Directions for research in the certified organic management of *Phytophthora cinnamomi* in avocados

Report written for New Zealand Organic Avocado Growers (NZOAG)

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Dr Charles N Merfield

The BHU Future Farming Centre

Permanent Agriculture and Horticulture Science and Extension

www.bhu.org.nz/future-farming-centre

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2. Introduction

This report was compiled at the request of the NZ Organic Avocado Growers Inc. (NZOAGI) who requested a written report based on the brief “Directions for research in the certified organic management of *Phytophthora* in avocados”.

This report follows directly on from the preceding, quick overview, report ‘Initial findings from the literature on management of *Phytophthora* cinnamomi in organic avocado orchards’ which recommended that this report focus on surface biological / organic mulches, both living and dead, and biocontrol (biological control) agents. Feedback was requested from NZOAGI members on the report. The feedback, was wide ranging, and in general supported the recommendations in the overview report and also made some additional suggestions of ideas worth considering.

This report is a blend of explanation of the particular research area as well as recommendations, with the aim of providing sufficient background information to help the reader understand the suggestions made.

While this is a more extensive report than the overview, it is not a full in-depth study and synthesis of the literature as this could take weeks to months to complete as there are thousands of original research papers on *Phytophthora cinnamomi*. If the recommendations of research areas are taken up it is suggested that a more in-depth review of the primary research literature relating to the specific research areas be undertaken as part of the new research to fully inform the design of experiments. Alternatively a *Phytophthora*, or more preferably a *Phytophthora cinnamomi* avocado expert / specialist with organic agricultural experience is engaged in an overview role as the accumulated experience and wisdom (both book and especially practical) of such individuals is exceptionally valuable and often much more cost effective than funding researchers new to a topic to get up to speed via extensive literature reading.

3. Overview

Phytophthora cinnamomi (Pc) is a major, world-wide, disease of a large number of plant species, from exotic crops to native species in natural habitats. A very considerable amount of effort, from both producers and scientists has therefore been spent, over many decades, on finding ways to control and/or manage the disease in a wide range of situations. This includes countries such as Australia, the USA (especially California) and Europe, where many millions, probably billions have been spent over the years. It is therefore clear that there is **no** silver bullet, even using agri-chemical fungicides, and that an integrated solution that uses a collection of management techniques, from soil husbandry through to interventions with biocontrol agents, must be used, and these at best can manage the disease to sufficiently low levels so that good production can be maintained, if used on an ongoing basis, but not eliminate it.

3.1. Integrated management

Unlike many diseases where interventional techniques, such as fungicides both non-organic and organic approved, can make up for sub-standard basic production requirements (e.g., soil health, soil nutrient levels, pruning, irrigation, etc.) management of Pc where the basics have not been achieved, is impossible. These basics are now very well established, both from research and extensive practical grower experience, in many countries, i.e. many soil climate / combinations over decades. While this report focuses on outlining and recommending areas for further research, it is worth repeating the key IPM techniques that must be in place for the more specific / interventional techniques reviewed in this report to be able to work.

3.1.1. Avoidance!

As Pc is an introduced (exotic) disease the best defence is prevention, i.e. don't grow avocados in soil infested with Pc, and to implement very strict phytosanitary controls to prevent infestation of uninfected avocado orchards. However, once an orchard is infested and trees infected, elimination is probably practically impossible, even if it is theoretically possible at considerable cost and effort (e.g., total and deep soil fumigation / thermal pasteurisation). Under the requirements of organic standards elimination would be even harder and is probably impossible.

3.1.2. Soil and water management

Pc is principally a disease of avocado roots, and it is dramatically affected by soil conditions. Of these drainage / water management are by far the most critical.

3.1.2.1. Soil moisture / irrigation

Soil moisture must be in the 'Goldilocks zone' i.e. not to wet, not too dry. Irrigation must be determined by measuring, not estimating, soil moisture in the rooting zone. Rainfall, excess to tree requirements must be able to drain out of the soil as fast as possible. First and foremost this requires first rate soil quality, particularly soil structure and minimal compaction. On soils of less than optimum natural drainage, e.g., clays, soils with natural pans, etc., artificial drainage through use of drains and/or mounds, will almost certainly be essential.

3.1.2.2. Soil structure / mulching

Good soil quality / structure can **only** be achieved by biological means, i.e. a continual supply of organic (biological) materials, e.g., wood chips, compost, green manures, animal manures, to the soil surface, i.e. a mulch. Non biological / mechanical means, e.g., subsoiling, compressed air soil shattering, can only help speed up the repair of damaged soils, not create a healthy soil.

