and water 25%.

Soil organic matter is the key to healthy soil

One of our first jobs in shaping the microbial community is making sure that there is an input of organic matter. This can be a challenge to maintain under high temperatures. Additional organic matter needs to be provided to achieve the level of soil microbial activity that we'd like for soil health.

Mycorrhizal symbiosis with avocado

Mycorrhizae are a fundamental part of soil and root health. High quality soil is likely to contain a good population of mycorrhizae. They help avocado trees take up nutrients and protect their health. You should never have to inoculate mycorrhizae, except possibly in a nursery situation.

Mycorrhizae are attached to the roots; they help with the transfer of nutrients from the soil to the plant. They form a structure inside the cell (called vascular mycorrhizae) and in the soil. The tree produces sugars and different exudate materials that are taken up by the hyphae inside the root cell which then transport it out to support the growth of the mycelial network in the soil. This network penetrates soil aggregates and provides a tremendous increase in the surface area for absorption of nutrients.

Most of what affects the mycorrhizal network may also affect plant health e.g. soil compaction

Soils tend to compact over time with foot traffic and machinery moving across the orchard. Aggregate structures are crushed and this negatively affects aeration and drainage in the soil.

Once you set up your orchard, you need to maintain good, loose, friable soil through the introduction of organic matter. This is where the mycorrhizal can establish and help to build the aggregates. Over time, once that mulch layer begins to build up, you have a less requirement for imports of these materials.

There's often this idea that sandy soils don’t compact and roots can penetrate through the large pores and they should have good air exchange and porosity, but there are examples of avocado roots growing in a soil that's comprised primarily of sand, and the roots reach down a couple of inches below the surface of the soil, and there they encounter compacted layers that are too hard for them to penetrate. Compacted layers of organic material can also form that are impenetrable for avocado roots and that also impede drainage and can create a perched water table. We've seen problems with phytophthora even in sandy soils that you would consider to be well aerated.

Measurement of soil resistance to root penetration

Some very simple tools can be used for monitoring the physical and chemical factors that affect the soil biome. A soil penetrometer is a very simple tool to use.

With this gauge, if you're in the yellow zone then you're in the hazard zone. If you're in the red, you're in danger. And when you get to 300 psi, you'll have zero root growth (like a root trying to penetrate concrete).

<u>Trying to keep soil bulk density low is one of the factors that you want to try to incorporate into your management plan.</u>

Phytophthora: the primary challenge to soil health in avocado

Phytophthora is a little bit different to the average fungus and is classified as something more closely related to algae. The difference is that it has cellulose in its cell walls instead of chitin, and this provides an opportunity to attack the phytophthora. By adding organic matter into the soil, you encourage the multiplication of micro-organisms that produce the enzyme **cellulase** that breaks down cellulose, and in doing so the cell walls of the phytophthora will also be attacked, thus diminishing its potential to colonize the soil.

Excessive soil moisture causes an increase in root rot. The evidence from research in Chile is that as soon as you go below 17% airfield porosity, you are encouraging phytophthora to colonize the roots.

Methods to prevent and suppress phytophthora were developed in Australia back in the eighties, with the use of organic mulches. **It was demonstrated that using compost and mulches combined with gypsum or calcium source which has a mild fungicide effect was very helpful for suppressing phytophthora root rot.** This method was referred to as the **Ashburner method**.

Growing trees on mounds with soil that's been scooped up and mixed with compost material to create a light aerated system ensures trees are off to good start. The use of a micro-sprinkler irrigation system delivers water in a very effective way to the outer zone of the root system which creates ideal conditions for soil biology and root health. Chemicals are also included in phytophthora management. One of the most unfortunate aspects of some of these chemicals is that they do have impacts on mycorrhizae.

Irrigation

One of the soil management practices that is critically important is irrigation scheduling. Irrigation scheduling requires that we don't fill up the entire volume of soil pores with water. Good irrigation uniformity is also important.

Root depth distribution water use by avocados

Probably half the roots in the avocado are within the top ten centimetres of the soil, and this is the interface between the mulch layer and the mineral soil. But in well-drained soils, you will find increasing numbers of roots at depth. You can have different rooting depths depending on rootstock, and some roots can move deeper. This illustrates the importance of maintaining good conditions for the roots to penetrate the soil and for mycorrhizal fungi activity.

Consequences of salinity

Now in California and possibly in Australia as well, salinity is one of the major issues we're seeing. Water supplies are becoming increasingly limiting for crop production in general. In California people have turned to using treated wastewater, which unfortunately often has a very high salt content, and we end up with salt accumulation in soils and accumulation of chloride as well. It's becoming increasingly necessary to leach the soil. Dealing with leaching fractions and trying to avoid hypoxia and anoxia at the same time is a really difficult task that is challenging even for the best irrigators.

Other consequences of salinity include the dispersion of soil particles, especially in clay soils where the soil particles will disperse and destroy the aggregate structure. As a consequence, you get less infiltration of water and more runoff. It becomes increasingly difficult to leach the soil as you lose soil pore space and oxygen decreases - a vicious circle.

You will also see an increase in soil erosion because the soil structure has been broken down, this leads to higher bulk densities and decreased root growth, and the possibility of anoxia increases. It is a downward spiral and **salinity is now becoming one of the top concerns after phytophthora root rot**. Dealing with this is something that we're going to have to look at for a long time - a possible management goal is using and shaping the soil microbiome to increase the resilience and tolerance of the roots to stress caused by salinity.

I**mpacts of soil management on soil biology and root health**

Soils are enormously diverse, a typical gram of soil would have 50,000 to 60,000 species of bacteria from a dozen different genera, all participating in soil function.

