Improved management of avocado diseases

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QLD Department of Primary Industries & Fisheries

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Avocados Australia Limited
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Purpose of report: The purpose of this report is to present the final results of all activities conducted under HAL Project AV04001 "Improved management of avocado diseases". The report also provides a summary of project findings, a description of technology transfer activities, and recommendations arising from the outcomes of the project. The overall objective of this project was to improve disease management practices for 'Hass' avocado based upon a number of approaches including rootstock selection, management of root rot and management of fruit diseases, as well as providing feedback from a scoping study.

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1. Media Summary

The avocado industry continues to search for methods to improve the way they manage diseases in their orchards. This project has provided some clear guidelines to manage several common avocado diseases.

Our research has shown that clonal rootstocks are superior to seedling rootstocks in their tolerance to Phytophthora. We have made substantial progress in evaluating a range of new and traditional avocado rootstock varieties for their tolerance to Phytophthora root rot, already showing that clonal rootstocks tolerate root rot far better than seedling rootstocks. Considering their uniform growth, which allows for easier orchard management, this makes clonal rootstocks very attractive. Avocado growers have been keenly anticipating these results. Ultimately, this program will provide data to help a grower decide on the best type of rootstocks to use when planting a new orchard.

The devastating pathogen, *Phytophthora cinnamomi*, continues to cause root rot which reduces tree health and eventually kills the tree. If an avocado grower has soil infested with this pathogen, it is essential that they use an integrated approach to controlling the disease. Although these approaches can be effective, it is still possible to reduce the need to rely on chemicals.

We have shown that a single injection of phosphonate in late autumn provides adequate levels of phosphonate in the roots of the avocado tree to maintain tree health in the presence of *P. cinnamomi* in the soil. This is great news for growers, who often find injecting twice yearly time consuming, costly and, ultimately, damaging to the trunks of their trees. Another positive outcome of our phosphonate studies is the prospect of being able to spray phosphonate onto the trunks of trees with the assistance of a bark translocating agent. In our studies, this method still achieved adequate levels of phosphonate in the roots.

There are also ongoing problems with fruit quality in the 'Hass' variety due to anthracnose, pepper spot and stem-end rot. These diseases are caused by microbial pathogens, the most important of which is the fungus, *Colletotrichum gloeosporioides*. This pathogen infects the fruit on the tree throughout the season from fruit set to harvest. However, the sunken, black lesions which render the fruit unmarketable only appear once the fruit starts to ripen on the shelf. This can lead to fruit being wasted in the marketplace and can make consumers think twice before buying an avocado.

It appears that a new fungicide treatment, Cabrio®, has the potential to be added to the line-up of control measures against the insidious disease, anthracnose. With some chemicals falling out of favour and the increased desire for less chemical use, adding a more effective treatment is desirable. Applying silicon, as is commonly done to boost disease defences, gave inconsistent results in our trials. The relationship between the fungus and the avocado tree is extremely complex and so silicon applications cannot be recommended.

Throughout the project, important information was gathered from growers from several areas concerning their key issues. This information will be used for future R & D projects.

2. Technical Summary

The avocado industry has identified key areas for disease management research. Phytophthora root rot continues to hamper tree health and postharvest anthracnose and stem-end rot of fruit continue to reduce fruit quality. Phytophthora control still has limitations so it was also important to evaluate phosphonate application methods and rates for root rot control. In addition, rootstock selection has become a vital consideration for new plantings. Hence, old and new rootstocks are being evaluated for their Phytophthora tolerance and vigour under varying conditions, taking into consideration essential attributes such as their influence on fruit quality and yield. A further important component of this project was to evaluate fruit disease control using new fungicides and activators, including silicon products.

The current recommendation for growers with healthy trees is to inject their trees with phosphonate twice a year following hardening of spring and summer flushes. We have tested the hypothesis that an injection once a year after summer flush maturity (when root flushing is complete, but before floral bud development has advanced) will be adequate. These trials are continuing, however, results suggest that this hypothesis is correct and sufficient levels of phosphonate in the roots to maintain disease control can be achieved through appropriate injection timing. Samples for phosphonate analyses have been routinely collected from our field site to monitor its movement and decline in leaves, roots, flowers and fruit over time. In other trials, it was found that injection of trees with phosphonate can actually inhibit feeder root growth if applied at the commencement of root flush. Consequently we have been comparing injections with trunk sprays for control of root rot. When injected, most of the phosphonate travels to the leaves via the xylem and then down to the roots. The concentration in the roots is relatively high and, therefore, temporarily inhibitory. When sprayed onto the trunks, a lower but more consistent supply of phosphonate travels via the phloem into the roots where it is needed, with little or none ending up in the canopy. Previous studies have found that phosphonate alone cannot be applied in adequate levels to the bark of the avocado tree. Therefore, we have been adding bark penetrating surfactants to our phosphonate solution to act as translocation aids. Using 2% Pulse, phosphonate has been readily absorbed into the trunks of the trees.

Rootstock trials have been established at various locations in eastern Australia and assessments will continue into Project AV07000. Dr Tony Whiley's Rootstock Improvement Program will also provide useful data from a disease management perspective. Results so far have identified some superior rootstocks. It appears that the clonal rootstocks are exceeding the seedling rootstocks in their root rot tolerance. At the high pressure Phytophthora site at Duranbah, 'Hass' grafted to cloned 'GE' showed a very high level of tolerance to *Phytophthora cinnamomi* thereby demonstrating the merit in recovering and testing rootstocks from isolated survivors growing in orchards where trees have been subjected to long term selection pressure by *P. cinnamomi*. Since tolerance to *P. cinnamomi* is variable in seedlings, promising rootstocks invariably must be cloned. 'Merensky 2' (Dusa) is also doing well in a replant trial at Hampton. It has also been noted that 'Hass' growing on its own roots is doing well and it is thought that the lack of graft union in these trees has allowed for better vigour due to uninhibited nutrient flow. This is an aspect to be further considered.

In the root regeneration studies, a robust technique was developed. Optimising methods required careful technical manipulation, however, even under reasonably consistent conditions, differences between rootstocks were more significant than expected. The important conclusion from this work is that root regeneration ability of trees is a critical issue when trees are grown in the presence of Phytophthora and further evaluations as rootstocks become available will be undertaken.

A preliminary analysis of mineral nutrient concentrations in the roots of two different rootstocks was undertaken and it was found that rootstocks can vary in their nutrient uptake and this may correlate to Phytophthora tolerance in rootstocks. It is likely that root rot affected rootstocks will probably also vary in their ability to respond to phosphonate applications. Eventually, correlations between nutrient contents in the plants and phenolic compounds will be assessed. Such work will continue into project AV07000.

In an effort to improve the management of Phytophthora root rot in avocados, glasshouse experiments were carried out to evaluate soil applications of silicon products and to compare these treatments with potassium phosphonate. Experiments showed that silicon can be taken up by the avocado seedling and transported to the leaves. Comparisons of a range of different silicon formulations indicated that some effect was achieved for suppression of *P.cinnamomi* in the glasshouse; however, none of the products were as effective as phosphonate. These results showed variation in many of the silicon treatments and rates and timing of applications seem to be important. Silicon may be found to improve overall tree health and disease resistance and may eventually be incorporated into an effective disease management programme, but more experimentation is essential.

A major component of the fruit disease work was to evaluate the effects of potassium silicate products as both host defence promoters and in enhancing physical resilience properties of fruit against pathogen infection. Early experiments found that postharvest anthracnose could be significantly decreased by using trunk injections (750ppm) 8 and 12 weeks prior to harvest. In experiments where silicon treatments were applied earlier, results were variable, but 750ppm applied 32 weeks prior to harvest and 1500ppm applied 12 weeks prior to harvest were highly effective. There was a trend for reduced disease in fruit from most of the injected trees, however, data was often not statistically significant. None of the treatments had a significant effect on the development of stem-end rot.

In experiments to determine if rootstock has an effect on uptake of silicon by injection to control postharvest anthracnose (caused by *Colletotrichum gloeosporioides*), there were no significant differences between treatments. However, high disease levels interfered with disease assessments. In field silicon fertigation experiments there were no significant differences between fertigation treatments on the development of anthracnose. However, high levels of disease may have masked any differences. It is possible the amount of silicon taken up from the soil into the tree was not sufficient to activate a response.

Preliminary experiments have identified a new strobilurin fungicide (Cabrio®) with the potential to further reduce the incidence and severity of anthracnose and stem-end rot. After further field testing, it is hoped that this fungicide can be added to the suite of chemicals already available to manage fruit diseases.

Evaluations were made on the effect, if any, of the particle film product, Surround®, for the management of heat stress and disease in 'Hass' avocado fruit. The use of Surround in the regime used in these trials did not significantly decrease sunburn of fruit and did not provide control of postharvest diseases. It was shown that the fungus *C. gloeosporioides* was able to penetrate through the Surround coating into the fruit.

Based on reports of copper tolerance in the USA, local isolates of the anthracnose pathogen *C. gloeosporioides* were tested for their tolerance to copper fungicides *in vitro*. It was important to ensure that current copper spray programs are not creating a resistance problem and, at this time, no problems were detected.

As part of an avocado scoping study in Western Australia and Queensland, considerable information was gained from growers who were given the opportunity to discuss their concerns. The main area of interest for the WA growers was canopy management and most growers were aware of the work already being achieved in this area (Project AV04008). The Northern Queensland growers' main request was for a sustainable IPM to be developed with particular emphasis on management of fruit spotting bug which is an economic pest for many subtropical crops. Once a good understanding of the fruit spotting bug has been achieved, the IPM program could then be expanded to include other avocado insect pest species. The Bundaberg region growers were interested in research into improving farming profitability through reduced production costs and increased market prices. This is a concern for the industry as a whole. A suggestion is to discover new outlets for the increasing volumes of avocado fruit being produced. It is recommended that a study be conducted into the cost benefits of developing avocado 'value adding' products such as frozen slices, guacamole, avocado oils, organic fruit etc. Such technology has been developed in other countries. Expanding export markets is also an issue for the industry.

3. Introduction

The most important diseases of avocado in Australia are anthracnose, stem-end rot and Phytophthora root rot. Definitive control measures are not available for these diseases and new strategies to manage these diseases are required. This is particularly relevant to fruit disease control because of the expectations from increasingly sophisticated consumers. Outcomes from HAL Project AV01004, especially the impact of rootstock on fruit disease, laid the foundations for this research. The Australian industry is currently heavily involved in rootstock research. This is important as rootstocks have a significant impact on yield and resistance to soil-borne diseases. Research conducted by DPI&F has shown that avocado rootstocks also impact on the quality of, and disease development in, fruit that are produced by the 'Hass' scion. Thus it is important that the industry, when evaluating new rootstocks, considers the influence of the rootstock/scion combination in total and should include Phytophthora resistance and influence on fruit quality, which includes disease development. New compounds for disease control in plants, which are more environmentally benign than current synthetic fungicides, are being developed throughout the world. These include the plant activator products which induce systemic acquired resistance in plants. It is important that these products be evaluated against avocado diseases. These compounds enhance natural disease defence and thus a greater knowledge is required of preformed and induced compounds in the avocado host.

The aim of this project was to further reduce the impact of disease, with emphasis on two main areas: Phytophthora root rot management and fruit disease management.

For Phytophthora root rot management, the two major components were to evaluate new rootstocks for greater Phytophthora tolerance and to improve application technology of phosphonate. This was achieved by: (a) conducting field trials to evaluate the root rot tolerance of clonal and seedling rootstocks by planting in *Phytophthora cinnamomi* infested soil; (b) conducting growth cabinet experiments to measure root regeneration capacity, to assess Phytophthora tolerance, and to evaluate a non-invasive inoculation technique; (c) investigating the effectiveness of plant defence promoters alone and in combination with phosphonate to control Phytophthora root rot and; (d) evaluating the effectiveness of trunk sprays combined with bark penetrants in improving uptake of phosphonate in avocado trees.

For fruit disease management, the key objective was to investigate potential alternatives to synthetic fungicides to reduce fruit diseases. This was achieved by: (a) evaluating the effectiveness of new plant defence promoting compounds (e.g. potassium silicate) to elicit a defence response in avocado fruit to protect against fungal pathogens; (b) investigating particle films (e.g. Surround) in the field for their ability to improve fruit quality through postharvest disease reduction; (c) screening new fungicides with better 'kick-back' activity for the control of fruit pathogens (d) evaluating *Colletotrichum* isolates for tolerance to copper fungicides following a claim that the fungus becomes tolerant over time (e) screening rootstocks for defence compound production and mineral nutrient content and correlating with disease resistance.