3.1.2.3. Soil / plant nutrients

Soil nutrients that are not at optimum levels for avocados, i.e. are deficient, are in excess, or where the ratios of specific nutrients are out of 'balance', can and do significantly exacerbate Pc. There are known specific nutrient requirements for avocados, that are best checked using both soil and leaf testing to make sure that the soil nutrients are being taken up as expected. There are also nutrients that have a direct inhibitory effect on Pc, e.g., calcium, or exacerbational effect, e.g., ammonium nitrogen, that need to be taken into consideration when planning fertilisation programmes. The use of organic / biological fertilisers, e.g., compost, fish, can complicate nutrient management, as the nutrient profile of the organic fertiliser, may not match what the crop needs (e.g., seaweeds are often high in potassium and low in phosphorous and nitrogen), which means then can create nutrient imbalances. Specialist advice is recommended and it must not be assumed that because organic / biological fertilisers are being used that soil nutrients will be at optimum levels as highly unbalanced and excessive soil nutrients status can be crated through incorrect use of such materials, including compost.

3.1.3. Rootstocks

Use resistant rootstocks for new plantings where possible. However, even resistant rootstocks will fail where soil conditions are too sub-optimal.

4. Biocontrol

Biocontrol of Pc has been the "great white hope" of the avocado and other Pc affected industries and native species since the discovery of disease suppressive soils in the 1970s. However, biological control is a lot harder in practice than in theory and there is still no silver bullet solution, despite the many millions of dollars spent, in many countries, by many scientists, some who have spent their whole working lives on the problem. The review by Keen and Vancov (2010), gives a good summary and overview of suppressive soils and the problems with extracting biological control agents from them. The following summaries the issue and their paper.

4.1. Suppressive soils and biocontrol agents: hunting snarks?

A key issue is whether the suppressive nature of the soil is 'general' or 'specific'. Specific means that there is one, or a handful, of organisms (normally microbes) in the soil that are responsible for the control of Pc due to direct interactions between the biocontrol agent (BCA) and Pc, i.e., the BCA attacks and kills Pc. Generally suppressive soils are those where the effect is due to many soil organisms interacting with Pc in many ways, e.g., competing for food, space, parasitism etc., that result in reduced populations and/or reduced impact of Pc. In addition, physical soil properties e.g., moisture and nutrient levels, also have both positive and negative effects on Pc and BCAs. Research has unambiguously shown that the suppressive effects of many soils are biological, not just physical. However, it appears than in many, if not most cases, Pc suppressive soils are generally, not specifically, suppressive, i.e. the effect is not due to just one, or a handful of organisms, but to many organisms and with physical conditions also having a critical part to play. This is not to say that individual organisms have not been shown to have significant beneficial effects against Pc, but rather, the effects of the many are greater than the few. This means the hunt for a single BCA to control Pc from suppressive soils, will in most cases fail, because for anyone suppressive soil, the odds are that the suppression is general, not specific, and therefore there is no single BCA in the soil to be found: i.e., it is something of a snark hunt.

In addition changes to physical conditions can change a biologically suppressive soil into a disease conducive soil. This further reduces the chances of finding the BCA silver bullet, as it shows that an effective BCA can be rendered ineffective if environmental conditions are unfavourable.

Even where the suppressive nature of the soil may be due to a single or a few organisms, the notorious difficulty of growing most (e.g., 95% or more) of soil microbes in the laboratory (i.e. they cannot be grown outside of the soil) means (on average) that most of the potential BCAs in any given soil probably cannot be cultured, and therefore cannot be turned into a control agent. While new identification techniques based on DNA and related analysis, mean that the majority of soil organisms can now at least be identified in some way (e.g., by their proteins), if they cannot be cultured, they cannot be manufactured and cannot therefore made into a BCA. In addition, of those species that can be cultured, many are difficult to culture, and scaling up laboratory techniques to mass-production can be many times harder than the initial effort to culture an organism in the lab. This means only a few percent of the possible BCAs in a suppressive soil can be identified, only a few percent of those can be cultured, and a few percent of those can be manufactured. This is why, while there may well be billions of species of microbes in soil, most of which are benign or beneficial (i.e., very few are pathogens) there are only about 60 microbial BCA agents for sale globally.

In addition most BCA's are targeted at above ground / aerial plant pathogens, as these are much easier to control due to: (1) easy and direct access to the infect plant tissues, (2) the amount of microbes on plants is small compared with the amounts of BCA's that can be applied, i.e., the BCAs can swamp existing microbe communities; while soil borne pathogens are much harder, as (1) the soil prevents direct application to plant tissues, (2) the amount and diversity of microbes in the soil is vast, e.g., tonnes per ha, compared with on plants, therefore unless BCAs are applied in huge quantities, e.g., 100s tonnes per ha, they can not swamp soil microbe communities, and therefore have to compete in the existing ecosystems as newcomers - a notoriously difficult task.