Microbial activity can be measured through different techniques but in general it is the composition of the microbial community that is of interest and trying to target those organisms we know are involved in growth promotion and disease suppression.

Many of the plant growth promoting bacteria have evolved with plants and they've adapted to the particular soils they are found in. On the other hand, we have disease suppression, and this can involve antibiotic production, parasitism, effects on ethylene, and competitive exclusion where those that are already in place are able to keep out new pathogens. This also has effects on efforts to try to introduce inoculates.

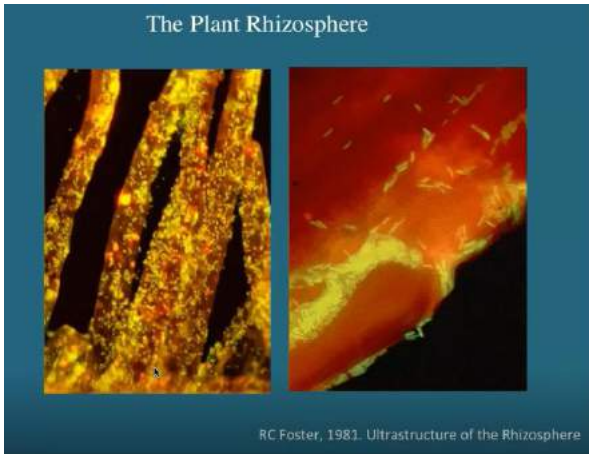
The plant rhizosphere

> *Definition of rhizosphere courtesy of Wikipedia:*
>
> *The rhizosphere is the narrow region of soil or substrate that is directly influenced by root secretions and associated soil microorganisms known as the root microbiome. Soil pores in the rhizosphere can contain many bacteria and other microorganisms that feed on sloughed-off plant cells, termed rhizodeposition, and the proteins and sugars released by roots, termed root exudates. This symbiosis leads to more complex interactions, influencing plant growth and competition for resources. Much of the nutrient cycling and disease suppression by antibiotics*

required by plants, occurs immediately adjacent to roots due to root exudates and metabolic products of symbiotic and pathogenic communities of microorganisms. The rhizosphere also provides space to produce allelochemicals to control neighbours and relatives. The rhizoplane refers to the root surface including its associated soil particles which closely interact with each other. The plant-soil feedback loop and other physical factors occurring at the plant-root soil interface are important selective pressures in communities and growth in the rhizosphere and rhizoplane.

The rhizosphere is one of the areas that's really fascinating, whereas the soil contains say 50,000 different species we only find a few genera and maybe 500 - 600 species as predominant members of the rhizosphere. In the rhizosphere, the plant is recruiting bacteria from the general soil matrix, and they grow on the rhizoplane and in between the cells where the root exudates are leaking out. They'll reach densities of a billion cells per gram of root tissue. In the laboratory, it is difficult to get cell cultures up to that same density.

The organisms in the rhizosphere have the potential to have profound effects on root growth through the chemicals that they produce in these microsite locations. Most of the active microbial growth is going to be on the new root growth behind the root tips on many plants, but in avocado, the white roots are expected to be active in exudation and this then stimulates the activity and growth of the microorganisms which produce different compounds that inhibit diseases or that improve plant growth. Some organisms are both plant growth promoters and disease suppressants.



Plants use microbial siderophores which are types of iron chelates to exclude other micro-organisms by tying up all the available iron in these chelates that only the producer organism is able to use and therefore it is able to suppress the growth of pathogens by starving them of iron.

There are a variety of mechanisms and new signalling from microorganisms in the soil that have been studied that influence plant growth. The plant growth-promoting bacteria produce auxins, cytokinins, and unknown metabolites which stimulate root growth. All these can alter root morphology. They can increase the uptake of nutrients and improve fertilizer use efficiency. Additionally, cytokinin moderates the effects of abscisic acid, the production or destruction of reactive oxygen species during drought conditions and can influence plant health.

One of the more interesting ones is the role of ACC deaminase, which is an enzyme produced by many different types of bacteria that colonize the plant root. This enzyme blocks the production of ethylene, ethylene is produced any time a plant is stressed. By suppressing the production of ethylene, roots

can continue to grow during a stress event which therefore increases the tolerance and resilience of plants.

The microorganisms that live in the avocado rhizosphere have been investigated and the types of bacteria present were mainly *Pseudomonas* and *Bacillus* species. All the isolates produce auxins. Most have some phosphate stabilization capability (phosphatases), most produce siderophores, many of them produce cyanide which is one of the tools they use against pathogens, and five of the ten pseudomonas isolates were shown to be tolerant to fairly high levels of salt.

There may be potential for some of these types of microorganisms to be inoculated and increase the tolerance of the plant. This is the idea behind some of the new efforts to modify the rhizosphere with inoculation techniques.

We know that every plant selects its own microbiome and has a different species composition in the rhizosphere. But whether or not different individual avocado rootstocks support their own individual microbiome is a good question. Having tools now to look at and characterize the variety of bacteria and their genetic capabilities are really opening the door to understanding this relationship.

Disease suppressive soil

We need to distinguish between general disease suppression and specific suppression.

General disease suppression

What we would like to see here is that the rhizosphere is so crowded (hyper-colonised) by beneficial microorganisms that nothing else can get in there, and all the carbon that is being released (as root exudates) is being consumed about as fast as it's released from the plant roots. This situation creates extreme competition and nothing else (pathogens included) can get in there and create a problem for root growth.

Because it's a collective action, it's generally non-transferable to other soils. So that means it's just a trait of that soil because you've created the best possible conditions for them to flourish.