A scoping study of avocado producing areas was also integrated into this project. This was intended as a means to introduce new researcher Dr Danielle Le Lagadec to the avocado industry but, more importantly, gave us the opportunity to survey growers and gather data on the key issues affecting their avocado production.

4. Phytophthora root rot studies

4.1 Introduction

Root rot of avocado is caused by *Phytophthora cinnamomi*. This organism is a destructive soil pathogen and has major consequences on tree health. Phytophthora chlamydospores can survive for long periods in the soil. During wet periods, these chlamydospores can rapidly produce sporangia which liberate infective motile zoospores. These zoospores can swim towards the root zone where they penetrate and infect the roots. Avocado trees are particularly sensitive to the loss of feeder roots, as these roots lack root hairs, making them relatively inefficient at absorbing water and nutrients.

Progress has been made in understanding and reducing the impact of the pathogen but it has not been enough. There are still many important questions to be answered. Further research was necessary in three main areas:

- the pursuit of useful field tolerance in rootstocks
- further testing of phosphonate application strategies
- the evaluation of plant activators

The aim of these experiments was to reassess current control measures and to undertake large scale rootstock evaluations for tolerance to the pathogen in the soil.

Statistical analysis
The data were analysed using Genstat® seventh edition (Lawes Agricultural Trust, Rothamsted Experimental Station). Most analyses used analysis of variance (ANOVA) in randomised blocks incorporating Fisher's pairwise comparison tests, unless stated otherwise.

4.2 Screening avocado seedlings for root regeneration capacity in the glasshouse

4.2.1 Introduction

The root system of avocado is shallow and does not spread much beyond the canopy (Scora *et al*. 2002). The roots have few or no fine root hairs. Hence, even healthy roots are relatively inefficient in absorbing water and nutrients. Avocado roots are very vulnerable to infection by *P. cinnamomi*. Some avocado rootstocks can tolerate *P. cinnamomi* by (1) their ability to regenerate new roots in the presence of the pathogen and by (2) limiting the growth of the pathogen in the roots.

The aim of these experiments was to screen young avocado seedlings for their ability to regenerate new roots in the presence of the oomycete, *P. cinnamomi.*

4.2.2 Materials and Methods

A preliminary trial was conducted on 'Hass' grafted to 'A10' and to 'Reed' rootstock seedlings in the growth cabinet. Ten seedlings of each rootstock were used. Roots were trimmed using two different techniques to determine the best method. Some were trimmed right back to the tap root, some were trimmed leaving ca. 1cm of roots from the tap root, and some were left as controls. Seedlings were re-potted and assessed for regrowth after 3 weeks.

The main trial was conducted on 'Hass' seedlings grafted to the following six different seedling rootstocks:

1. 'Reed'
2. 'Edranol'
3. 'Velvick A'*
4. 'V1'
5. 'Velvick B'*
6. 'A10'

*Velvick A = Anderson, Velvick B = Whiley

Forty plants of each rootstock were used (10 replicates of each treatment). Half the trees from each rootstock had their feeder roots trimmed to within 1cm of the tap root. Half the root-trimmed and half the root-untrimmed trees were inoculated with *P. cinnamomi (Pc)*. Therefore, the following treatments were applied to 10 trees of each rootstock:

1. *Pc* infested soil + trimmed roots
2. *Pc* infested soil + untrimmed roots
3. Control (sterile soil) + trimmed roots
4. Control (sterile soil) + untrimmed roots

Plants were re-potted in sterile potting media or *P. cinnamomi* infested potting mix (0.5%) in black planter bags. Plants were kept in the glasshouse and watered daily. Roots were assessed for regrowth after 8 weeks.

For the plants with trimmed roots, only new, white, unsuberised roots were removed from the root bundle. For plants with untrimmed roots, the entire root mass, including the tap root, was cut off immediately below the seed joint. Roots were washed and placed in paper bags. Bags were placed in an oven at 55^0C for 7 days. Roots were weighed and dry weights recorded.

4.2.3 Results

It was found that trimming right back to the tap root was too severe for optimal regrowth to occur. Trimming to 1cm and leaving roots untrimmed gave similar results and there were no significant differences between the two rootstocks.

For the main experiment, dry weights of the root tips (inoculated with Pc) or whole root system (uninoculated) were recorded and it was found that the 'Velvick A' had the greatest and 'Edranol' the lowest root regeneration capacity, under both high (inoculated with Pc) and no (uninoculated) disease pressures (Table 1). The 'Velvick B' rootstock performed almost as well under disease pressure and in the control treatment. 'Reed' was ranked with 'Velvick B' under disease pressure, however, there appears to be a discrepancy in the uninoculated data with untrimmed values being unusually low.

The last two rootstocks ('V1' and 'A10') performed differently depending on the disease pressure. Under no disease pressure, 'V1' performed very well and was ranked second with 'Velvick B'. However, under disease pressure, it dropped to ranking last with 'Edranol'. The 'A10' rootstock was the reverse to 'V1'. Under no disease pressure, the root regeneration capacity of 'A10' was ranked last with 'Edranol'. However, under disease pressure 'A10' was ranked second with 'Velvick B'. Trimming the roots did not significantly change the rankings for uninoculated or inoculated plants (Table 1).

Table 1: The effect of avocado seedling rootstock on root regeneration capacity, measured as dry weight of healthy root tips (*P. cinnamomi* inoculated plants) or entire root system (uninoculated plants) after roots were left untrimmed or trimmed back to ca. 1cm from the tap root (mean values with the same letter are not significantly different at $P < 0.05$) (n=8)

Rootstock	**Trimmed roots**	**Untrimmed roots**
	Inoculated with Phytophthora cinnamomi	
'Velvick A'*	0.22 cde	1.25 a
'Velvick B'*	0.17 de	0.58 b
'V1'	0.01 e	0.20 de
'Reed'	0.13 de	0.33 bcd
'A10'	0.13 de	0.46 bc
'Edranol'	0.01 e	0.02 e
P	<0.001	
lsd	0.254	
	Uninoculated (no Phytophthora cinnamomi)	
'Velvick A'*	7.77 bc	12.24 a
'Velvick B'*	5.43 cd	10.03 ab
'V1'	5.54 cd	7.83 bc
'Reed'	5.29 cd	0.90 e
'A10'	3.31 de	5.47 cd
'Edranol'	3.10 de	5.12 cd
P	<0.001	
lsd	2.756	

*Velvick A = Anderson, Velvick B = Whiley

4.2.4 Discussion

This work assessed several aspects of experimental design in order to optimise the methods. For measuring root regeneration, it was important to determine the level of root trimming necessary to achieve healthy and measurable regrowth. Although not described in the methods, it was also necessary to optimise the concentration of Phytophthora used to achieve adequate infection and it was also necessary to standardise moisture levels. Previous studies reported the necessity for maintaining a waterlogged state; however, it was found that daily watering was sufficient for attaining infection.

The data collected in this trial is extremely important when considering the value of rootstocks in the field. If a rootstock has greater ability to regenerate roots, then it will be more resilient in the presence of a soil pathogen, where the roots will be able to compete by growing away from the source of infection. These experiments have provided a basis for future experimental work with the development of valuable techniques. It is anticipated that further root regeneration analyses will be carried out in the new project (AV07000) in conjunction with rootstock field evaluations.

4.3 Evaluation of a non-invasive inoculation method for *Phytophthora cinnamomi* in avocado seedlings

4.3.1 Introduction

A simple, effective method for screening jarrah plants for resistance properties to *P. cinnamomi* has been developed in Western Australia (Lucas *et al.* 2002).

The aim of these experiments was test this method to determine whether such a technique is a reliable predictor of root reaction to *P. cinnamomi* in avocado.

4.3.2 Materials and Methods

A preliminary trial was conducted on eight 'Reed' rootstock seedlings (~30cm tall) in small pots (10mm) in the glasshouse. Some of the stems and petioles of plants of each rootstock were pre-moistened with sterile wet cotton wool for 2 days prior to inoculation. The cotton wool was held in place with cling wrap. Two agar plugs colonised by *P. cinnamomi* were placed face down onto unwounded stem or branch tissue. A third agar plug was placed over a shallow wound made with a scalpel. Some of the plugs were covered with wet cotton wool and held in place with cling wrap (Table 2).

Table 2: 'Reed' seedling treatments for inoculation method evaluation

Treatment	Premoistened/Dry	Stem covering
2 treated plants (Pc plugx3)	Moistened 2 days	Cotton wool
2 treated plants (Pc plugx3)	Moistened 2 days	No cotton wool
2 treated plants (Pc plugx3)	Not moistened	Cotton wool
2 treated plants (Pc plugx3)	Not moistened	No cotton wool

After 3 weeks, all of the seedlings were assessed for disease.

A second preliminary trial was conducted on ungrafted seedling ‘Velvick’ and ‘A10’ rootstock seedlings (~15cm tall) in small pots (10mm) in the glasshouse. Three trees of each rootstock had stems pre-moistened for 2 days prior to inoculation as described above and three left untreated. Three trees had stems wounded by cutting a 3mm strip with a scalpel and pushing agar plugs colonised by *P. cinnamomi* into the wound site. Another three trees of each rootstock had leaves wounded (by piercing with a sterile thumb-tack) and inoculated with an agar plug colonised by *P. cinnamomi*. For both wounding inoculation treatments the wound site was kept moist by either using moistened cotton wool with cling wrap or by placing a moistened plastic bag over the entire plant for leaf inoculations.

Colonisation was assessed 14 days after inoculation.

4.3.3 Results and Discussion

No *Phytophthora cinnamomi* infection could be induced on unwounded stems and petioles of 'Reed' rootstock plants. Infection was found on three of the eight wounded sites but there was no relationship with moistening treatments.

No visible lesions were observed on unwounded stem tissue or on wounded leaves of the ungrafted seedling ‘Velvick’ and ‘A10’ rootstock seedlings. Only the wounded stem tissue trees had lesions. It was decided that this method of disease susceptibility assessment for avocados would be too time-consuming and wounding is an invasive and unnatural infection mode. Therefore, no work was undertaken beyond these two preliminary experiments.

4.4 Evaluation of potassium silicate for the control of Phytophthora root rot of avocado seedlings in the glasshouse

4.4.1 Introduction

Management of Phytophthora has been successful using potassium phosphonate (phosphorous acid) and metalaxyl, along with other management practices (avoiding high disease pressure sites, maintaining good drainage, use of disease free nursery trees, use of more tolerant rootstocks, mulching, use of animal manures, gypsum application) (Pegg *et al*. 2002). Reliance on a single chemical is not ideal, so we are keen for alternatives to be incorporated into disease management strategies. We are currently trialling the use of silicon products and assessing their mode of action in avocados.

Phytophthora control studies in South Africa (Bekker *et al*. 2005) found that silicon treatments enhanced root regeneration capacity when applied prior to inoculation with *P. cinnamomi*. The Indooroopilly research team also found some improvement in tree health after injecting ageing trees with severe root rot decline with potassium silicate.

In an effort to improve the management of Phytophthora root rot in avocados, preliminary glasshouse experiments were carried out to evaluate soil applications of silicon products and to compare these treatments with potassium phosphonate.

4.4.2 Materials and Methods

Experiment 1: Kasil® drench of young avocado seedlings in the glasshouse

The aim of this preliminary experiment was to assess movement and effects of potassium silicate (Kasil – PQ Australia Pty Ltd) applied as a drench to young avocado seedlings in the glasshouse.

Twenty-five young ‘A1’ (Guatemalan) avocado seedlings were used for this experiment. The following treatments were applied to five tree replicates for each treatment:

1. Untreated control
2. Drench with 500ppm potassium silicate once
3. Drench with 1000ppm potassium silicate once
4. Drench with 500ppm potassium silicate twice
5. Drench with 1000ppm potassium silicate twice

Whole leaf samples were taken to measure silicon uptake. Leaves were dried, ground and sent to SGS Agritech (Toowoomba) for analysis.

Experiment 2: Evaluation of Kasil® and phosphonate treatments on young avocado seedlings inoculated with Phytophthora cinnamomi in the glasshouse

The aim of this experiment was to assess the efficacy of a single drench application of potassium silicate (Kasil), of potassium phosphonate, and a combination of both, in reducing root rot in young avocado seedlings (inoculated with *P. cinnamomi*).

The trial was conducted on forty 1-month-old 'Reed' (Guatemalan) seedlings in small pots in the glasshouse. Seedlings were removed from their pots and their roots were trimmed to allow for root regeneration. Seedlings were re-potted and twenty-four were inoculated with *P. cinnamomi*. The following treatments were applied to six tree replicates:

1. Control
2. Kasil (200ppm)
3. Phosphonate (20%)
4. Kasil (200ppm) + phosphonate (20%)

Sixteen seedlings were not inoculated with *P. cinnamomi* and the following treatments were applied to four tree replicates:

5. Control
6. Kasil (200ppm)
7. Phosphonate (20%)
8. Kasil (200ppm) + Phosphonate (20%)

After 8 weeks, seedlings were removed from the soil and rated for overall seedling health. Soil was rinsed from the roots and root tips were also rated for disease.