Despite this very significant difficulty, the potential offered by BCAs lead Keen and Vancov (2010) to conclude with the recommendation that despite the limited success to date, the continued study of suppressive soils, using up to date molecular techniques, is vital for the long term management of Pc as biocontrol, along with resistant rootstocks, are the two best options for long term management of Pc as resistance to the main chemical fungicides is a demonstrated possibility and the general public is becoming more hostile to agri-chemicals therefore alternatives to agri-chemicals will be needed sooner or later.

4.2. Suggested research

As the above indicates, locating a BCA from a suppressive soil and getting it to market in a grower useable form is huge exercise, e.g., a 10 to 15 year programme, with costs tens of millions of dollars. This clearly is not a good fit for NZOAGI as it is looking for research with a rapid outcome and considerably less cost. This may be something that could be considered to undertake with the New Zealand Avocado Growers Association (NZAGA) and possibly other crops that suffer from Pc.

The alternative is to look at BCAs that are already on the market, ideally in NZ and/or overseas that have or indicate potential for Pc management and trial those in a commercial orchard setting, ideally multiple orchards. The advantages are, that commercial products are already available, so if they do produce a result, then they can be used immediately if they have NZ licences, or if an NZ licence is required, a lot less work will need to be done compared with a completely novel organisms. The product owners are also likely to be interested in supporting research as it may create a new market for them, especially larger avocado producing areas overseas and non-avocado crops. Such support would reduce costs and increasing funding leverage. Most BCA companies can also supply technical expertise and assist with laboratory analysis tracking their BCA in the plant / soil system.

4.2.1. BCAs to consider for testing

A number of possible BCAs have been identified from the literature and personal contacts in industry and the research sector.

Agrimm Technologies Ltd. www.tricho.com were formed to commercialise Trichoderma BCAs produced by researchers at Lincoln University. Many of the key scientists behind that work, including the lead researcher Prof. Alison Stewart, are now part of the Bio-Protection Research Centre, which is a national Centre of Research Excellence, based at Lincoln University specialising in biological control of microbial plant pathogens. David Gale, the co-founder and Managing Director of Agrimm believes that there is potential for their products to have an effect, mostly as a ‘plant tonic’ rather than by directly killing Pc.

His belief is supported by the scientific literature and it goes further in that it shows that Trichoderma spp. have the potential to parasitise and otherwise directly harm Pc, rather than just being a plant tonic. At the same time Trichoderma are an evolutionary complex genus, and below the species level, there are a multitude of ‘strains’ which vary widely in their behaviour, i.e., one strain can be a very good BCA and the next can itself be a pest. So, just because a particular Trichoderma strain / product is a good BCA for one crop / pest or it did well in one research paper, does not mean that it will also be a good BCA for other crop / pest combinations, even for the same pest, i.e., every Trichoderma strain has to be tested for the specific climate / crop / soil combination of interest to see if it is effective.

Continuing with Trichoderma, Prof. Enrique Monte, from www.usal.es identified a Trichoderma strain specifically for Pc control on Avocados (Monte & Llobell, 2003) which has been commercialised by Newbiotechnic in Seville, Spain, www.nbt.es as ‘TUSAL’ which has been registered as biofungicide both in Spain and the EU. This should be a particularly promising BCA as it has been developed for control of Pc on avocado, but, getting the product into NZ may face phytosanitary problems, and if effective, licensing issues will need to be addressed.

Prof Alison Stewart has suggested Serenade (*Bacillus subtilis*) produced by AgraQuest www.agraquest.com and sold in NZ by BASF www.agro.basf.co.nz and Sonata (*Bacillus pumilus*) also produced by AgraQuest as possible good bets. There are some recent soil formulations only available in the USA that may be better bets than the current NZ retail formulations.

She also noted that Biostart www.bio-start.co.nz have made some claims for *Phytophthora* control with their product Mycorrcin though data are scant. This is probably a longer shot.

From a compilation of the 60 odd commercial BCAs available globally:

- EcoGuard (*Bacillus licheniformis* SB3086) is claimed to be effective against *Phytophthora drechsleri* among a range of fungal pests;
- Mycostop (*Streptomyces griseoviridis* K61) is claimed to be effective against *Phytophthora* spp and other fungi;
- Companion (*Bacillus subtilis* GB03, other *B. subtilis*, *B. licheniformis*, *B. megaterium*) is claimed to be effective against *Phytophthora* spp and other fungi; and
- Binab TF (*Trichoderma harzianum* ATCC 20476 and *Trichoderma polysporum* ATCC 20475) is claimed to be effective against *Phytophthora* spp and other fungi.