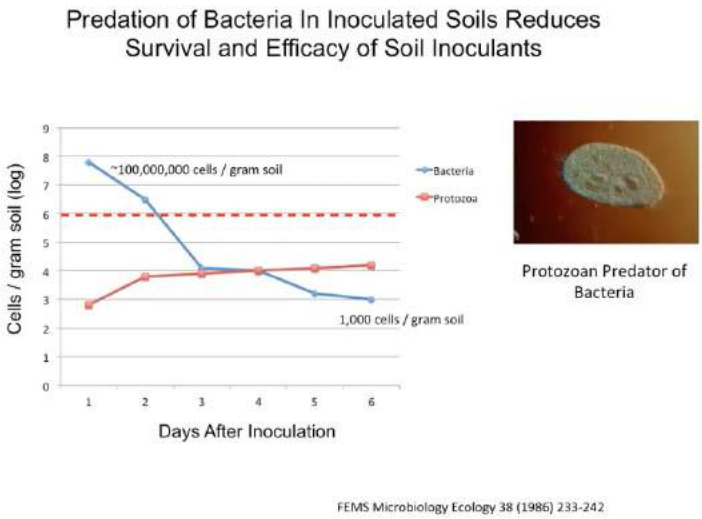
Typically, you need about 100,000 cells/gram of soil of **plant growth-promoting rhizobacteria (PGPR)** to carry out this suppression, as it falls to lower levels you end up having opportunities for pathogens to enter. PGPR are soil bacteria that colonize plant roots and can enhance plant growth.

Having good nutrition, good aeration, and all the conditions that support active growth and result in photosynthate going down to the roots to feed the biome of the root system, results in a very positive feedback loop. On the other hand, if you have poor root growth, exudation levels drop, beneficial microorganism activity goes down, then you lose that benefit. It is self-sustaining when its working and when it’s not it ‘crashes’.

Specific suppression

On the other hand, we can look at specific suppression and we are dealing there with phytophthora suppression by organisms such as *Trichoderma* spp.

There is a lot of interest now in trying to add these to the soil by inoculating them. The difficulty is that when you add them you might start with 100 million cells per gram of soil, but three days later, you will only find 10,000 cells per gram of soil, and then after six days, you're down to a thousand cells. A lot of this has to do with the activity of protozoa, cruising the soil pores and consuming these fresh cells that you’ve added like it’s a buffet table for them.



The cells that you've added have come from a laboratory medium and are not fit for survival in the extreme starvation conditions of the soil 'jungle'.

So even with the best possible processes, it's very challenging to maintain a high density of the disease-suppressive bacteria that are introduced for that purpose.

Studies have shown that soil conditions including soil pH, clay content, electrical conductivity (EC), water soluble organic carbon etc all affect soil micro-organisms (the soil microbiome) in different ways.

For specific suppression there is a lot of interest in *Trichoderma* spp, and studies show that the inoculation of *Trichoderma* spp of avocado roots infected with phytophthora resulted in a decrease in avocado plant death. This is a very exciting thing that pushes the concept of biocontrol and how we want to use these organisms and monitor them. Trichoderma is a very aggressive micro parasite that produces cellulase that will punch holes in the phytophthora, causing it to leak cytoplasm, and then it will wrap around it and consume it. It's activity peaks at pH 6.5. This is one of those fascinating stories of the microbial world. Successfully inoculating the soil is a challenge though.

Bioject system to apply microbes in the soil

The unit is a fermentation vessel in which beneficial microbes multiply to high concentrations and are injected on a daily basis into the irrigation system for distribution over the farm. In this way, the BioJect is able to consistently treat large areas while conserving valuable labour resources.

One of these units could essentially treat 50 hectares soil with pretty high densities of bacteria.

This system was tried with citrus to control *Phytophthora parasitica*. Once-a-year and once-a-week applications of *Pseudomonas putida* were compared to a pesticide (Ridomil®) as control.

The weekly applications maintained soil populations of *Pseudomonas putida* at a level that would control the pathogen. However, if you only applied it once a year then within a few months the population dropped down too low. During the two years of the study, the effect of weekly applications was pretty much equivalent to chemical control.

Biochar

Biochar received a huge amount of attention for its ability to improve soils. It's not decomposable carbon, it is pyrolyzed carbon. You can take wood pallets, agricultural waste, or anything that's organic, pyrolyze them at 400 – 450°C and end up with residual carbon (if you take the temperature up higher you get activated carbon). You can incorporate this in the soil and get carbon credits for doing this, it will last in the soil for thousands of years. Biochar has been found in South American soils where the native South Americans used it in their production systems there 5,000 years ago.

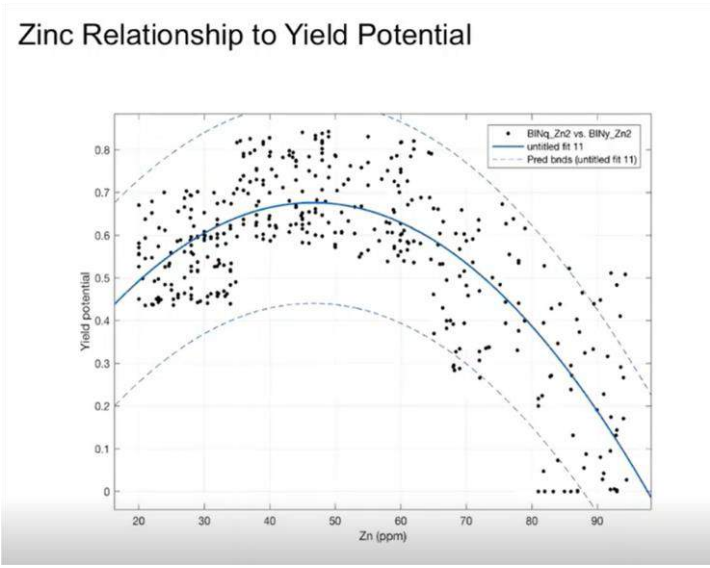
In Australia this has been looked at by Stephen Joseph's group in avocado.