Experiment 3: Evaluation of different formulations of silicon when applied to the roots of young avocado seedlings in the glasshouse

The aim of this experiment was to evaluate different silicon products when applied to the roots of young avocado seedlings

This trial was conducted on 1-month-old 'Reed' seedlings in the glasshouse. Seedlings were replanted into 15mm diameter pots and four bamboo sticks were inserted into the soil around each plant. Prior to the roots being inoculated with *P. cinnamomi*, silicon treatments were applied to the soil at various intervals (4 weeks, 2 weeks, 1 week and 2 days). One group of plants received each silicon treatment at each application time. After 4 weeks, the sticks were carefully removed to facilitate *P. cinnamomi* inoculation into the holes. All seedlings were inoculated with the pathogen, which was growing on wheat. The following treatments were applied to five seedling replicates:

1. Kasil® (SiO_2/K_2O) drench (200ppm) - 10mL per pot
2. Stand SKH™ (SiO_2) drench (200ppm) - 10mL per pot
3. Silvine® (MgSi) powder - 1.5g per pot
4. Wollastonite ($CaSiO_3$) powder - 1.5g per pot
5. Photo-Finish™ (SiO_2) drench (200ppm) - 10mL per pot
6. Wollastonite powder + phosphonate drench (20%) - 1.5g+10mL per pot
7. Phosphonate drench (20%) - 10mL per pot
8. Control – *P. cinnamomi* only

After 5 weeks, the roots were assessed for disease severity and were oven-dried to give a root mass value.

4.4.3 Results

Experiment 1: Kasil® drench of young avocado seedlings in the glasshouse

The experiment revealed that the application of the higher rate of Kasil (1000ppm) increased the content in the leaves significantly higher than in the control plants (Table 3). When Kasil was applied twice at this rate, the amount of silicon in the leaves was over four times the amount found naturally in the control leaves. Although the lower rate (500ppm) of Kasil increased the levels in the leaves when compared with the control leaves, the analysis results were variable with some extreme outliers; hence the data is not accurate.

Table 3: Effect of Kasil (potassium silicate) as a drench treatment in the soil containing young 'A1' avocado seedlings (mean values with the same letter are not significantly different at $P < 0.05$) (n=5)

Treatment		Si (mg/kg) content
Kasil - 1000ppm x2		3216 a
Kasil - 1000ppm x1		2674 a
Kasil - 500ppm x2		1148 b
Kasil - 500ppm x1		1935 ab
Control		783 b
	P	0.006
	lsd	1319

Experiment 2: Evaluation of Kasil® and phosphonate treatments on young avocado seedlings inoculated with Phytophthora cinnamomi in the glasshouse

Table 4 shows data for the control seedlings which were treated with chemicals but not inoculated with the pathogen. All of the seedlings not inoculated with *P. cinnamomi* had 100% healthy root tips and seedlings were healthy (Table 4).

Table 5 shows data for seedlings treated with chemicals and inoculated with *P. cinnamomi*. Seedlings in *P. cinnamomi* infested soil and drenched with Kasil were no healthier than the control plants (Table 5). Seedlings drenched with phosphonate, however, were significantly healthier with healthier root tips. Kasil mixed with phosphonate did not enhance the treatment nor was it detrimental to its ability to reduce root rot. Neither treatment had an adverse effect on plant growth or root tip health.

Table 4: Effect of Kasil® (potassium silicate) and phosphonate treatments on root tip health and seedling health of 'Reed' avocado seedlings (not inoculated) (n=4)

Treatment		Healthy root tips (%)	Seedling health (1-5)*
Control		100	1
Kasil drench		100	1
Phosphonate drench		100	1.5
Kasil + phosphonate drench		100	1
	P	0	0.07
	lsd	0	0.44

*1 = healthy, 5 = dead

Table 5: Effect of Kasil® (potassium silicate) and phosphonate treatments on root tip health and seedling health of 'Reed' avocado seedlings inoculated with *P. cinnamomi* in the glasshouse (June 2005) (means with the same letter were not significantly different at p<0.05) (n=6)

Treatment		Healthy root tips (%)	Seedling health (1-5)*
Control		0.33 a	4.17 B
Kasil drench		0.00 a	4.17 B
Phosphonate drench		67.50 b	1.67 A
Kasil + phosphonate drench		67.50 b	1.83 A
	P	<0.001	<0.001
	lsd	10.53	0.527

*1 = healthy, 5 = dead

Experiment 3: Evaluation of different formulations of silicon when applied to the roots of young avocado seedlings in the glasshouse

Figures 1 to 5 show the results of treatments given at various time intervals and the subsequent health ratings (%) of the roots (columns) and dry weights (g) of the roots (diamonds). It was found that none of the silicon treatments were effective in the control of root rot and none were as effective as phosphonate drench, which gave significant differences at each time interval. Some of the silicon treatments resulted in fewer healthy roots than the control alone. It was noted that there was some variability between inoculated control plants across the trial.

Root mass data was inconsistent as indicated by the control trees (particularly Figure 5). However, there appeared to be some benefit in adding wollastonite to the roots along with phosphonate in some cases, although the differences were not significantly different in any of the graphs. When phosphonate was added just 2 days prior to inoculation with *P. cinnamomi* it was sufficient to maintain root health but root mass appeared to be inhibited by the presence of the pathogen (Figure 1). When phosphonate was added repeatedly (Figure 5) to seedlings prior to pathogen inoculation, it had a phytotoxic effect on root mass, however, the addition of wollastonite appeared to alleviate this effect. The reason for this is unknown.

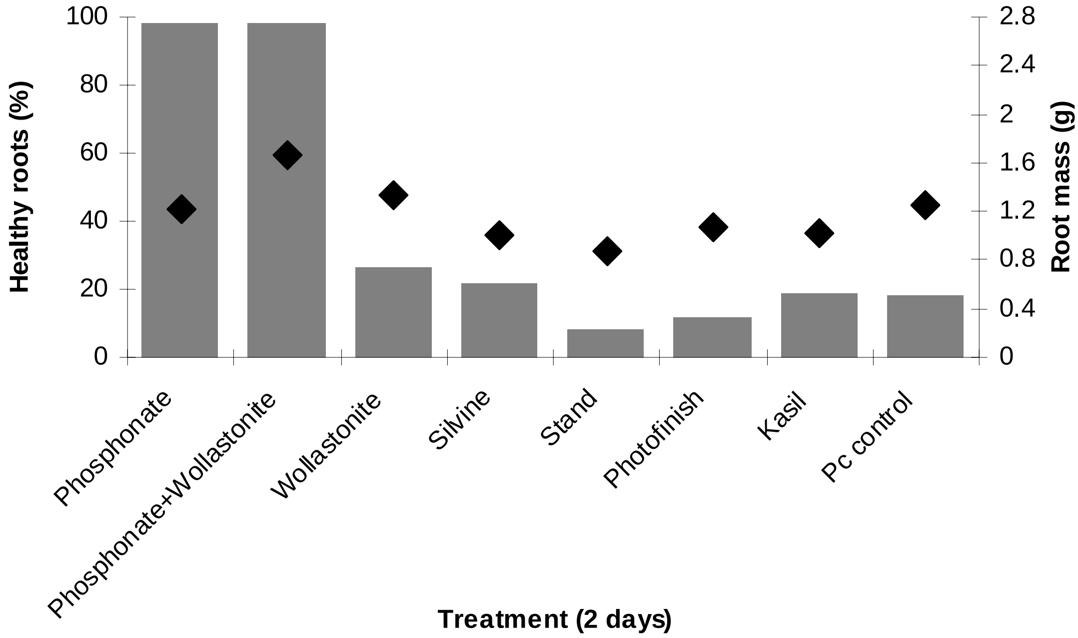

Figure 1: Effect of 5 silicon formulations and phosphonate treatments on root health of 'Reed' avocado seedlings **2 days** prior to inoculation with *P. cinnamomi* in the glasshouse (June 2006) (n=5) (Root mass: lsd = 0.8097, P = 0.607) (Healthy roots: lsd = 23.21, P = <.001)

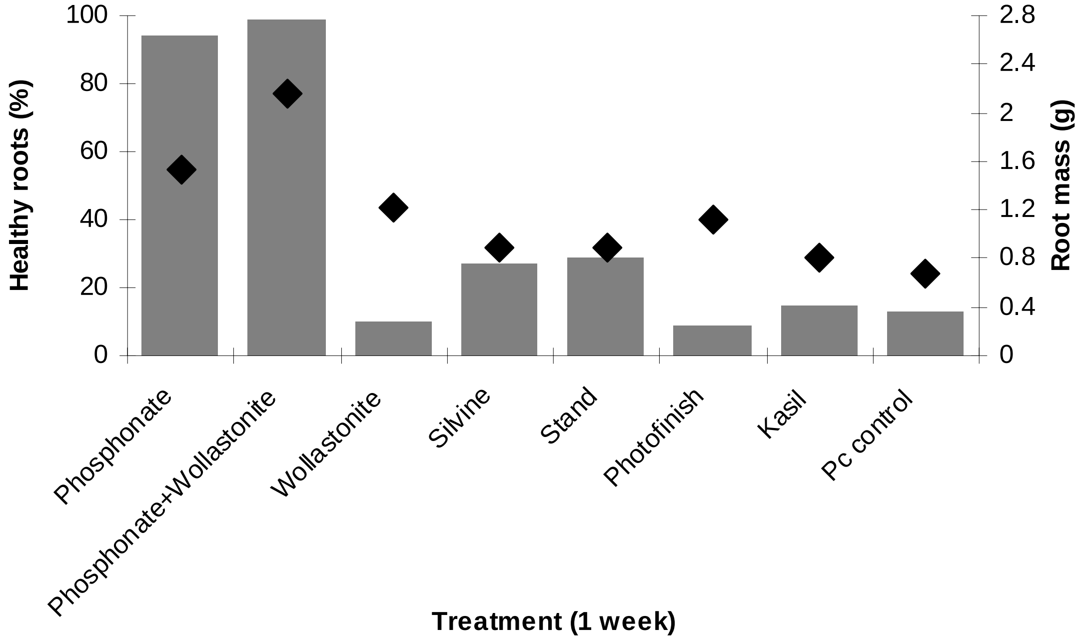

Figure 2: Effect of 5 silicon formulations and phosphonate treatments on root health of 'Reed' avocado seedlings **1 week** prior to inoculation with *P. cinnamomi* in the glasshouse (June 2006) (n=5) (Root mass: lsd = 0.7708, P = 0.011) (Healthy roots: lsd = 19.64, P = <.001)

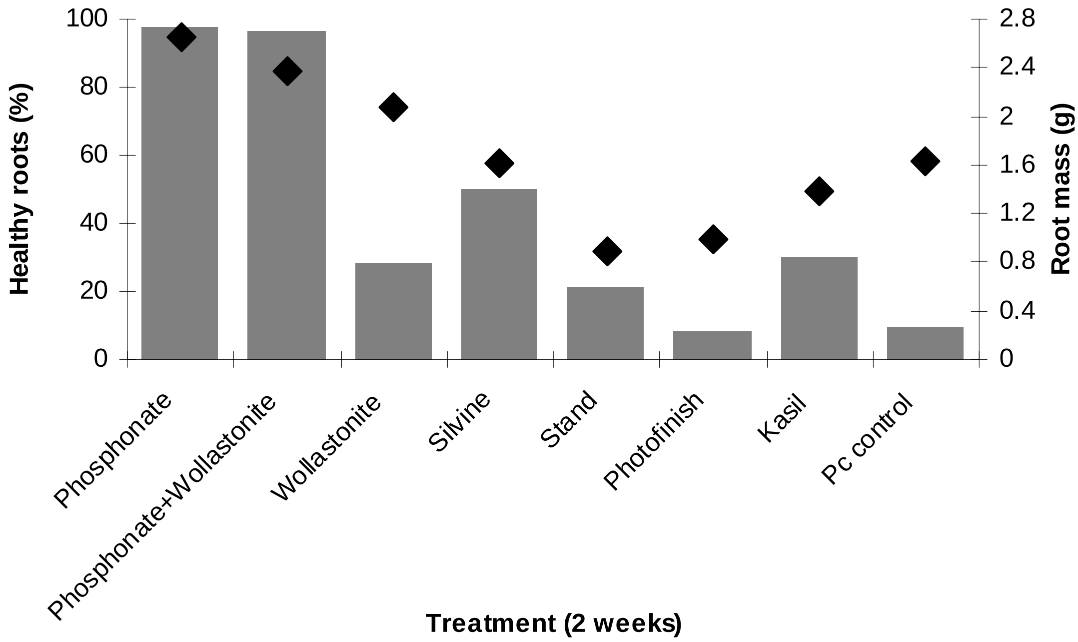

Figure 3: Effect of 5 silicon formulations and phosphonate treatments on root health of 'Reed' avocado seedlings **2 weeks** prior to inoculation with *P. cinnamomi* in the glasshouse (June 2006) (n=5) (Root mass: lsd = 0.8304, P = 0.003) (Healthy roots: lsd= 22.46, P = <.001)