All of these are very long shots, as while they are generalist BCAs there is a greater chance they will fail to manage Pc on avocados, especially as they will need to be applied to the soil, and none are understood to be available in NZ, though this needs to be checked with the manufacturers.

Effective Microorganisms (EM) www.naturefarm.co.nz is a mixture of a range of beneficial microbes, including species such as *Trichoderma* and *Bacillus*, that were initially extracted from compost and natural forest soils in Japan, where the concept originated. There are now a large number of EM products, but the two key ones are the original liquid formulation and one where the liquid is added to a high carbon substrate, e.g., rice bran, and then fermented. Its proponents make a very considerable number of claims for the products, but the amount of independent peer-reviewed research on these claims is very small, and mostly negative in its conclusions. However, there is one independent report, (Aryantha & Guest, 1997) that indicates that EM has potential to control Pc. So, while the general scientific conclusions on EM are not positive, they do acknowledge there are no good reasons why it should not work, only that it is unlikely to work. However, unlike other commercial BCAs EM has been promoted by philanthropic organisations as a beneficial tool for all of agriculture. It is therefore relatively inexpensive compared with other BCAs produced with a profit motive. If it does prove to be effective, then it will probably be one of the cheaper options in the long term.

Some or all of the above BCAs should be considered for testing. However, some of the commercial products are not available in NZ and obtaining these materials and the necessary permits from the NZ government could take some time. There can also be a multitude of different ways to use a product, e.g., Agrimm has suggested dowel trunk treatments along with soil applications, which means that the number of possible BAC × treatment methods combinations rapidly balloons making experiments unwieldy, if not completely impractical within a commercial orchard setting. This is particularly pertinent, because the effectiveness of the BCAs is expected to vary widely as their effects can be strongly affected by orchard conditions, such as soil conditions, irrigation practices, root stocks, etc., for example previous research testing the same BCA and mulch on two orchards got completely contrary results from the two sites. Multiple sites are therefore considered essential for BCA testing.

In addition, the effects of BCAs and changes to other management practices, e.g., mulches, can and mostly do, take several years to have a clear effect, with short term results (1-3 years) differing from long term (3-6 years) effects. This all suggests that a maximum of about five of the best bet products, should be selected for testing, to keep things manageable, and they need to be tested over several years.

5. Mulches

In organic agriculture nutrient management and use of mulches are utterly intertwined, because of the use of organic matter, e.g., compost, manure, as both a nutrient source and supply of soil organic matter (i.e., in non-organic agriculture nutrients are supplied in mineral form and organic mulches are mostly for building soil organic matter). This means that many of the recommendations from non-organic research work may be of lower or no relevance due to the wider range of mineral, especially soluble fertilisers (particularly nitrogen fertilisers) that non-organic agriculture is permitted to use. This means that the whole topic of mulches in organic production has limited directly relevant research. However, the benefits of organic (biological) mulches for avocado production and especially Pc management is now unambiguous and is standard practice around the world. But, what makes an ideal mulch is still debated and probably still some way from being settled.

While there have been a considerable number of trials of mulches, both comparing them against bare soil and among different types of mulches, most experiments are of limited use because they don't run for long enough, e.g., greater than five years and/or they are wholly empirical. To explain:

The rule of thumb is that with any change in soil management practices (e.g., changing from mineral to organic fertilisers, from tillage to no-till, from no-mulch to mulch) it takes about five years for the soil to change from the old state and settle down to the new regime. Some very long term experiments find a changes in management practices can still be working their way through the soil after 50 years! Therefore the first five years results / effects of a new management practice may have little or no similarity with the next five years.

Within agricultural science empirical has a special meaning beyond its normal meaning in science: it refers to research where the knowledge only comes from the results of experiments and lacks any form of underlying explanation of the causal effects that produced the result, i.e., a theory or model. This is sometimes referred to as stamp collecting - i.e., amassing lots of data, but with no way of explaining what the data means. In some situations, for example comparing different crop cultivars, this is not a problem, as the underlying complexity is so vast, i.e., causal connections are so many, that elucidating them is impossible, and a big data set is sufficient to provide the required information. However, for situations, such as the effects of mulch, understanding the main causal factors is utterly essential, i.e., a theory / model must be developed, so that general predictions can be made about how any mulch will perform, otherwise each and every mulch has to be experimentally tested to determine its performance, as is done with crop cultivars. Fortunately there is some underlying theory for why mulch is beneficial for the management of Pc.