Hundreds of studies have shown that biochar improves mycorrhizae. Incorporating and mixing it into the soil reduces the soil's bulk density which has positive effects for phytophthora management. Reducing the bulk density of the soil would be one of its main attributes but the matrix of the biochar itself has an ideal pore space for incorporating micro-organisms into it. This could be done through a variety of mechanisms. The pyrolysis process sterilises the material and you can introduce the beneficial bacteria, fungi and/or mycorrhizae into this matrix. The inoculants will grow in the biochar first and they can occupy the site and dominate it. It's a nice way of introducing microbes into the soil.

Probably best for biochar to be applied in combination with compost mixtures as the compost contains a naturally growing population of plant growth-promoting bacteria.

Healthy Soils: Optimisation of Avocado tree fertilisation for disease suppression and fruit yields

During the last eight years of David's program at UCR he was looking at the effects of nutrition on avocado yields and carried out a survey across southern California orchards and collected some 5,000 observations on the relationship between the elemental content of the foliage, fruit yields and potential yield. A relationship was developed for every single nutrient that is managed. A curve of the right application correlated with leaves and soil levels was developed for each nutrient. With this curve, David can determine what elements are missing and what the loss in yield potential might be.

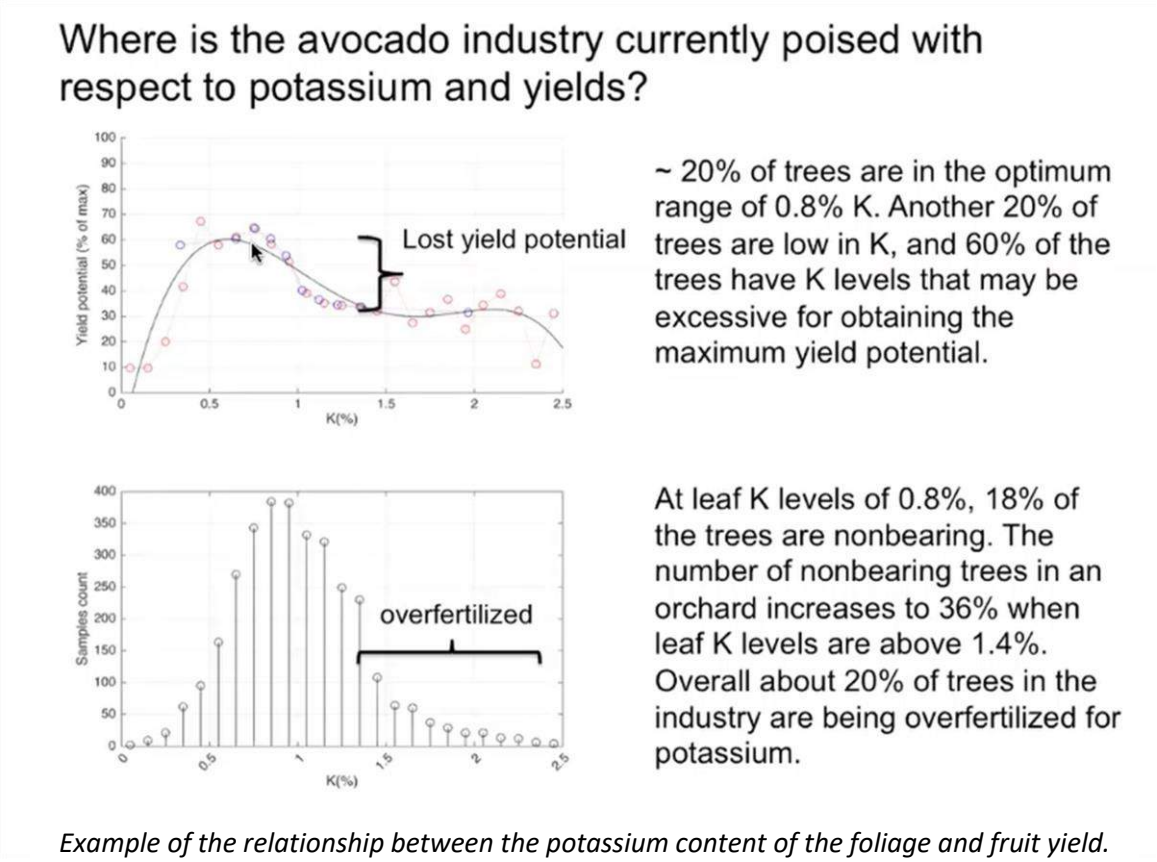


Example of the relationship between the elemental content of the foliage (in this case zinc) and fruit yield.

Zn leaf level on the x axis and yield on the y axis.

The example above shows that the optimum leaf level for zinc is about 40 to 60 ppm.

For potassium, it was shown that many orchards were being over-fertilized. Potassium was being advocated for increased production and many growers were found to be over-fertilising and were losing around 50% of their yield potential by applying potassium in excess quantities.



Example of the relationship between the potassium content of the foliage and fruit yield. K leaf level on the x axis and yield on the y axis.

This information has been developed into a service. The "Avocado support tool – yield potential calculator" is considered a valuable tool. It was developed into a service where you look at the rankings and prioritise which elements are most limiting in terms of the potential. It is a useful tool for guiding fertiliser recommendations.