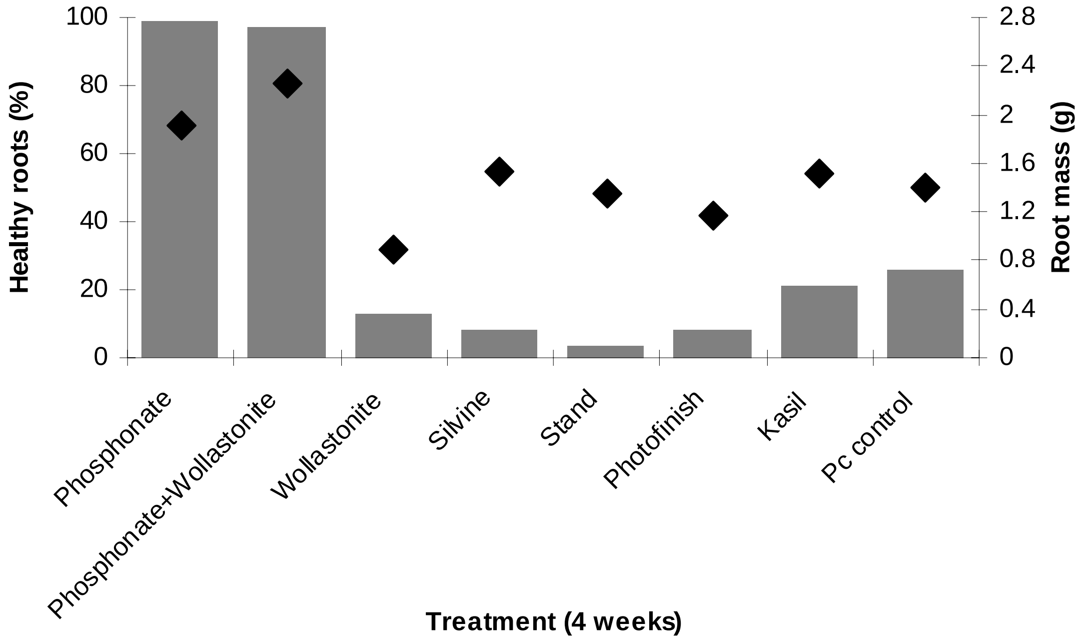

Figure 4: Effect of 5 silicon formulations and phosphonate treatments on root health of 'Reed' avocado seedlings **4 weeks** prior to inoculation with *P. cinnamomi* in the glasshouse (June 2006) (n=5) (Root mass: lsd = 1.024, P = 0.225) (Healthy roots: lsd = 18.92, *P* = <.001)

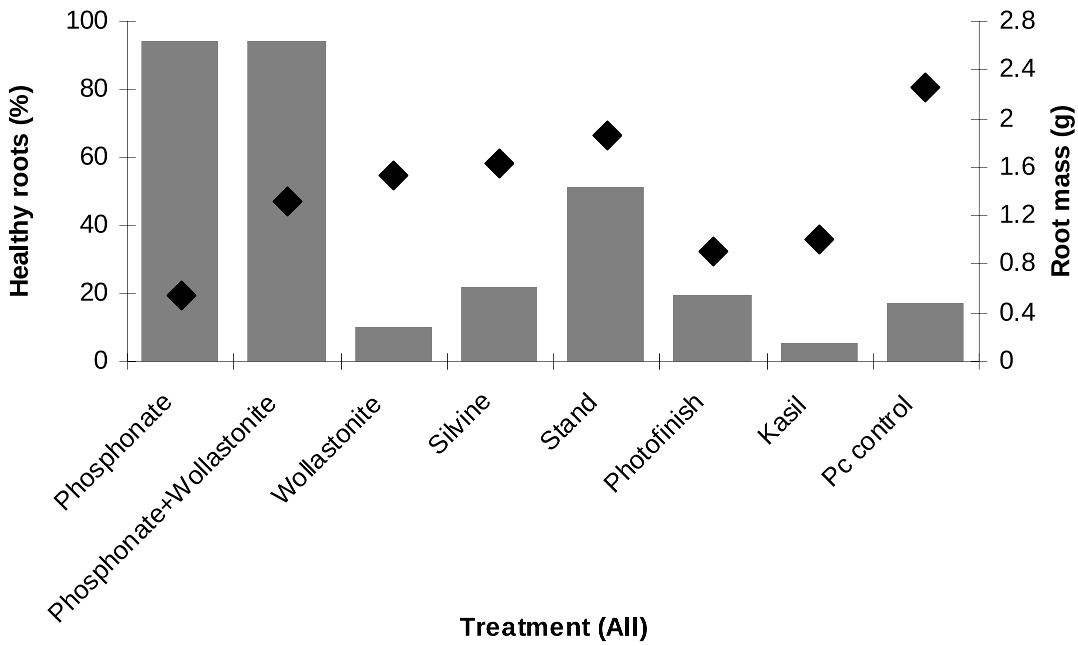

Figure 5: Effect of 5 silicon formulations and phosphonate treatments on root health of 'Reed' avocado seedlings **2 days, 1 week, 2 weeks and 4 weeks** prior to inoculation with *P. cinnamomi* in the glasshouse (June 2006) (n=5) (Root mass: lsd = 1.302, *P* = 0.224) (Healthy roots: lsd = 36.77, *P* = <.001)

4.4.4 Discussion

These experiments so far have found that the application of silicon to avocado trees is not a 'quick fix' disease solution. There are many silicon products available and application rates and timing appear to be critically important. Some recent field work has revealed that application of some forms of silicon may upset the balance of other nutrients in the tree. For the control of root rot, silicon cannot replace phosphonate treatments. Silicon may be found to improve overall tree health and disease resistance and may eventually be incorporated into an effective disease management programme. More experimentation is essential.

Glasshouse experiments showed that silicon can be taken up by the avocado seedling and transported to the leaves. When seedlings were inoculated with the root rot pathogen and assessed for tree and root tip health after application with Kasil, no effect could be seen. Phosphonate treatment, on the other hand, significantly improved tree and root tip health.

Comparisons of a range of different silicon formulations indicated that some effect was achieved for suppression of *P.cinnamomi* in the glasshouse; however, once again, none of the products were as effective as phosphonate.

Although phosphonate is the superior product, it would be desirable to reduce reliance on a single chemical. These preliminary results showed variation in many of the treatments and rates and timing of applications seem to be important. A combination of phosphonate and a silicon product could prove to be beneficial in reducing root infection and improving tree health and to enable avocados to be produced economically in the presence of *P. cinnamomi*. Further research is needed.

4.5 Effect of potassium silicate (Kasil®) injection on avocado trees affected by Phytophthora root rot

4.5.1 Introduction

The aim of this experiment was to provide a preliminary assessment of the ability of potassium silicate (Kasil) to induce a defence response in avocado trees in the field.

4.5.2 Materials and Methods

In a preliminary field experiment, potassium silicate was injected into 'Hass' avocado trees severely affected by Phytophthora root rot at Graham Anderson's property at Duranbah NSW. These trees had an average rating of 5.5 on the 0 (healthy) to 10 (dead) scale used in Phytophthora research (Darvas *et al.* 1984). The following two treatments were applied to four single tree replicates:

1. Untreated control
2. Kasil injection (200ppm) – 200mL/tree

Trees were injected in January 2004 and were assessed for tree health using the Darvas rating scale after 6 weeks, 11 weeks, 15 weeks, 24 weeks, and 31 weeks.

4.5.3 Results and Discussion

The change in tree health over 31 weeks was recorded and it was found that the control trees continued to decline in health, whilst the injected trees made an average tree health improvement of 31.1%. These injections stimulated the rapid growth of dormant epicormic buds with an eventual significant increase in canopy density (Table 6). This rapid vegetative response was thought not to be due to Phytophthora control; however, it did appear to be stimulated by the injection and may have been due to the redistribution of tissue components such as manganese in the tree.

Table 6: Effect of potassium silicate injections on mean tree health improvement in Phytophthora affected trees at Duranbah (means with the same letter were not significantly different at a $P<0.05$) (n=4)

Treatment	Mean tree health improvement (%)
Untreated control	-3.6 a
Kasil injection	+31.1 b

4.6 Evaluation of potassium silicate treatments compared with phosphonate and Pentra-bark® treatments for the control of Phytophthora root rot at Mt Tamborine

4.6.1 Introduction

Pentra-bark is a unique bark periderm penetrating surfactant specifically designed for use on herbaceous woody plant surfaces with Agri-Fos® or Reliant® fungicides for disease control. The fungicidal properties are translocated through the bark layer enabling subsequent transport throughout the vascular system of the plant. This provides an alternative to foliar spraying and injecting for effective control of *Phytophthora* spp. and *Pythium* spp. in woody plants. Pentra-bark was developed in the US in response to the devastation caused by *Phytophthora ramorum* on oak trees.

The aim of these experiments was to test the effectiveness of Kasil injections compared with phosphonate treatment as well as phosphonate mixed with the bark penetrating compound, Pentra-bark.

4.6.2 Materials and Methods

Experiment 1: February 2004 at Mt Tamborine

In February 2004, twenty five trees affected with *Phytophthora cinnamomi* were selected in two orchards at Charlie Eden's property at Mt Tamborine. Trees were assessed on a one to ten rating scale for severity of symptoms of *P. cinnamomi* and blocked according to tree health rating and location. Within each block each tree received one of the following treatments:

1. Untreated control
2. Phosphonate injection (20%)
3. Phosphonate (20%) + Pentra-bark (25mL/L) spray
4. Potassium silicate (200ppm)
5. Potassium silicate (1000ppm)

Trees were assessed after one month.

Experiment 2: November 2004 at Mt Tamborine

In November 2004, another twenty five trees affected with *Phytophthora cinnamomi* were selected in two orchards at Charlie Eden's property at Mt Tamborine. Trees were assessed as described above. Within each block each tree received one of the following treatments:

1. Untreated control
2. Phosphonate injection (20%)
3. Phosphonate (20%) + Pentra-bark (25mL/L) spray
4. Potassium silicate (1000ppm)
5. Potassium silicate (2000ppm)

Trees were assessed after six months.

Experiment 3: February 2005 at Duranbah

In February 2005 twenty four 'Hass' grafted to seedling 'Duke 6' rootstock trees affected by root rot were selected at Duranbah. Trees were rated on the one to ten visual scale and trees rating between 4 and 8 were selected to receive treatments. The trees were blocked according to their rating and six single tree replicates received the following treatments:

1. Untreated control
2. Potassium silicate injection (2000ppm)
3. Phosphonate injection (20%)
4. Pentra-bark (2.5%) + Phosphonate (20%) trunk spray– 400mL/tree

The trees were treated a second time in March 2005 and assessed two months later.

4.6.3 Results and Discussion

In the first experiment, there was little change in tree health ratings after one month. When this experiment was repeated using increased rates of Kasil, six months elapsed before assessments were carried out. Results were insignificant with some trees improving slightly and some declining slightly. However, no distinction could be made between different treatments and even untreated controls and phosphonate treatments gave little response. The third experiment at Duranbah was also inconclusive. It is possible that other factors such as nutrition and insufficient irrigation impeded these trials.

4.7 Evaluation of avocado rootstocks for tolerance to Phytophthora root rot in the field

4.7.1 Introduction

Phytophthora root rot remains the most damaging disease of avocado in many countries where it causes significant tree deaths and reduces yield. The selection of rootstocks with superior root rot tolerance has become a major aspect of the disease management program. Because avocado and *P. cinnamomi* have originated in different parts of the world (Central America and Asia respectively) they are not co-evolved. This means, therefore, that avocado is unlikely to have genetic resistance to this oomycete.

Three ecological races are identified within the avocado species, *P. americana,* and are given varietal status within the species: *P. americana* var. *drymifolia* (Mexican race), *P. americana* var. *guatemalensis* (Guatemalan race) and *P. americana* var. *americana* (West Indian or lowland race). These different races have different horticultural traits which may impact on their susceptibility or tolerance to root rot. Many years ago the root rot tolerant rootstock 'Velvick' (West Indian race) was selected by Dr Tony Whiley. This rootstock, among many others, will be evaluated in our program.