To start with, soil, by definition, is a living biological entity, and living things need to 'eat' and soils 'eat' dead plant and animal residues (e.g., leaves, wood, dung, flesh and bones), i.e., organic matter (OM). If a soil does not received a regular 'meal' of OM then it will not be as healthy as it should be. In low OM soil it is often easier for pathogens to prosper, than in a healthy, biologically active soil, though not always. Regular inputs of OM therefore stimulate biological activity, and that, in simple terms, makes life harder for Pc to prosper.

Organic matter is also vital for forming good soil structure, through a multitude of pathways, including being food for soil organisms, from bacteria and fungi up to earthworms, that create soil structure, to providing the chemicals, e.g., humus, that help bind soil particles together, and that also serve as water holding materials and cation exchange sites. Good soil structure is essential for good drainage, poor drainage is highly beneficial for Pc, so good drainage helps minimise Pc.

Therefore regular inputs of organic matter are essential for Pc management, due to both the effects on soil ecology and structure / drainage.

However, different forms of organic matter (e.g., wood, lucerne, compost) have different effects on soil, both long and short term. Organic matter can be principally defined by its carbon to nitrogen ratio. Low C:N (i.e., high N) materials are green (or 'red' if they come from animals e.g., blood and bone), and these contain higher proportions of simple carbohydrates (i.e., sugars), lipids (fats and oils) and proteins. These materials are easy for soil microbes to decompose and are almost completely and quickly broken down to their constituent 'mineral' / in-organic components i.e., water, oxygen, carbon dioxide, nitrogen gas, reactive nitrogen compounds (e.g., nitrates, ammonium) and compounds of phosphorus, potassium etc. These materials are therefore an important energy and nutrient source for soil life, but as they are almost completely mineralise they don't increase stable soil organic matter, so only have a short term effect on soil structure, mostly by allowing soil organisms to thrive. Materials with a C:N ratio above 25:1 are considered high carbon materials, with ratios going as high as 500:1. High C:N ratio materials are woody, i.e., they contain larger amounts of long chain carbohydrates, e.g., cellulose, and little lipids and proteins, so are composed mostly of carbon, hydrogen and oxygen, and few, if any, other nutrients (P, K, Mg, etc.,). These materials are much harder for soil microbes to decompose, indeed most can not digest them and only specialist species can do so. Some chemicals, particularly lignin, are so 'tough' that they can resist decomposition and persist in soils for degrades even centuries. These are the materials that form the dead organic matter in the soil, including humus, and are therefore critical in creating soil structure and increase cation exchange capacity.

For Pc management in avocados mulches are used, as described above, to increase the amount of biological activity, especially microbes, in the soil, **and** to improve soil structure in the long term to in-turn improve drainage and water holding capacity. It is difficult for just one form of mulch to achieve both these objectives equally well. Low C:N materials are best for stimulating biological activity, though it may not stimulate the best kinds of microbes to counteract Pc. High C:N materials are needed for soil structure improvements.

Typically the mulches used in experiments and grower developed techniques (e.g., the Guy Ashburner method), are:

- Green, e.g., lucerne hay, in-situ green manures, e.g., mustard;
- Mixed or balanced, e.g., 'yard trimmings' which are a mixture of green and semi-woody material, e.g., hedge trimmings;
- 'Brown', e.g., wood and bark chips;
- Compost, i.e., composted green, mixed or brown materials.

Animal manures are also used, though they are of limited use as a mulch, but are mostly used as a nutrient source.

Compost needs particular reflection, considering the almost sacred position it holds for some sections of the organic movement. While compost is undoubtedly good for soil, and can be a valuable (and cheap) source of nutrients, it is not so much soil food (as described above) but more like soil dung, i.e., it is the kind of material that is left within the soil after fresh (i.e., undecomposed) organic matter is added to soil and has been decomposed by soil biology. Compost, therefore is not good soil food, in terms of feeding the soil food web. This is why some scientists say compost can be counter-productive for Pc management, as it does not boost soil biology sufficiently to compete with Pc.

In the debate as to whether green brown, or mixed materials are best for Pc management, without conducting an meta-analysis (which will take considerable time), it appears that brown, i.e., woody materials are wining the argument, as it appears that some of the wood decomposing species and/or the by-products of wood decomposition, are harmful to Pc. However, in organic systems, which have a higher reliance on organic materials for supply of nutrients, woody materials are poor nutrient (NPK, etc.) sources. Green, materials, especially, undecomposed green materials (which have higher N content) are preferable, or animal manures, which are more concentrated still.