Summary

Ken Pegg did an amazing job putting all these tools together in the 'Pegg Wheel' and we've talked about a lot of them today. It includes the importance of setting up a site that's well drained. Good soil health relies on maintaining mulch, using good quality compost, reducing compaction, monitoring irrigation to maintain optimum soil moisture, using leaf and soil analysis to maintain optimum nutrition and then appropriate use of chemicals for disease suppression. Altogether it's a great integrated system.

"I look at my own experience since retiring I've started brewing beer and making sourdough bread. There are huge differences in the quality of the product that you produce from that. And yet the only control variables that you have there are temperature and pH and then the type of carbon substrate that you're applying to generate your product. And I see these principles of microbial ecology anytime you are working microorganisms that if you create the right environment, things will happen in the direction that you want to go. And if you don't pay attention to detail on getting these different details right the system doesn't work so well. So I think we have a good opportunity to use these soil management practices for improving soil health." David Crowley

It makes much better sense to modify the chemical and physical environment and add organic matter than adding micro-organisms. The indigenous plant root promoting bacteria will grow and thrive. "If you build it, they'll come".

The idea of creating healthy soils by soil management practices is where we need to go.

QUESTION & ANSWER SESSION WITH DAVID CROWLEY

Question 1: I was just wondering whether inoculation may have a place when you're transplanting trees from the nursery to help reduce transplant shock, and by soil drenching by absolutely dumping into the soil with a lot of water in that transplant place.

Answer 1: Yes. The use of inoculants in the nursery situation is an absolutely great idea. This was the case with mycorrhizae. You sterilize the media and then the trees were non-mycorrhizal and you put them on a strip mine site or out into the environment and they would do so well. I saw over and over again the wonders that mycorrhizal inoculation does on adapting plants to extreme conditions and that is something that's easily done. I also think the use of biochar in a container medium can substitute completely for peat-based media and if you have an inoculated biochar with mycorrhizae and PGPR, that's the direction that many of the biotech companies are going now. They're selling bagged products for home gardeners and even houseplants where you can buy pre-inoculated materials and it really makes sense to do that. On the other hand, once your plant gets out to the site, it's going to be subjected to the indigenous microbes, and work in that area has shown that the native mycorrhizal will take over and dominate the root system, but that's because they are adapted to the environment where they've been.

Question 2: I just wanted to ask a question about sodium, which is a limiting factor for avocado production. There are some discussions here on whether measuring sodium concentrations in roots is a more sensitive tool than measuring sodium concentration in leaves. I was wondering if you got any thoughts on that?

Answer 2: Well, I would encourage that. We've included sodium in all our analysis on thousands of observations. I've never seen sodium in the leaf tissue from California samples that was a problem for avocado health. It's just not there. But I'm sure it is accumulating in the roots but we haven't looked at that. But if it is going to have an impact, it would definitely have to be in the roots and whether or not that's translocated later on, that's another factor. But we just don't see it in the leaves. So yes, I think it'd be a good idea to study that in roots.

Question 3: I was just wondering, what's your opinion on reducing soil compaction from the top down after it's already occurred in an old orchard using organic matter or bacteria and fungi and how long it would roughly take.

Answer 3: I say it is possible mainly through the activity of soil animals, earthworms, beetles, things that move through the soil that are loosening the soil structure up. Also, you have root growth that leaves root channels. So over time, the soil can become looser as the soil aggregates develop porosity. I'm sure there's things going on underneath the soil, but it's probably a slow process. But I would think that especially if you are, say, to introduce earthworms into the system or encourage earthworm activity through organic amendments, that would be one way of loosening the soil. I'm not aware of any studies yet that have tried that, but that's what I have to look up.

Question 4: Do you want to talk briefly about the service you offer, I know this is not a commercial thing, but I'm interested in that nutrition process that you have developed.

Answer 4: What I would encourage - there is a group of growers from Southern California that initiated the 'Avocado café' talks online, and they invited me to speak back in April. And there's an hour-long talk about the development, the method, how we went about it, and the results for each of the individual elements. And so based on that talk, you can largely go ahead and do this for yourself. You can look at the individual graphs and see the changes in yield potential for each of the elements. And then what I do is put the equations into an Excel spreadsheet and, and then macro that will sort them according to what are the most limiting yield potential factors and then play that out to the advice or provide some guidance on what I would suggest, the type of material on which to correct first or some detailed information in particular. If someone wanted to send leaf analysis data, I'd be glad to look at it and run the analysis for you or if you want to learn more about the method, go to this YouTube site (https://www.youtube.com/watch?v=k0ZlkNE3LQ0) and it'll give you the most complete seminar on that topic. I'm pretty proud of that work. That was really, I think, a major contribution to figuring out what really optimizes fruit yield potential. It can also be found under 'Avocado café' in www.avocadosource.com.

Question 5: I'd like a few more of those graphs on each individual element. I've got a fair few leaf analysis results I'd like to put into that.

Answer 5: This all based on leaf analysis. But yes, looking at the soil analysis, you can determine that there's something else involved, e.g. a pH problem. You need both soil and leaves in order to make a full interpretation. But the leaf analysis guides you about what's missing and where to further investigate. But again, that YouTube video, I march right through every element, and you should be able to 'frame capture' (screen shot) and print those out.

Question 6: Can I just ask David's opinion on leaf analysis frequency and also maybe comment on soil analysis frequency and whether he has an opinion or a suggestion as to what might be a good idea.

Answer 6: The leaf analysis is calibrated to a particular time of the year because the nutrients in the leaf tissue will vary depending on growth stage and time of year. So, everything in California was geared towards the leaf analysis being conducted in late September, October, when the nutrient levels are stable *(autumn, so April/May for Australia)*.