Australian avocado orchards are currently planted on seedling rootstocks, which are genetically diverse and include all three botanical races of avocado. In current research rootstocks have been recovered from old grafted trees still growing well in areas where most surrounding trees have died from root rot. These cloned rootstocks grafted to Hass are being compared with resistant rootstocks developed overseas.

To select for tolerance to root rot, field experiments have been established in replant sites heavily infested with *P. cinnamomi.* These trials will evaluate all aspects of tree health and productivity and will continue for several years.

4.7.2 Materials and Methods

Experiment 1: Tolerance to P. cinnamomi in 18-month-old Hass grafted to three seedling rootstocks planted in infested soil at Hampton

The aim of this trial was to undertake a preliminary assessment of young trees in the field.

This field trial was established at Graeme Thomas' property at Hampton in 2004. Included in this trial were 30 'Hass' on rootstock 'A8', 34 'Hass' on rootstock 'A10' and 34 'Hass' on rootstock 'Velvick'. Trees were sown in adjacent rows down a block, with high disease pressure at one end. The foliage of individual trees was visually rated at monthly intervals on a scale of 0 -10 (Darvas *et al.* 1984) where 0 = healthy and 10 = totally defoliated.

Experiment 2: Effect of rootstock on mineral nutrient concentrations in the leaves and rootlets of 4 month old ungrafted avocado seedlings

The aim of this trial was to undertake a preliminary analysis of mineral nutrient concentrations in two different rootstocks.

Four-month-old ungrafted avocado plants were selected for these analyses. Ten single tree replicates of each of the following rootstocks were used:

1. 'A10'
2. 'Velvick'

Six leaves were harvested from the top of each plant for mineral analyses and root tips were sampled and analysed as well. Samples were dried and ground and sent to SGS Agritech, Toowoomba.

Experiment 3: Evaluation of tolerance of avocado rootstocks in P. cinnamomi infested soil at Duranbah NSW

The aim of this trial was to establish a long-term field site for the assessment of 'Hass' on a range of avocado rootstocks as they become available for their tolerance to root rot in replant land at Duranbah NSW.

Old, diseased trees were removed from the field in early 2006 and the tree block was ploughed. The site was divided into four raised beds, each with two planting rows. The trial was completely randomised in blocks across the rows. Ten replicates of the following eleven rootstocks were included in this trial:

1. ‘Merensky 1’ Latas (clone)
2. ‘Merensky 2’ Dusa (clone)
3. ‘Velvick’ (clone)
4. ‘Velvick’ (seedling)
5. ‘Duke 7’ (clone)
6. ‘Barr Duke’ (clone)
7. ‘Thomas’ (clone)
8. ‘A10’ (seedling)
9. ‘Reed’ (seedling)
10. ‘GE’ (clone)
11. ‘Hass’ (clone)

Young rootstocks (ca. 8 months old) were planted in May 2006. As rootstocks are extremely sensitive to *P. cinnamomi* for 12-18 months after planting, remedial treatments were applied so that trees had the opportunity to express their tolerance. Ridomyl/Metalaxyl was applied to the soil surface at planting (100mL per tree) and again three months later. Potassium phosphonate was used to drench nursery trees and, after planting, was applied to the foliage and stems at regular intervals. Trees were tied to stakes and planter bags were left around the trees for protection. Tree spacing within rows is 3m.

The foliage of individual trees was visually rated at monthly intervals on a scale of 0 - 10 (Darvas *et al.* 1984) where 0 = healthy and 10 = totally defoliated.

Experiment 4: Evaluation of tolerance of avocado rootstocks in P. cinnamomi infested soil at Hampton QLD

The aim of this trial was evaluate the tolerance of 'Hass' avocado rootstocks to *P. cinnamomi* in replant land at Hampton QLD.

This trial was conducted in a relatively flat replant block. Three rows were used and the completely randomised design was blocked across the rows. Nine replicates of the following seven rootstocks were used:

1. 'Merensky 2' Dusa (clone)
2. 'A10' (seedling)
3. 'Barr Duke' (clone)
4. Toro Canyon' (clone)
5. 'SHSR-01' (seedling)
6. 'V1' (seedling)
7. 'Velvick' (seedling)

Young rootstocks (ca. 8 months old) were planted in December 2005. Trees were planted using the same guidelines as in Experiment 3.

Experiment 5: Evaluation of tolerance of avocado rootstocks in P. cinnamomi infested soil at Childers QLD

The aim of this trial was evaluate the tolerance of 'Hass' avocado grafted to various rootstocks in *P. cinnamomi* infested replant land at Childers, Central QLD.

The trial was established in a known infested block at Childers. The block had been fallow for less than a year, after removal of very old, unhealthy trees. Trees were removed entirely. The field site is a valley. The trial was single row able to contain 86 trees. Trees were randomly planted in blocks along the row. Ten replicates of each of the following rootstocks were used:

1. 'A8' (seedling)
2. 'A10' (seedling)
3. 'Merensky 1' Latas (clone)
4. 'Merensky 2' Dusa (clone)
5. 'Reed' (seedling)
6. 'Velvick' (seedling A)*
7. 'Velvick' (seedling B)*
8. 'Velvick' (clone)

*seedling A=Anderson, seedling B=Simpson

Young rootstocks (ca. 8 months old) were planted in May 2006. Trees were planted using the same guidelines as in Experiment 3.

4.7.3 Results

Experiment 1: Tolerance to P. cinnamomi in 18-month-old Hass grafted to three seedling rootstocks planted in infested soil at Hampton

Under low disease pressure, the 'Velvick' seedling rootstock showed superior root rot tolerance but this level of tolerance was insufficient under high disease pressure (Table 7). The 'A10' rootstock is known for its ability to rapidly replace damaged feeder roots but failed under both conditions, indicating that rootstock vigour does not necessarily equate to Phytophthora tolerance.

Table 7: Tolerance to *P. cinnamomi* in 18-month-old 'Hass' grafted to three seedling rootstocks planted in infested soil at Hampton (n= 30-34)

Rootstock	Mean tree health (0-10)*	
	Low disease pressure	**High disease pressure**
'Velvick' (West Indian race)	1.3	6.6
'Anderson 10' (Guatemalan race	5.8	7.2
'Anderson 8' (Guatemalan race	5.9	7.3

* tree health on 0 (healthy) to 10 (dead) scale (Darvas *et al.* 1984)

Experiment 2: Effect of rootstock on mineral nutrient concentrations in the leaves and rootlets of 4 month old ungrafted avocado seedlings

'Velvick' had significantly lower concentrations of N in the rootlets (but not leaves) and lower K (roots and leaves), Mg (roots only), B (leaves only), with higher Ca and Fe in the roots (Table 8). In future studies, it is likely that different rootstock/scion combinations will be found to vary in their uptake, transport and assimilation of different nutrients and this will be monitored.

Table 8: Effect of rootstock on mineral nutrient concentrations in the leaves and rootlets of 4 month old ungrafted avocado seedlings grown in the glasshouse (means with the same letter were not significantly different at a *P*<0.05) (n=10)

Rootstock	**N** %	**P** %	**K** %	**Ca** %	**Mg** %	**Na** %	**S** %	**Zn** mg/kg	**Fe** mg/kg	**Cu** mg/kg	**Mn** mg/kg	**B** mg/kg	**Mo** mg/kg	**Ca+Mg/K** ratio	**N/Ca** ratio
Leaves															
Velvick	2.98	0.242	1.232 b	0.903	0.518	0.0342 a	0.261	38.8	111.9 a	8.2	504	46.9 b	0.124	1.156	3.364
A10	3.05	0.267	1.443 a	0.991	0.557	0.0245 b	0.246	33.3	80.0 b	13.3	499	64.6 a	0.253	1.084	3.104
P	n.s	n.s	0.004	n.s	n.s	0.008	n.s	n.s	<0.001	n.s	n.s	<0.001	n.s	n.s	n.s
lsd			0.133			0.00687			12.47			5.51			
Rootlets															
Velvick	3.53 b	0.333	4.36 b	0.289 a	0.590 b	0.135	0.206	86.5	576 a	11.84	290	44.6	0.41	0.2019	12.49 b
A10	3.99 a	0.39	4.88 a	0.240 b	0.830 a	0.095	0.192	75.2	377 b	11.59	319	43.3	0.44	0.224	16.88 a
P	0.016	n.s	0.019	0.003	<0.001	n.s	n.s	n.s	0.013	n.s	n.s	n.s	n.s	n.s	0.003
lsd	0.3619		0.422	0.0296	0.1183				152.3						2.669

Experiment 3: Evaluation of tolerance of avocado rootstocks in P. cinnamomi infested Duranbah soil

Results so far have identified some superior rootstocks (Table 9). It appears that the performance of clonal rootstocks is exceeding that of the seedling rootstocks. At the high pressure Phytophthora site at Duranbah, 'Hass' grafted to cloned GE is showing a very high level of tolerance to *P. cinnamomi* (Table 9). It has also been noted that 'Hass' growing on its own roots is doing well and it is supposed that the lack of graft union in these trees has allowed for better vigour due to uninhibited nutrient flow.

Table 9: Performance of 12-month-old seedling and clonal rootstocks planted in *P. cinnamomi* infested replant soil at Duranbah NSW (where 0 = healthy and 10 = dead) (means with the same letter were not significantly different at $P<0.05$) (n=10)

Rootstock		**Mean tree health (0-10 rating)**
M1 Latas clone		5 ab
M2 Dusa clone		3.5 bcd
Velvick clone		4 bcd
Velvick seedling		4.3 abcd
Duke 7 clone		4.4 abcd
Barr Duke clone		4.78 abc
Thomas clone		3.7 bcd
A10 seedling		4.9 ab
Reed seedling		6.8 a
GE clone		2.089 d
Hass clone		2.1 cd
	P	0.048
	lsd	2.686

This trial will continue for several years into Project AV07000.

Experiment 4: Evaluation of tolerance of avocado rootstocks in P. cinnamomi infested soil at Hampton QLD

In the replant site at Hampton, 'Hass' grafted to cloned 'Dusa' were the healthiest trees together with 'Hass' grafted to cloned 'Barr Duke', to seedling 'SHSR-01', to cloned 'Toro Canyon' and to seedling 'Velvick' (Table 10). Previous results from South Africa also found a high level of disease tolerance in the rootstock 'Dusa (Kremer-Köhne and Duvenhage 2000 and Kremer-Köhne *et al*. 2001).

This trial will continue for several years into Project AV07000.

Table 10: Performance of 18-month-old seedling and clonal rootstocks planted in *P. cinnamomi* infested soil at Hampton QLD (where 0 = healthy and 10 = dead) (means with the same letter were not significantly different at $P<0.05$) (n=10)

Rootstock		Mean tree health (0-10 rating)
V1 seedling		4.79 a
A10 seedling		4.44 ab
Velvick seedling		2.33 abc
Toro Canyon clone		2.11 abc
SHSR-01 seedling		1.88 abc
Barr Duke clone		1.67 bc
Merensky 2 clone		0.11 c
	P	0.044
	lsd	3.021

Experiment 5: Evaluation of tolerance of avocado rootstocks in P. cinnamomi infested soil at Childers QLD

This field trial has been established for over 12 months. Although this site is purported to be a heavily infested replant site, the drought appears to have reduced the inoculum level and, consequently, all irrigated trees are performing equally well. These trees have not received any fungicide treatments since November 2006, yet there are no signs of disease.

This trial will continue for several years into Project AV07000. Dr Danielle Le Lagadec will continue to monitor trees.

4.7.4 Discussion

Rootstock results clearly revealed the problems faced by industry and the vital need for large scale experimental trials to be undertaken in a range of avocado growing regions.

‘Velvick’ seedlings have shown superior root rot tolerance under low disease pressure, but this level of tolerance is insufficient under conditions of high disease pressure. ‘Anderson 10’, a rootstock with an outstanding ability to rapidly replace damaged feeder roots, has failed in both situations. This illustrates that the capacity to replace roots, lost to disease or other factors, is alone insufficient to cope with the pathogen. It appears that ‘Velvick’, under reasonable disease pressure, may have natural defence mechanisms to minimise infection. As studies by George Zentmyer at The University of California in the 1950s-60s showed that the tolerance factor is only inherited in 1% of seedlings, clones of 'Velvick' have been included in recent field trials. Thus any studies in the pursuit of greater tolerance to root rot will benefit from a greater understanding of the host/pathogen interaction. The capacity of these natural defence responses will vary considerably with rootstock.