In addition to the above, there are also 'green mulches' i.e., green manures, grown in-situ underneath the trees. Some plant species have allelopathic effects, i.e., produces one or more biochemicals that influence the growth, survival, and reproduction of other organisms. Most allelopathic effects are of plants affecting plants, not other kingdoms, e.g., fungi . Oats as a green manure was raised in the email exchange after the 'overview' report, as a possible control measure. It is quite possible that some plant species could have a significant allelopathic against Pc, however, the amount of quality research in this area is very limited, and the whole topic of allelopathy is notorious for poor research which produces misleading results. There were no reports found in the literature of green manures controlling Pc, but with the time limits available, an exhaustive search on this topic was not conducted, but with the lack of reports indicates it is an area that has hardly been looked at. On the other hand it was also noted by NZOAGI members that growing any kind of crop under avocado trees is a bit of mission due to the shading from the trees, so growing a strong enough green manure crop to have an effect could be hard. However, if there is a green manure with a strong allelopathic against Pc where the allelochemicals is in the leaves, it could be grown as a stand alone crop and cut and carried and used as a surface mulch.

It must also be noted that green manures are **not** a source of nutrients, in that they can only use the nutrients that already exist in the soil, the only exception being nitrogen for leguminous species, i.e., they can help increase the amount of available, but not total nutrients.

What is clear from the above, is that clarity is rather limited regarding the optimal mulches to use for Pc management, especially in organic systems where they have the duel role of Pc management and nutrient supply. Where clarity is lacking, research is clearly needed.

5.1. Suggested research

It is recommended that a more detailed review of the literature is required and/or contracting some of the leading researchers of the effects of mulches on Pc on avocado to determine what are currently considered optimal mulches for organic systems, where further research is required, and to build a better theoretical understanding of the interactions of Pc, avocados, soils, irrigation and mulches. While it would be perfectly possible to launch straight into some field trials comparing mulches (e.g., compost vs. wood chip), the long time frames (5+ years) needed to determine the ultimate effects of these materials, means making the best decisions at the start, would almost certainly dramatically increase the value of the results in the end.

6. Nutrient management

As noted at the start of section 5, in organic agriculture mulches have the duel role of providing both organic matter and nutrients. However, with the exception of nitrogen, mineral forms of all other nutrients are permitted in organic production, with varying levels of restriction. Total reliance on organic / biological sources of nutrients can be problematic if the nutrients required by the soil / trees are different to that provided by the organic matter. For example, seaweed, as noted in section 3.1.2.3, is often high in potassium e.g., 9% and low in phosphorous 0.2% and nitrogen 1%, i.e., were it an NPK fertiliser it would be a 1:0:9, which is clearly little use if the soil / trees are short of N and P but have plenty of K, especially as excess K can cause Ca and Mg deficiencies. Therefore long term use of organic / biological fertilisers can lead to significant nutrient imbalances and/or deficiencies, that are difficult to correct using only organic / biological fertilisers unless their nutrient content is accurately matched with the soil / plant deficiencies, and therefore approved mineral fertilisers are likely to be required.

Calcium is a nutrient that has Pc control potential beyond its straight-forward use as a nutrient by the avocado tree. It appears that calcium has a direct and negative effect on Pc and it also improves soil structure. Calcium and agricultural lime, for pH management, are often synonymous, however, it is critical to understand that it is not the calcium in lime / calcium carbonate, that increases pH but the carbonate. Calcium applied in non carbonate forms, e.g., gypsum (calcium sulfate) does not raise pH levels but does increase soil calcium. Balancing soil calcium with other cations is the key tenet of the base-cation saturation ratio (BCSR) approach to soil management, also know as the Albrecht system as promoted by Neal Kinsey. It is therefore quite likely that BCSR recommendations to increase soil calcium for the purposes of balancing the cation ratios may be working by direct effects of calcium on Pc, rather than due to the effect on cation balances, a concept which is not supported by mainstream science.

It is briefly worth noting that ammonium is toxic to Pc and avocado roots while nitrate forms are not (or less so). Non-organic recommendations are to avoid the use of ammonium forms of N fertilisers and use nitrate forms instead, to avoid root damage. While organic systems don't use mineral nitrogen fertilisers, animal manures, especially poultry manures, can contain considerable quantities of ammonium and more can be produced by the breakdown of more complex nitrogen containing compounds. Therefore there is a general recommendation not to put animal manures directly on the root layer, but rather on top of more woody mulch layers. However, this could result in more nitrogen being lost back to the atmosphere, both as di-nitrogen and ammonia and therefore not be available to the trees. If nitrogen supply in organic avocado production is an issue, the use of animal manures and supply of N via organic residues may also be a valuable research topic.