Salvatore Campisi a post doc who worked for me on this and did a lot of the data analysis, also developed a method for looking at flowers and looked at the ability of the flowers to predict nutrient deficiencies. I do think that we need other tools that look at different times of the year in order to make these corrections because in September-October you're wondering, well, was it last year's that affected yield or is this going to predict yields for next year? But I think the more information, more

time that we have where we can look at these nutrient deficiencies or excesses that will really help us. There's a paper on this in HortScience which can be accessed here:

> *Optimal Nutrient Concentration Ranges of 'Hass' Avocado Cauliflower Stage Inflorescences—Potential Diagnostic Tool to Optimize Tree Nutrient Status and Increase Yield (avocadosource.com)*
>
> *Campisi-Pinto, S., Zheng, Y., Rolshausen, P., Crowley, D., Faber, B., Bender, G., Bianchi, M., Khuong, T. and Lovatt, C. (2017). Optimal nutrient concentration ranges of 'Hass' avocado cauliflower stage inflorescences – potential diagnostic tool to optimise tree nutrient status and increase yield. HortScience 52 (12): 1707- 1715*

Question 7: David, have you done any work on calcium uptake?

Answer 7: No. The only thing I know is that gypsum is 300 times more soluble than lime. And so when we're looking at calcium recommendations, the gypsum is what we recommend as the fertiliser to apply. Unless you're doing a pH adjustment. But no, I haven't studied calcium uptake.

QUESTIONS FROM LISTENERS OF THE WEBINAR ANSWERED BY DR DAVID CROWLEY AFTER THE SUMMIT

1. DOES PRE-PLANT DEEP RIPPING OF CLAY SOIL CONTRIBUTE TO SOIL HEALTH?

Yes, soil aeration and avoidance of waterlogging is essential for root health. Avocado trees are highly susceptible to hypoxia and anoxia, which results in poor root growth in compacted, poorly drained soils, and root death following even short periods (48 hours) of soil waterlogging. Trees subjected to flooding have lower vigor and decreased resistance to Phytophthora root rot. Preplant ripping increases soil porosity and facilitates drainage. There are many reports on the benefits of soil ripping for increasing soil aeration and drainage prior to planting. A few are provided below.

Use of Soil Ripping to Improve Root Health for New Avocado Groves

https://www2.ipm.ucanr.edu/agriculture/avocado/Phytophthora-root-rot/

https://www.goodfruit.com/six-steps-to-good-orchard-site-preparation/

General recommendations and methods for deep ripping to reduce soil compaction

https://www.agric.wa.gov.au/soil-compaction/deep-ripping-soil-compaction

Site preparation with soil ripping and biochar amendments

Science of the Total Environment 724 (2020) 138153

https://aqua-sil.info/images/Agriculture/Fertilisers_Adjuvants/Fertilisers/Biochar_increases_soil_organic_carbon_avocado_yields_and_economic_return_over_4_years_of_cultivation.pdf

Improvement of Soil Drainage using Hydraulic Soil Fracturing

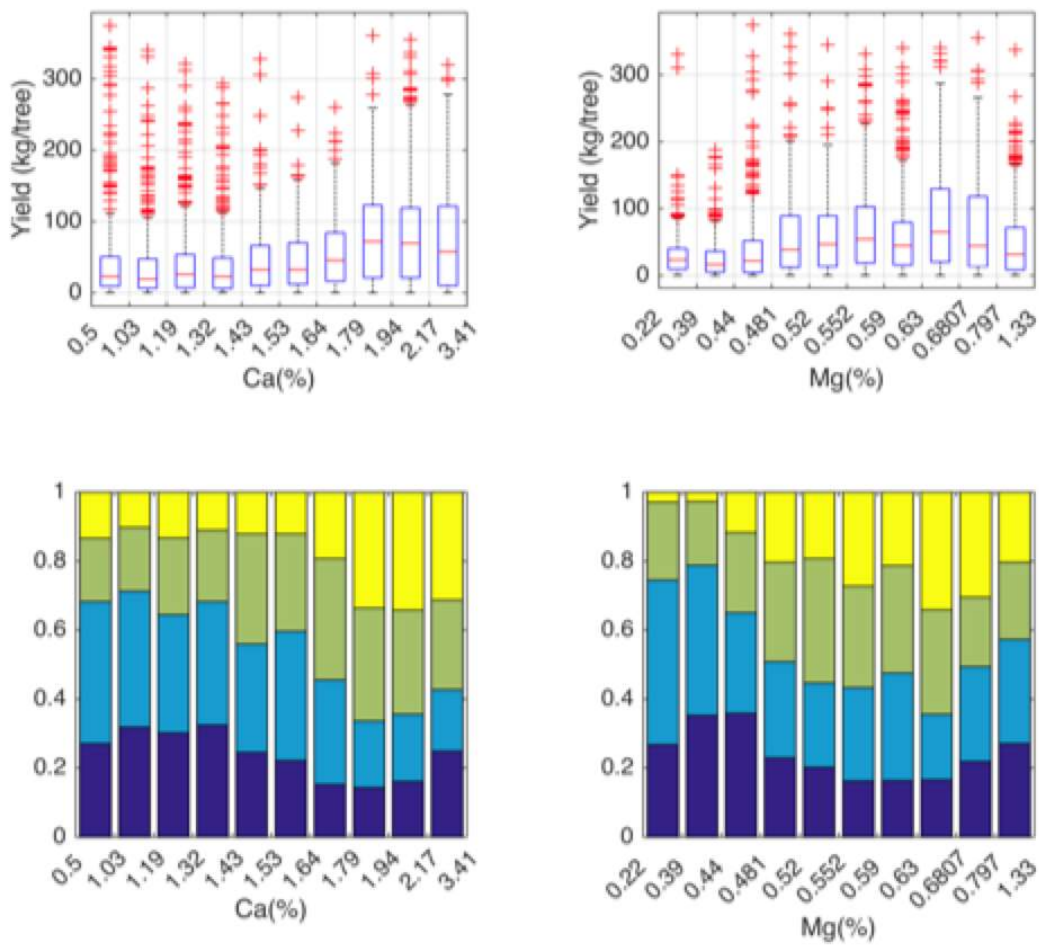
https://www.basscoastlandcare.org.au/uploads/8/9/8/3/89835233/demonstrating_soil_fracturing_for_the_improvement_of_drainage_in_avocados_.pdf