Other rootstocks such as 'GE' and 'Merensky 2' (Dusa) are doing well under high disease pressure and time will tell if they are able to maintain their resilience beyond their first year. It has also been noted that 'Hass' growing on its own roots is doing well and it is supposed that the lack of graft union in these trees has allowed for better vigour due to uninhibited nutrient flow to the roots. Graft unions can reduce the flow of carbohydrates to the roots (Whiley 1994) and, therefore, reduce the ability to regenerate roots. Although trees may be graft compatible, various stock/scion combinations vary in their physiological compatibility, which may influence this carbohydrate flow, affecting vigour and defence and, consequently, *P. cinnamomi* tolerance. This is an aspect to be further considered.

Mineral analyses of roots showed that rootstocks can vary in their nutrient uptake and this may correlate to Phytophthora tolerance in rootstocks. It is likely that root rot affected rootstocks will probably also vary in their ability to respond to phosphonate applications. Eventually, correlations between nutrient contents in the plants and phenolics will be assessed. All aspects of avocado production will be assessed through our disease trial orchards in the coming years. This work will continue into project AV07000.

Several field sites have since been established to assess a larger range of rootstocks for their tolerance in heavily Phytophthora infested soil. These trials will continue into the new avocado project (AV07000), although early results will be reported to industry. We have included both seedling and clonal rootstocks sourced from Dr Whiley's Rootstock Improvement programme as well as from Anderson's and Birdwood Nurseries. We now have two experimental sites at Duranbah, NSW (planted in May 2005 and May 2007), two experimental sites at Hampton, QLD (planted in December 2005 and December 2006) and one experimental site at Childers, QLD (planted May 2006).

4.8 Evaluation of phosphonate application of avocado in the field

4.8.1 Introduction

During the 1960s and 70s in Australia, Phytophthora epidemics destroyed entire orchards and the disease threatened the existence of the industry. A major breakthrough occurred in the early 1980s when cost effective injections of phosphorous acid (phosphonate) were found to reduce the disease (Darvas *et al.* 1984). Phosphonate is systemic in the avocado tree and high concentrations can occur in developing fruit, shoot and root tips. It is believed to work against Phytophthora at high concentrations by retarding hyphal growth. Phosphonate may also work indirectly by stimulating plant defence mechanisms. This occurs when phosphonate levels are low within the roots and release of stress metabolites from Phytophthora trigger host defence systems. These natural plant defence systems then bring the invasion under control. In addition, low levels of phosphonate significantly reduce sporulation of *P. cinnamomi* (Guest *et al*. 1995)

It has previously been shown for avocado that a concentration of phosphonate required to protect or rejuvenate feeder roots could not be absorbed through the bark of older trees. However, an organosilicone bark penetrating translocation aid (Pentra-bark®) has been developed to allow phosphonate to be absorbed through the bark of oak trees in the USA at a sufficient concentration for the control of *Phytophthora ramorum*. It has been determined that a phosphonate root level between 25 to 40ppm is required to protect the roots (pers. comm. Whiley 2000, Sunshine Horticultural Services Pty Ltd). Hence, our trials are comparing trunk sprays with trunk injections for control of root rot. For the trunk sprays phosphonate was used in combination with Pentra-bark as well as the organosilicone penetrant Pulse® (similar to Pentra-bark) and different rates are being assessed. Samples have been routinely collected for phosphonate analyses to monitor its movement and decline in leaves, roots, flowers and fruit over time.

4.8.2 Materials and Methods

Experiment 1: Application of phosphonate by trunk injection or by trunk spray at Duranbah

The aim of this trial was to test the effectiveness of applying phosphonate to tree trunks using Pentra-bark as a bark penetrant.

This trial was carried out on root rot affected 'Hass' trees at Duranbah NSW. Treatments were applied to five single tree replicates in a completely randomised design. The following treaments were used:

1. Untreated control
2. Phosphonate trunk injection (20% Agrifos - 200mL/tree)
3. Phosphonate trunk spray (20% Agrifos – 400mL/tree)
4. Phosphonate + Pentra-bark trunk spray (20% Agrifos - 400mL/tree + 2.5% Pentra-bark)

Trees were treated in December 2003. A second spray treatment was applied in January 2004. Tree health was assessed for improvement over time.

Experiment 2: Application of phosphonate by trunk injection or by trunk spray at Hampton

The aim of this trial was compare application methods for phosphonate.

This trial was carried out on healthy 'Hass' grafted to seedling 'Duke 6' rootstock trees at Hampton QLD. These trees had never been treated with phosphonate. Trees were selected randomly with two treatments and seven single tree replicates. The following treatments were applied:

1. Trunk injections (20% acid)
2. Trunk spray (10% acid + 0.5% Pentra-bark)

Treatments were applied to the trees in February 2005. Trunk injections of phosphonate followed the industry standard rate of 15mL/m^3 of canopy of 20% acid buffered to pH 7.4 (Pegg *et al*. 1987). Trunk spray trees received 150mL of acid/Pentra-bark solution which was applied to the trunk of the tree up to 1.5m using a wide paintbrush.

Seven days after treatment, root samples were taken 1m out from the base of the tree, below injection sites for injected trees and from the same location under trees which had received trunk sprays. Sixteen (four per quadrant) newly mature leaves were sampled at a uniform height from around the tree canopy. Samples were taken monthly for three months. After four months, root samples were taken prior to re-treatment. Trees were again sampled monthly. Samples were analysed for phosphorous acid content (Agritech, Toowoomba). Root abundance was also assessed.

Experiment 3: Trunk spray application of phosphonate using Pulse

The aim of this experiment was to compare the application of phosphonate using Pulse and comparing this with trunk injections.

In this trial, Pentra-bark was replaced with a similar product, Pulse (a bark penetrant used with Round-up for woody plants), as Pentra-bark caused flocculation of the blue vegetable dye present in the commercial phosphonate products, which led to spraying difficulties.

This trial was carried out on healthy four-year-old 'Reed' grafted to Velvick seedling rootstock trees, which had never been treated with phosphonate fungicides. Trees were selected randomly with two treatments and ten single tree replicates. The following treatments were applied:

1. Trunk injections (20% Ausphos 600)
2. Trunk spray (20% Ausphos 600 + 2% Pulse)

Treatments were applied to the trees in June 2006. Trunk injections of phosphonate followed the industry standard rate (Pegg *et al*. 1987). The volume of chemical injected was equivalent to the volume sprayed on the trunk.

In January 2007, a further application, using double the volume, was applied to the trunk sprayed trees only.

Root and leaf samples were harvested 1 month after initial treatment and then every 3 months after that. The most recent sample collection was in June 2007. Samples were taken as previously described. Flower and fruit samples were also taken as they became available.

4.8.3 Results

Experiment 1: Application of phosphonate by trunk injection or by trunk spray at Duranbah

Tree health improvement was assessed in this trial. Even though root levels of phosphonate may be less in trees receiving trunk sprays, this treatment was as effective as trunk injection for the recovery of severely affected trees in a field trial at Duranbah (Table 11).

Table 11: Improvement in health in 'Hass' trees severely affected by Phytophthora root rot at Duranbah (n=6)

Treatment	Improvement in tree health (%)
Untreated control	0
Trunk injection	15.8
Trunk spray	12.2

Experiment 2: Application of phosphonate by trunk injection or by trunk spray at Hampton

In this trial, where treatments were applied at early vegetative flushing, the concentration of phosphonate in the feeder roots was significantly higher in the injected trees (Table 12) and this was also the case in the leaves. The considerably lower leaf phosphonate levels after trunk spraying indicate that phosphonate applied in this way provides a lower but more consistent supply of phosphonate transported via the phloem into the roots where it is needed, with little or none ending up in the canopy, thus reducing the potential for unwanted fruit residues. When injected, most of the phosphonate travels to the leaves via the xylem (Figure 6) and then down to the roots (Guest *et al*. 1995). This occurs because the translocation to root tissue is affected by source/sink relationships at the time of injection.

Table 12: The concentration of phosphonate in leaf and root samples from trunk injection/ trunk sprays at Hampton (trees treated February 2005 and retreated June 2005) (means with the same letter were not significantly different at $P<0.05$) (n=7)

	24.2.05*		**15.3.05***		**14.4.05***		**16.5.05***		**21.6.05***		**26.7.05***		**8.8.05***		**8.9.05***		**13**
	Roots (mg/kg)	Leaves (mg/kg)	Roots (mg/kg)	Leaves (mg/kg)	Roots (mg/kg)	Leaves (mg/kg)	Roots (mg/kg)	Leaves (mg/kg)	Roots (mg/kg)	Leaves (mg/kg)	Roots (mg/kg)	Leaves (mg/kg)	Roots (mg/kg)	Leaves (mg/kg)	Roots (mg/kg)	Leaves (mg/kg)	Roots (mg/k
Trunk injection	30.4 a	220 a	47.1 a	228 a	58.0 a	125.1 a	52	95 a	47.4 a	40.6 a	70 a	74 a	78.9	300	76	98.6	44.6
Trunk spray	9.1 b	5 b	15.3 b	9 b	23.0 b	5.0 b	24.7	6 b	12.1 b	5.0 b	21 b	5 b	26.3	5	21	37.9	16.3
P	0.002	<0.001	0.019	0.002	0.034	<0.001	0.111	0.005	0.024	0.003	0.044	0.016	0.018	<0.001	0.024	<0.001	0.01
lsd	11.39	60.1	25.75	119.3	31.97	31.51	ns	57.2	29.8	20.53	48.1	53.4	41.91	124.7	46.4	29.66	20.39

* Some samples were at non-detectable levels, i.e. less than 5 mg/kg – for statistical purposes these values were changed to 5 mg/kg

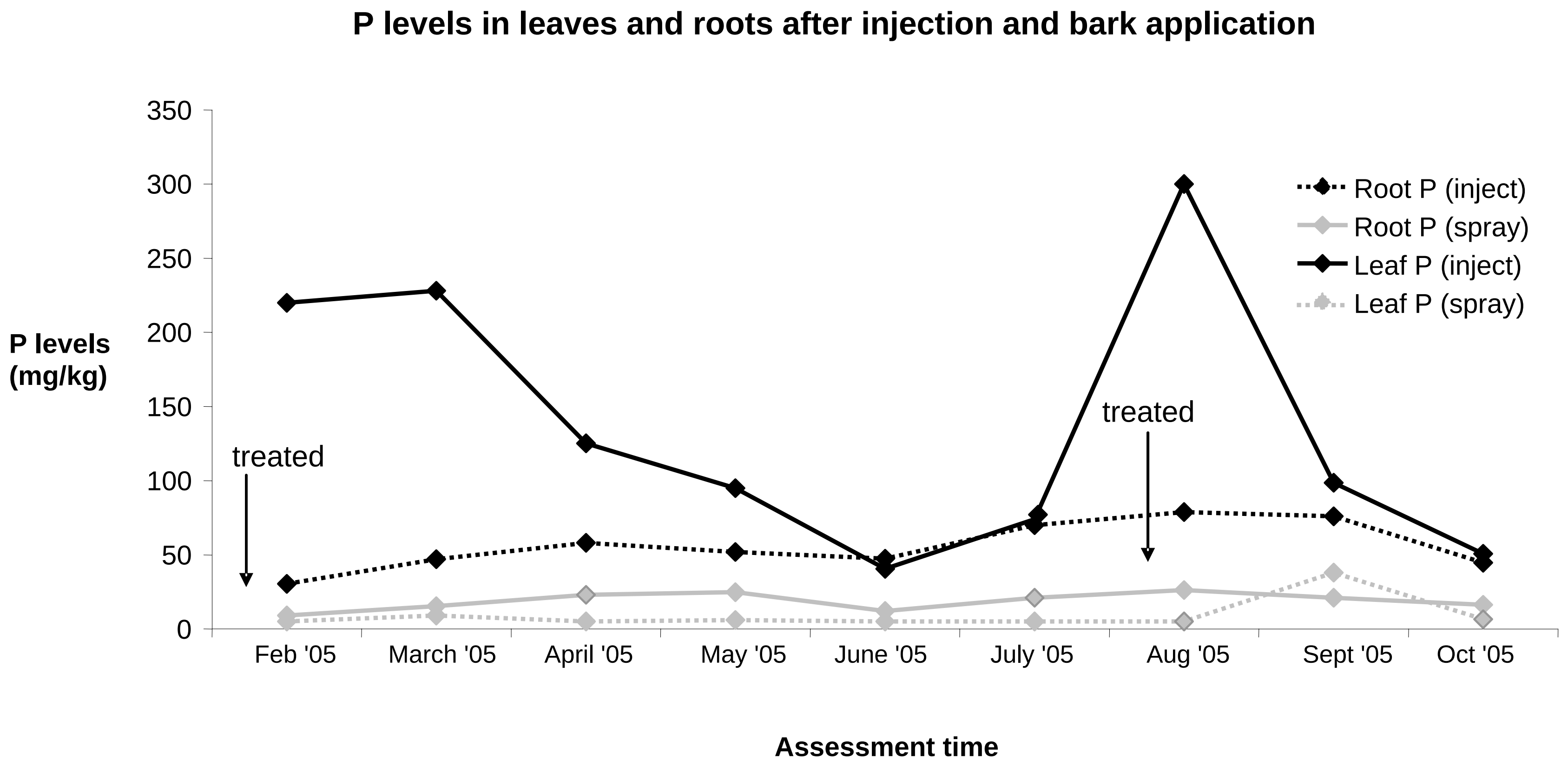

Figure 6: The concentration of phosphonate in leaf and root samples from trunk injection/ trunk sprays at Hampton (trees treated February 2005 and retreated June 2005) (n=7)

It was also found that feeder root development was inhibited under injected trees (Table 13), suggesting that high phosphonate levels in root tips in the early stage of the feeder root flush can have an adverse but temporary effect on root growth. As this reduction in root mass may be detrimental, it reinforces the recommendation to delay injections until the vegetative flushing, as well as the root flushing, is complete (late April/early May in subtropical Queensland when most of the canopy is in a quiescent stage). It has also been found that growers achieve a higher root concentration which persists longer by delaying injections (pers. comm. Thomas 2005, G.L.T. Horticultural Services Pty Ltd). He has found that growers achieve a higher root concentration and this concentration persists longer by delaying injections until June/July in subtropical Queensland when the feeder root system is fully developed but before flower bud development is advanced.