Boron is frequently cited in the literature as a nutrient for which avocados have an unusually high demand and deficiencies have been linked to high levels of Pc, though the linkages are not clear. If organic / biological materials are not providing sufficient boron, then organic approved off-the-shelf boron fertilisers, both soil and foliar are available. Care must be taken as excess boron is harmful to the point of being an effective herbicide. However, research on boron is not considered worthwhile.

A wild-card entry among the nutrients is silicon. Bekker (2007) conducted some very interesting, extensive and quality work looking at silicon for Pc management, with positive results. A few NZOAGI members in the email discussion after the 'quick overview' report talked of people using silicon with good or very good results, and also mentioned that the idea came out of South Africa, which is where Bekker did his research, so it sounds like these are linked.

Silicon which mostly occurs as silicon dioxide, i.e. quartz, i.e. sand, is a limbo nutrient as people still argue if plants need it or not, in that plants can grow without it, but many grow much better with it. Also while it exists in all soils in vast quantities as sand, the amount of available soluble silicon is tiny., and it needs to be topped up via external sources. The main form of mineral silicon fertiliser is potassium silicate (also known as waterglass) which is allowed under organic regulations including the USA NOP. Organic / biological materials originating in plants high in silicon are also good sources of plant available silicon. Building on Bekker's work could be very valuable, however, this is the only work found looking at using silicon in avocado production (there is one South African group looking at Si as a post-harvest treatment), so following this lead would be cutting edge with commensurate risks and benefits. Clarification would also be required from certifiers regarding its use, especially as it appears that applications must continue indefinitely, which may not sit well with standards.

A few NZOAGI members in the email exchange also talked about increasing soil phosphorous and making Phosphonic acid from rock phosphate fertiliser. My understanding of the chemistry is that it is not possible to make phosphonic or phosphorous acids, at least in the forms used as tree injections, from phosphate fertilisers without a laboratory, e.g., mixing with water simply dissolves the fertiliser rather than transforming it in any significant way . As the mode of action of phosphonic acid is to increase phosphorous in the trees roots which then has an inhibitory effect on Pc, it appears logical that making sure soil P is at optimum levels would be important for Pc management, however, there is no discussion of this in the literature reviewed for this report, including a number of Pc management guides, which therefore appears to be a strange omission. It is hard to draw conclusions as to why phosphorous fertilisation does not gain more 'air time' so it may be useful to follow this up further, to see why it gains so little attention.

6.1. Worm products - vermicast and leachate

One report by a grower made interesting claims for the use of vermicast and worm bin leachate (Campbell, 2003). A few NZOAGI members also raised worm products in the email exchange. Like compost and other materials favoured in organic agriculture, much is made of worm products but hard science is often limited, but, there are good reasons why worm products may have positive effects, no scientific reasons why an effect is impossible, but like BCAs as a whole, the possibility of them having a real and biologically significant effect has a lot of odds stacked against them. Worm products, like compost teas, fall between stools - they are not a biocontrol in the normal sense and they are more than fertilisers in the normal meeting. They can also be highly variable unless production systems are standardised, and even then variability between batches and therefore efficacy can be high. However the nature of the claims by Campbell, although anecdotal, i.e. not scientifically rigorous, are sufficient for cautious interest and exploring further, especially as NZOAGI members also report positive benefits of using worm products. Also as worm products have been widely shown to have straight forward nutrient value and soil and crop health benefits, and the likelihood of negative effects if used according to recommendations is considered very low, so the risks and costs of such work are considered to be low, and at least some benefits should be realised, so undertaking some methodologically rigorous experiments is likely to be useful.

6.2. Compost teas

Having touched on the issue of vermicomposting, the related product (a cousin perhaps?) compost teas are recommended in NZ organics avocado production guides. This could also be an area of profitable research, however, existing research on compost teas indicates the main issue is variability of product and therefore lack of repeatability of results, which means that the apparent profitability of compost tea research evaporates. EM (see section 4.2.1) can be viewed as a highly standardised compost tea, being made from organisms originally found in compost, but produced from laboratory standardised cultures. If there is significant interest in compost teas among NZOAGI members, EM would be a better first step down this route.

6.3. Suggested research

Nutrient management is an area that is much harder to make clear recommendations on what research to pursue without a better idea of what current NZOAGI members are already doing, i.e. this could be an area more in need of extension than new research, or it may need research into current grower practices and what they consider to be working and what does not.

However, in terms of research areas that sound promising from the literature, if growers are not already using calcium amendments this would be a good research area, probably tending towards demonstration research.

Silicon fertilisation is a bit of a wild card, but considering the positive results both in South Africa and in NZ, following it up, at least with a deeper literature search and contacting the South African researchers and NZ growers to see what further progress has been made would be worth while.