2. MORE INFORMATION ON OPTIMIZATION OF TREE NUTRITION FOR AVOCADO YIELDS, ESPECIALLY FOR CALCIUM?

An online presentation of Dr. Crowley's research on avocado tree nutrition is available at: https://www.youtube.com/watch?v=k0ZlkNE3LQ0

Specific information on calcium and magnesium is presented below:

Figure 4. Optimization of avocado yield potential with respect to leaf calcium and magnesium concentrations.



Top: Fruit yields per tree are summarized for trees grouped in categories corresponding to their leaf tissue Ca and Mg concentrations. Bottom: Proportion (%) of trees in different yield categories, yellow bars are trees producing at 90% of maximum yield potential, green bars, trees producing at 10-90% of yield potential, light blue bars, trees producing at <10% yield potential, dark blue bars, nonbearing trees (<10 kg/tree).

With respect to Ca, the highest yielding trees have leaf tissue concentrations ranging from 2.0-3.4% Ca. However, as shown in the lower figure for Ca, the proportion of low yielding and nonbearing trees increases when leaf Ca levels increase above 2.2%. Thirty five percent of the trees in the study were low or non-bearing at low levels of 1.4% Ca. The number of trees in the low yield group decreased by half from 35% to 18% for trees having 1.6 to 1.94% Ca. Above 2% Ca, the number the number of non-bearing trees increased from 18 to 25%. Thus, the summary mathematical model shows that a leaf

calcium target of 2.0 - 2.4% is optimal for maximum fruit yield potentials when summarized across all the fruit yield categories.

A nearly identical nutrient response pattern is observed for magnesium, with optimum magnesium levels targeted at 0.6 – 0.68%.

In general, it appears that growers in California are under-fertilizing for both calcium and magnesium. As shown in the figures below, the average leaf calcium level for trees in the commercial groves we sampled is poised at 1.4% Ca (red line). Remarkably, the yield potential more than doubles from 80 kg at 1% Ca to190 kg for trees at 2.2% Ca. Magnesium deficiencies are also likely for approximately 1/3 of the trees in our trial that have leaf Mg concentrations below 0.4%. In this case, yield potential for the top performing trees increases from 90 kg to 250 kg per tree as Mg levels increase from 0.4 to 0.68 % Mg. This value for Mg agrees with that recommended for achieving the greatest number of on-cycle trees, which occurred for trees having 0.6 to 0.68% Mg (see Fig 4).

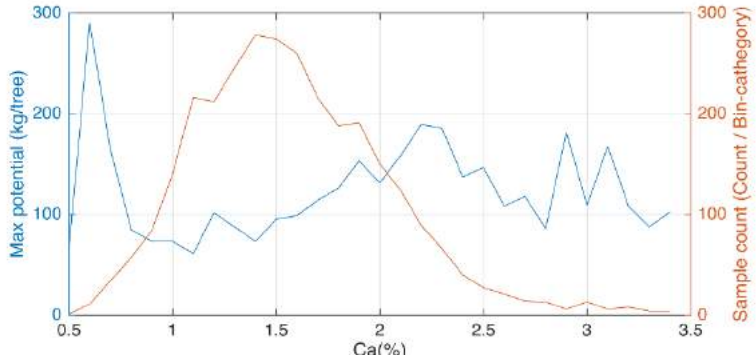


Figure 5A. Calcium response curve for the top 5% producing trees (blue line) versus the frequency of individual trees having different levels of Ca (red line). Data suggest that the industry is poised too low on Ca.

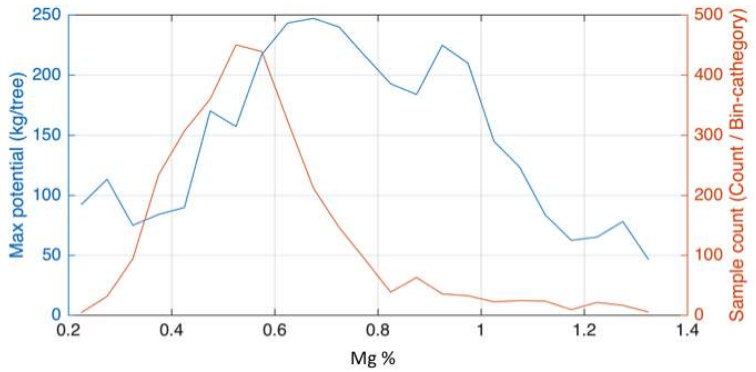


Figure 5B. Magnesium response curve for the top 5% producing trees (blue line) versus the frequency for all trees having different levels of Mg (red line).