Table 13: The effect of trunk injection or trunk spray at Hampton on feeder root mass four months after treatment (means with the same letter were not significantly different at $P<0.05$) (n=7)

Application method		Mean root mass[1]
Trunk injection[2]		2.14 b
Trunk spray[3]		2.86 a
	P	0.004
	lsd	0.44

1. 1 = roots sparse, few roots, 2 = roots present, network not developed, 3 = roots abundant, network developed
2. Injection 20% phosphonate
3. Sprays 50% phosphonate (20% soln) + 50% water + 2.5% by volume Pentra-bark

Experiment 3: Trunk spray application of phosphonate using Pulse

In this trial, where treatments were applied after vegetative and root flushing, even though injected trees generally gave higher levels of phosphonate in the roots (Table 14) the trunk spray treatment using the same chemical volume per tree gave sufficient levels to control root rot for 6 months. Re-application of trunk spray was necessary after 6 months as phosphonate levels in the roots had dropped below the optimal level for disease control. Leaf analyses (Table 15) show the undesirable movement of phosphonate to the tree canopy after injection. The benefit of using trunk spray treatment is that leaf levels remain consistently low.

Table 14: The mean concentration (mg/kg) of phosphonate in root samples from trunk injected/trunk sprayed avocado trees at Hampton 2006-2007

	Sampling time				
	Jul 06	Oct 06	Dec 06	Mar 07	Jun 07
Trunk spray	30.3	33.6	16.7	48.7	46.2
Trunk injection	65.8	34.7	47.2	63.3	48.1

Table 15: The mean concentration (mg/kg) of phosphonate in leaf samples from trunk injected/trunk sprayed avocado trees at Hampton 2006-2007

	Sampling time				
	Jul 06	Oct 06	Dec 06	Mar 07	Jun 07
Trunk spray	5.7	5.0	6.4	6.2	<5
Trunk injection	114.8	5.1	38.7	5.0	<5

4.8.4 Discussion

Phosphonate is a cost-effective chemical for reducing the impact of *P. cinnamomi*. It can be applied as a soil drench, foliar spray, trunk spray or pressurised trunk injection. Phosphonate concentrations in roots are maintained at high levels for a longer time when applied as injections. Injections are the best way to rejuvenate severely affected trees. Timing in relation to tree phenology is crucial in obtaining maximum levels and persistence of phosphonate in roots. This is because the translocation to root tissue is affected by source/sink relationships at the time of injection. Current studies have shown that for maintaining tree health, single annual injections made after leaf and root flushing are complete, give a high root concentration of phosphonate that persists for 12 months. As wound damage to trunks from injections is of concern to some growers, experiments are underway using organo-silicate bark penetrants added to the phosphonate solution to increase absorption from trunk sprays. Studies have shown that we are able to adequate levels of phosphonate into the roots to maintain root rot control by using trunk sprays of phosphonate mixed with a bark penetrating surfactant such as Pentra-bark or Pulse.

We have been conducting studies on the influence of phosphonate on the development of the feeder root system. It is not known why high levels of phosphonate in root tips inhibit feeder root growth. It is possible that there is a specific reaction to PO_3^{2-} ions and an interaction with root phosphate levels or that osmotic stress is caused by a high concentration of PO_3^{2-} ions. It is also possible that production of chromosome abnormalities in root tips could interfere with cell division (mitosis). Cytological research would be required to determine whether phosphonate affects cell division in avocado root tips and causes a reduction of root growth.

These experiments are ongoing and it is anticipated that we will have a more cohesive disease management recommendation to deliver to avocado growers in the future. The cost implications and environmental impacts of the various application methods for phosphonates will be an important component of our analyses.

5. Fruit disease studies

5.1 Introduction

Despite research and development of fungicides to control fruit diseases of avocado, the challenge still remains to increase the percentage of healthy fruit reaching the market place. The most important postharvest disease of avocado fruit is anthracnose and is particularly serious in high-rainfall growing regions of the world (Pegg *et al*. 2002). Anthracnose is predominantly caused by the fungus, *Colletotrichum gloeosporioides* (Penz.) Penz. and Sacc. This fungus is also responsible for preharvest anthracnose and pepper spot. Another important disease of avocado fruit is stem-end rot. Several fungal pathogens can cause this disease, such as *Colletotrichum gloeosporioides*, *Dothiorella* spp., *Lasiodiplodia theobromae* (Pat.) Griff. and Maubl., *Thyronectria pseudotrichia* (Schwein.) Seeler and others. Control strategies are crucial and a management program needs to be maintained throughout the growing season.

The aim of these experiments was to maintain increased fruit quality through reduced synthetic chemical dependence.

Statistical analysis
The data were analysed using Genstat® seventh edition (Lawes Agricultural Trust, Rothamsted Experimental Station). Most analyses used analysis of variance (ANOVA) in randomised blocks incorporating Fisher's pairwise comparison tests, unless stated otherwise.

5.2 The effects of particle film application on avocado fruit

5.2.1 Introduction

Surround® WP is a natural mineral-based product for the management of heat stress and for the suppression of insect pests and plant diseases. When applied to plants a dry white film is produced. Thorough, uniform and consistent coverage is essential for best results and it should be applied before the onset of hot summer conditions and maintained during the hot season.

5.2.2 Materials and Methods

Experiment 1: Field trial at Duranbah (2003/2004 season)

The aim of this experiment was to evaluate the effect of a particle film (Surround® WP) based on kaolin (an aluminosilicate mineral) for the management of heat stress and disease in 'Hass' avocado fruit.

The field trial was conducted on a block of 4-year-old 'Hass' avocado trees grafted to clonal 'Velvick' rootstocks on Graham Anderson's property at Duranbah NSW. The trial design was randomised with two treatments and ten single tree replications. Treatments were:

1. Untreated control
2. Surround spray

Applications commenced at fruit set and continued at monthly intervals until the onset of cool weather. The first application was in late spring (November) 2003 at a rate of 5kg Surround per 100L of water. The suspension was applied by spraying to run-off to obtain an even coverage on the top surface of leaves, fruit and stems. Further applications (Table 16) were applied at a rate of 2.5kg/100L water. Where significant rainfall had occurred since the last application, the rate was increased to 5kg/100L water. Once good coverage was achieved on the trees and the weather had cooled, applications ceased. The final application was in late summer (February) 2004.

Table 16: Application timing and rate of Surround® WP at Duranbah NSW 2003/2004

Application number	Date	Rate (kg Surround/100L of water)
2	11th November 2003	2.5
3	11th December 2003	2.5
4	23rd December 2003	5
5	21st January 2004	5
6	20th February 2004	2.5

Fruit on the south-east and north-west sides of the trees were assessed for sunburn and yellowing in March 2004. Fruit were assessed by randomly selecting 30 fruit at each aspect and counting the number of fruit which were healthy (no markings), sunburnt (black markings) or photo-oxidised (yellow markings). In July 2004, twenty fruit per tree were randomly selected and the number of the scale insects *Hemiberlesia lataniae* (*H. lataniae*) per fruit rated to compare treatment effects.

Fruit were harvested in July 2004. Eight fruit were taken from all 20 trees to determine maturity (dry matter analysis). The first five tree replicates for each treatment were strip picked and the fruit counted and weighed to give an average fruit weight. From all 20 trees, two commercial count 20 trays of fruit were harvested from both east and west sides of the trees and ripened at 22°C (65% RH). Fruit were assessed for disease development at the eating ripe stage which was determined by applying gentle hand pressure to fruit. Fruit were assessed for the development of anthracnose by determining the percentage of surface area affected. Fruit were assessed for stem-end rot by determining the volume of stem flesh affected. The causal organism of the stem-end rot was determined by making isolations onto streptomycin-amended potato dextrose agar (SPDA). Plates were incubated under near UV light for 2 weeks to encourage spore development. Treatments were compared for maturity (dry matter), fruit weight and anthracnose and stem end rot development.

Experiment 2: Inoculation with benlate resistant Colletotrichum gloeosporioides isolate

The aim of this experiment was to evaluate the ability of Surround® WP to provide a barrier against infection by the anthracnose pathogen *Colletotrichum gloeosporioides* (*Cg*).

The field trial was conducted on a block of 4-year-old 'Hass' avocado trees grafted to clonal 'Velvick' rootstocks at Duranbah NSW. The trial design was randomised with two treatments and three single tree replications. Treatments were:

1. Untreated control
2. Surround® WP spray

In January 2004, a spore suspension ($1x10^6$ spores/mL water + 0.01% Tween 80) of a benlate resistant isolate of *Colletotrichum gloeosporioides* (BRIP 19778) was prepared. Thirty-six fruit (6 fruit per tree) were selected for treatment and the fruit were dipped in the spore suspension and then covered with a plastic bag and white sandwich bag for 48 hours to maintain humidity.

Seven days later the fruit were harvested and isolations were made from the skin of the fruit onto SPDA. Plugs of isolates of *Cg* recovered were then transferred to potato dextrose agar (PDA) amended with 1% benlate and new SPDA plates. The growth rates of these isolates were compared to determine which isolates were benlate resistant. Any occurrence of benlate resistant isolates was recorded.

Experiment 3: Evaluation of frost protection materials on ice nucleating bacteria

The aim of this experiment was to evaluate a range of frost protection materials for their effect on ice nucleating bacteria.

The field trial was conducted on a block of 3-month-old 'Reed' trees grafted to seedling 'Velvick' rootstock on Graham Thomas' property at Hampton QLD. A randomised block design was used with 5 blocks with 5 treatments and 3 trees replications. The following treatments were applied:

1. Untreated control
2. Kocide® (copper hydroxide) – 2g/L
3. Surround® - 5g/L
4. Mangocote® (copper oxychloride - 1g/L + Surround - 5g/L)
5. ENVY® (carboxylated hydrophilic polymer) - 2L/20L

Treatments commenced in May 2004. 1-2 L of spray suspension was applied to each tree every 28 days. Measurements were taken using a chlorophyll meter and a visual rating was also made on a scale of 1 to 4, where 4 is a healthy green colour.

5.2.3 Results

Experiment 1: Field trial at Duranbah (2003/2004 season)

The Surround treated trees consistently had lower numbers of sunburnt and photo-oxidised fruit than the control trees; however, these values were not significantly different (Tables 17 and 18). Fruit which had been sprayed with Surround had significantly greater levels of the scale insect *Hemiberlesia lataniae* than the untreated controls (Table 19). The insects tended to cluster around the stem of the fruit where the deposits of Surround were heaviest. Spraying the avocado trees with Surround from November to February had no effect on the shelf life, development of postharvest disease, fruit size or maturity of the fruit (Table 20). Also, there was no effect of aspect or an interaction between aspect and treatment of the trees. When the treated fruit were put through a commercial packing line the white Surround residue was difficult to remove from the fruit.