7. Mulches plus biocontrols - synergistic effects?

The two main research areas suggested in this report are biocontrol agents (BCAs) and mulch. However, there are good reasons to expect that using biocontrols and mulch together should have synergistic effects. To some extent this is standard practice, in that mulches are a key component of the Pc IPM strategy, and an essential part of organic avocado production, so any BCAs would be used in addition to the existing mulching practices. However, it is not clear if specific mulch materials could be deliberately selected to optimise the benefits of particular BCAs. However, researching the interactions of mulches and BCAs and any synergistic effects of Pc, is probably far beyond simple empirical field trials and requires 'deeper' research to delve into the causal factors, meaning that such work is longer term, more research centre based and expensive.

8. Conclusions

As noted in the introduction, this report is not a complete synthesis of the literature, but a initial overview to show the lie of the land. It is hoped that it provides sufficient insight to allow NZOAGI members to better understand what existing research has achieved, where there are gaps that it could pursue, and the pros and cons of each research area. This document should therefore be considered as the start of the process not the end, and that if the process is to be taken further, more desk study / literature research will almost certainly be required before experimental work is undertaken.

Also many of the research topics could also be of interest to non-organic avocado producers, because:

- There is a clear concern among scientists that Pc can (not could) become resistant to current agri-chemical control measures, and considering how Pc has spread around the world and the impossibility of total NZ phytosanitary boarder control (as the kiwifruit industry has found out with Psa), if resistance does develop it may well spread world wide including to NZ.
- The general public and lawmakers are increasingly concerned about pesticides (though less so in NZ than other developed countries) which means that non-agri-chemical control methods are being demanded.

Therefore having alternatives to agri-chemical controls is increasingly important, even vital for the whole avocado industry. Therefore, the New Zealand Avocado Growers Association (NZAGA) may well be open to joining with NZOAGI in supporting research as it will benefit the industry as a whole in the longer term. If other horticultural industries in NZ also have problems with Pc they may also be interested in joining in.

8.1. Participatory research

Most of the suggested research topics are well suited to experiments that can be conducted on commercial avocado orchards with significant input from growers, i.e. participatory research. To some extent this was an inherent bias in the research selection process due to the nature of NZOAGI. Some advantages of participatory research are that:

- it maximises the return on investment dollars, both from growers and funding sources;
- grower participation means that only research that will have outcomes that can be practically and economically implemented on commercial orchards will be undertaken;
- undertaking research on commercial orchards means that successful research will have high uptake rates by growers.

The downsides of participatory research are that:

- More in-depth and possibly hazardous experimental techniques, e.g., using radioactive tracers, is not possible, so research tends to be more empirical than theoretical, i.e. understanding causal factors, which tends to limit its ultimate usefulness;
- The costs, especially hidden costs, to growers hosting research can be quite substantial and this should at least be recognised and possibly compensated by other growers benefiting from the work;

8.2. Research topics

- Testing existing BCAs is recommended as the first priority of research, as there is an extensive existing literature, successful products can be rapidly taken up by producers, and research costs should be comparatively low.
- Looking for new BCAs requires major industry and central government funding, long time scales and considering the low success rate, huge cost, and small size of the NZ avocado industry compared with other crops, means it is recommended not to pursue this route without wider industry support.

- A better understanding of what makes for a good Pc suppressive mulch, especially in synergistic combination with promising BCAs, could be valuable, but, the improvements above what current best practice achieves may not be that great, e.g., any mulch is good but the ideal mulch may not be a lot better than the average. Alternatively, researching organic specific topics, such as 'traditional' compost compared with industry standard mulches such as wood chips, and interactions between mulches and nutrient management could be of greater value. Looking for green manures with an allelopathic effect on Pc is considered a longer shot but if a plant exists that is easy to grow, it would be a very cheap control option.
- A survey or collation of existing grower nutrient management practices would be a good first step to inform if and what nutrient management research is required. In the absence of this testing the use of calcium, especially in non-pH altering forms e.g., gypsum, would be worth following up as would silicon.

8.3. Organic avocado *Phytophthora cinnamomi* management guide?

From researching this report, and the feedback from NZOAGI members to the 'overview' report, it appears that it could be worthwhile to produce a specific and detailed guide to Pc management in organic avocados, as the sections in existing NZ organic avocado guides is quite short, which is to be expected in general guides, unless they are huge. Collating existing research and overseas guides, which contain a lot more ideas than this report has covered, along with NZ growers experiences and written specifically for organic production, could be of significant value in and of itself.

9. References

Rather than provide extensive references for all statements in the text, a few key / particularly good, references are provided. Copies of the papers and information used in the writing of this report can be supplied if desired.

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