3. GENERAL READING ON SOIL HEALTH AND AVOCADOS

California Avocado Commission web site on cultural management:

https://www.californiaavocadogrowers.com/sites/default/files/Avocado-Root-Health.pdf

General review of soil chemical and physical properties related to tree growth and fertilization:

http://www.avocadosource.com/cas_yearbooks/cas_90_2007/cas_2007_v90_pg_107-130.pdf

Powerpoint presentation on avocado fertilization and root health

https://www.avocado.org.au/wp-content/uploads/2017/01/SGM-CQ-5-Nutrition-overview-PPT.pdf

DISCUSSION BY DELEGATES ABOUT DAVID CROWLEY'S PRESENTATION

- David's presentation reinforced a lot of what was said yesterday. In particular, that broad application of microbiology to the orchard is probably a big waste of time. And to get more better results one needs to use the bioreactor to keep applying the micro-organisms repeatedly on a regular basis. However, the company went broke, and it looked like a pretty expensive facility to have in your garage.
- What is the amount of nitrogen applied to avoid the negative effect in the microbes?
- David showed that the bacterial populations introduced in the soil went down over six weeks as the protozoa were eating them, the soil has a complex ecological system with plenty of other organisms. In this way, it is better to improve the soil to simulate better growing conditions rather than introducing the microbes.
- Regarding the microbial pumping (bio injecting), it is inconclusive if it was actually doing anything. It's not easy to grow microbial cultures on a large scale in case of contamination. And there's this whole issue with introducing it in the soil and also the soil condition.
- The biochar is more about conditioning the soil and providing the microbes somewhere to live.
- Maybe you use it in a way to structure the soil to create air spaces, especially in a transplant situation, but it doesn't have anything to do with the organic carbon/organic matter levels.
- The experiment presented tends to be indicating that biochar is good for encouraging mycorrhizal that are already there. But Liz has some reservations about that paper, as the control was only one row, and the treated trees were in the outside row.
- Tony mentioned that you have to be careful with biochar, as he has done a trial where it actually tied up nitrogen and plants grew worse. So, before you use it on a big scale in your whole orchard, test it on a small area first.
- We have growers putting out humic acid and fulvic acid. Is there any benefit, or are they wasting their time? If you've got a reasonable layer of humus, there's enough there and you probably don`t need extra. It's when you have low organic matter in the soil that it might help, that's when people want to put it on (as a shortcut), but it is not a long-term solution. Applying mulch and or compost must surely add much more carbon and also start the decomposition process that supports greater numbers and diversity of soil organisms.
- It's like having a sugar diet compared to something with complex carbohydrates. And that all gets broken down into glucose at the end of it.
- David's mentioned how important mycorrhizae are. Adding cover crops to stimulate growth might be something useful.

Delegate's experiences on strategies and tools used to improve soil health

- When I go from an old to a new orchard, I try to break the cycle. I give the paddock two years of rest (fallow). I was trying to come to some sort of cost-benefit, the financial benefit of putting those trees back in the soil so it can offset that cost a little bit (because currently I burn them), if I could afford it, I would definitely mulch them in.

Do you use any tool to measure soil moisture?

- Yes, using remote stations
- I think the Australian growers are ahead of the Californian growers

Other comments

- Organic matter is crucial
- We need to encourage the beneficial microbe populations that are already there in the soil.
- We should stop replacing the good practices with silver bullets.

WISH LIST FOR RESEARCH

Avocado core microbiome:

- Establish core microbiome of avocado (verify if there is a difference due to the region or rootstock)
- Core microbiome for avocados – related to promoting beneficial microbial interactions

Fertilization

- Determine the upper threshold of nitrogen rates for synthetic fertiliser that don't have a detrimental effect on soil biology
- Level of other nutrients that impact the soil microbiome

Plant-soil relationships

- Understanding the root hyphae network and signalling pathways

Soil health testing

- Trustworthy testing labs/ facilities
- What is the best microbial testing? Is there any point in doing it?
- Development of a test that growers can use to evaluate the impact to soil health related of different practices e.g. application of herbicides (Basta® and Roundup®)
- An analysis and report on the large range of 'soil conditioners' that are on the market
- Understand how to analyse sodium and chloride correctly (soil, leaves, and roots analysis)

Practices

- Soil biology related to cover crops - companion plants that promote avocado-friendly microbes
- Try to determine good and bad mulches for bacterial/fungal dominance
- Soil conditioners: what is good for promoting microbes/what are good food sources for microbes
- The effect of pre-emergent herbicides and herbicides on soil, micro-organisms, and root health
- More studies about salinity and how to manage saline soils

EXTENSION IDEAS FOR DISSEMINATING `BEST PRACTICES`

Information to be disseminated:

- About mulch (what to use, what's available) Mulching avocados (video) and 'farming in the interrow' (e.g. the need to use mixed species)
- Minimum guidelines - e.g. compost rates, testing the adequate rate
- Explain that some products are supposed to be used at the start of the process and are not quick solutions for an unhealthy soil
- Better benchmarking: how to deal with complexity and uncertainty

Ways to disseminate the information:

- Fact sheets – summarised information - hand out some printed copies (e.g. produced from information in the lit. review and the rest of the review (SJ recommends hard copies – articles from the review in 'Talking Avocados' magazine).
- 'Talking Avocados' articles
- Video of case studies – growers see outcomes and yield with the improvement of practices such as mulching, soil moisture probes use
- Cost-benefit studies – visual marketing concept (before and after)
- Best practices of all areas – production system approach cost benefit
- Field days that are topic focussed and easy to digest - focus on key messages
- Growers-teaching-growers – perspective
- Surveys are a great way to collect information and it is good to receive the results of the survey back with the summary of all results – use to benchmark your practices against the industry
- Field days - promote understanding, peer group interaction, and sharing information
- Better dissemination of the information, simplest information possible
- YouTube videos maybe

New ideas:

- Demonstration trials (ED – regarding demonstration trials – you need to have a contract with the collaborating grower with conditions spelled out – have the trial replicated in different regions)
- Podcasts – access through the BPR (quite a bit of interest in podcasts – 45 to 60 mins long – they need to be downloadable because of connectivity issues in some areas).
- Before and after examples

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