Table 17: The effect of Surround application on the percentage of healthy, photo-oxidised and sunburnt fruit on the **south-east** side of avocado trees at Duranbah (March 2004). Transformation improved residuals hence back-transformed data is presented (n=20)

Treatment	**Healthy fruit (%)**	**Photo-oxidised fruit (%)**	**Sunburnt fruit (%)**	**Photo-oxidised + Sunburnt fruit (%)**
Untreated control	89.7	4.26	4.1	5.11
Surround	94.4	2.83	0.64	2.8
P	0.117	0.425	0.1	0.123
lsd	ns	ns	ns	ns

Table 18: The effect of Surround application on the percentage of healthy, photo-oxidised and sunburnt fruit on the **north-west** side of avocado trees at Duranbah (March 2004). Transformation improved residuals hence back-transformed data is presented (n=20)

Treatment	**Healthy fruit (%)**	**Photo-oxidised fruit (%)**	**Sunburnt fruit (%)**	**Photo-oxidised + Sunburnt fruit (%)**
Untreated control	87.4	6.81	2.96	6.03
Surround	95.8	1.53	0.69	2.06
P	0.176	0.178	0.275	0.182
lsd	ns	ns	ns	ns

Table 19: The effect of Surround application on the population of scale (*H. lataniae*) on avocado trees at Duranbah 2004 (means with the same letter were not significantly different at a $P<0.05$) (n=20)

Treatment		**Mean scale rating***
Untreated control		1.2 b
Surround		2.7 a
	P	<0.001
	lsd	0.21

* on 0-5 scale where 0= no scale, 2=5 or fewer, 3=6-20, 4=21-50 and 5=51 or more

Table 20: The effect of Surround application and fruit aspect on the development of postharvest anthracnose and stem-end rot and on fruit size and percentage dry matter at Duranbah 2004 (n=20)

	Shelf Life (days)	% Anthracnose severity	% Anthracnose incidence	% Stem-end rot severity	% Stem-end rot incidence	Marketable Fruit* (%)	Fruit Size (g)	Dry Matter (%)
Treatment								
Untreated control	10.8	5.2	33.2	0.6	3.3	83.8	239.3	27.1
Surround	10.8	14.2	41.8	0.8	4.5	72.5	258.9	27.7
lsd	ns	ns	ns	ns	ns	ns	ns	ns
Aspect								
East	10.8	11.4	40.2	0.8	3.8	75.2	251.3	
West	10.8	8.0	34.8	0.7	4.0	81.0	246.9	
lsd	ns	ns	ns	ns	ns	ns	ns	
Treatment x Aspect								
Control								
East	10.8	7.4	36.0	0.9	4.5	79.5	238.3	
West	10.8	3.1	30.5	0.4	2.0	88.0	240.2	
Surround								
East	10.7	15.4	44.5	0.6	3.0	71.0	264.3	
West	10.9	12.9	39.0	1.0	6.0	74.0	253.6	
lsd	ns	ns	ns	ns	ns	ns	ns	

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Experiment 2: Inoculation with benlate-resistant Colletotrichum gloeosporioides isolate

There was no difference in the percentage of recovery of benlate resistant *Cg* between the Surround sprayed fruit and the untreated controls. Of the 20 *Cg* isolations from untreated control fruit, 13 were benlate resistant whilst 14 of the 24 *Cg* isolations from the Surround sprayed fruit were benlate resistant.

Experiment 3: Evaluation of frost protection materials on ice nucleating bacteria

Using a chlorophyll meter, there were no significant differences between the treatments (Table 21). Using a visual rating scale, there were significant differences between most treatments, but Kocide provided the greatest level of protection.

Table 21: The effect of various treatments on measures of frost damage on young 'Reed' avocado trees at Hampton 2004 (means with the same letter were not significantly different at a $P<0.05$) (n=3)

Treatment	**Chlorophyll meter reading**	**Visual rating (1-4 scale)***
Untreated control	48.4	2.833 b
Mangocote	47.63	2.367 a
Surround	49.36	2.833 b
Envy	49.94	2.967 bc
Kocide	50.95	3.167 c
P	0.364	<0.001
lsd	ns	0.3257

*where 1=yellow, 2=yellow/green, 3=green/yellow, 4=green

5.2.4 Discussion

Surround was tested to see if it could reduce sunburn and photo-oxidation of the fruit making the fruit more robust and hence less susceptible to postharvest disease development. However, the use of Surround in the regime used in these trials did not significantly decrease sunburn of fruit and did not provide control of postharvest diseases.

It was hoped that Surround might decrease tree stress associated with summer heat and hence increase the size of the fruit produced by the tree. Fruit was weighed at harvest and there were no significant differences between the average weight of individual fruit from Surround and untreated control trees.

The claim that Surround might provide a physical barrier to infection by *Colletotrichum gloeosporioides* (the anthracnose pathogen) was also tested. By using benlate resistant isolates of *C. gloeosporioides* it was shown that the isolate was able to infect the fruit through a coating of Surround.

Several frost protection products were tested and compared with a traditional copper fungicide. These products were found to be inferior to the copper fungicide use in disease management; hence, further testing was unnecessary.

5.3 Potential tolerance of *Colletotrichum gloeosporioides* to copper fungicides

5.3.1 Introduction

The aim of this experiment was to assess isolates of the anthracnose pathogen *Colletotrichum gloeosporioides* for their tolerance to copper fungicides *in vitro*. Highly regarded plant pathologist, John Menge (University of California), observed that in some areas of the USA, *C. gloeosporioides* has become resistant to copper fungicides.

5.3.2 Materials and Methods

C. gloeosporioides isolates from avocado from Australian orchards were divided into 2 groups: pre 2000 and post 2000. The pre 2000 group ranged from 1983 to 1999 and provided a comparison to the post 2000 group which represented a current assessment of copper tolerance from field application.

A total of 37 isolates were tested *in vitro*. Spore suspensions of each isolate were made in sterile distilled water and 25µl x 4 aliquots were dispensed on casitone yeast extract glycerol agar (CYE) plates amended with 0, 100, 150, 250, 350, 500 and 700µl ml^{-1} copper (Cu^{2+}). Plates were incubated at 24°C for 18 hrs (+ or – 2hrs) and counts were made to determine percentage germination.

5.3.3 Results

The percentage germination of the *C. gloeosporioides* spores decreased as expected, with increasing cupric ion concentration for both groups of isolates (Table 20 and 21). Almost all of the isolates stopped germinating at 350µl ml^{-1} and all germination was ceased at 500µl ml^{-1} (Tables 22 and 23).

Table 22: Tolerance of anthracnose *Colletotrichum gloeosporioides* isolates *in vitro* (pre 2000 group) to copper tested on CYE medium plates ranging from 0 - 700 µlml^{-1} (Cu^{2+}) measured as percentage germination

			Cu^{2+} concentration						
Isolate	**Year**	**Location**	**0**	**100**	**150**	**250**	**350**	**500**	**700**
19772	1990	Murwillumbah	100	100	50	30	0	0	0
19773	1987	Bli Bli	100	100	100	0	4	0	0
20127*	1989	NZ	100	100	1.75	0	0	0	0
26540**	1999	Mt Tamborine	100	100	100	-	0	0	0
26541**	1999	Mt Tamborine	100	100	100	-	0	0	0
28418	1983	Home Hill	100	100	100	20	0	0	0
28513	1987	Morayfield	100	100	100	0	0	0	0
28514	1987	Morayfield	100	100	100	80	0	0	0
28522	1987	Bli Bli	99	100	52	0	0	0	0
28568**	1999	Bangalow	100	100	55	30	0	0	0
28572	1999	Pemberton	100	100	80	7.5	0	0	0
28683	1993	Walkamin	100	80	80	80	0	0	0
28692	1993	Childers	100	100	100	80	0	0	0
28714	1993	Pomona	100	100	80	12.5	0	0	0
28719	1993	Victoria Point	100	100	100	5.5	0	0	0
28805	1993	Toowoomba	100	100	100	20	4	0	0

Table 23: Tolerance of anthracnose *Colletotrichum gloeosporioides* isolates *in vitro* (post 2000 group) to copper tested on CYE medium plates ranging from 0 - 700 µlml^{-1} (Cu^{2+}) measured as percentage germination

			Cu^{2+} concentration						
Isolate	**Year**	**Location**	**0**	**100**	**150**	**250**	**350**	**500**	**700**
45432	2000	Bangalow	100	100	100	-	3.75	0	0
45435	2000	Bangalow	100	100	100	-	0	0	0
45496	2000	Cudgen	100	100	100	-	0	0	0
45504	2000	Cudgen	92.5	73.75	66.25	-	1.75	0	0
45505**	2000	Cudgen	100	100	100	-	1	0	0
45543	2000	Duranbah	99.5	100	56.75	-	0	0	0
45558**	2000	Duranbah	100	100	100	-	0	0	0
45573**	2000	Duranbah	100	100	100	-	0	0	0
45580	2000	Green Pigeon	100	100	100	-	0	0	0
45597	2000	Green Pigeon	97.75	75.5	78.75	-	7.5	0	0
45607**	2000	Green Pigeon	100	100	100	-	0	0	0
45652	2000	N. Tamborine	100	100	50	-	0	0	0
45656**	2000	N. Tamborine	100	100	80	-	0	0	0
46159	2005	Bundaberg	100	100	100	-	4	0	0
46160	2005	Bundaberg	100	94.25	97	-	6.5	0	0
46161	2005	Bundaberg	100	100	3	-	2	0	0
46163	2005	Mareeba	100	100	100	-	1	0	0
46164	2005	Mareeba	100	100	100	-	0	0	0
46165	2005	Qld	100	100	35	0	0	0	0
46343	2005	Beerwah	100	99.5	50	-	0	0	0
46344	2005	Kairi	100	100	9.75	-	0	0	0

* *Colletotrichum acutatum* isolates
** Pepper spot isolates

5.3.4 Discussion

It was important to test populations of the fungus, *Colletotrichum gloeosporioides*, to ensure that current copper spray programs are not creating a resistance problem. In the USA, it has been reported that the fungus has become resistant to copper in many areas. In this experiment there was no tolerance variation between the pre and post 2000 groups of isolates.

5.4 The effects of new fungicide Cabrio® on post-infection activity in avocado fruit

5.4.1 Introduction

The aim of this preliminary experiment was to evaluate the new fungicide Cabrio® for post-infection ('kick-back') activity in avocado fruit.

5.4.2 Materials and Methods

The trial was conducted by harvesting trays of fruit from 'Reed' avocado trees at Duranbah NSW. Each treatment had two tray replicates and the following treatments were applied as dips postharvest:

1. Untreated control
2. Cabrio® (Nufarm)
3. Sportak® (Aventis)

At eating ripe, the fruit were cut open and assessed for the development of postharvest diseases as described in 4.2.2 (Expt 1).

5.4.3 Results

Although results were not statistically significant, Cabrio reduced both the incidence and severity of both anthracnose and stem-end rot infections (Table 24).

Table 24: The effect of fungicide treatments on the development of postharvest diseases of 'Hass' avocado (n=2)

Treatment	Shelf Life (days)	% Anthracnose		% Stem-end rot	
		severity	incidence	severity	incidence
Untreated control	7.9	25.2	80	4.183	40
Cabrio	7.933	4.85	73.33	1.35	33.33
Sportak	8.267	19.23	96.67	1.867	36.67
P	0.397	0.183	0.25	0.653	0.942
lsd	1.001	30.09	42.22	12.59	81.97

5.4.4 Discussion

This was a preliminary trial following reports of successful disease control in other crops, such as strawberry (Turechek *et al*. 2006). It also follows the registration of Cabrio for use in Australia on grapevines and bananas. The results are sufficient to necessitate further trials which are underway in the 2007/2008 season (Project AV07000).

5.5 Evaluation of potassium silicate for pre- and postharvest disease control of avocado fruit

5.5.1 Introduction

Silicon (Si) is the second most abundant element after oxygen in soil (Ma and Yamaji 2006). Accumulation of Si varies considerably between plant species and this difference has been attributed to Si uptake ability of the roots. Following uptake by the roots, Si is translocated to the shoot via the xylem. Most plants, particularly dicots (which includes avocados), are unable to accumulate high concentrations of Si in their shoots and most that is taken up will be found in older tissue. Si is taken up as silicic acid [Si $(OH)_4$], when the solution pH is below 9.0.

The nutritional role of Si in plant growth and development has been overlooked until recently, particularly because an excess or deficiency of Si is not apparent. With constant application of chemical fertilisers, such as nitrogen, phosphorous and potassium, through repeated cropping, available Si becomes depleted in the soil. The beneficial effects of Si on growth, development, yield, and disease resistance have now been recognised in a wide variety of crops.

Plants have evolved with passive or preformed defence mechanisms. Structural barriers, such as waxy cuticles or strategically positioned reservoirs of antimicrobial compounds, can prevent colonisation of the tissue (Hutcheson 1998). One of the mechanisms of Si is to act as a physical barrier as it is deposited beneath the cuticle. Further defences are induced upon exposure to compounds known as elicitors which may be released from either the pathogen or the plant (Montesano *et al*. 2003). These induced elicitors are of particular interest because of the possibility of exploiting them for defence against pathogens by enhancing a plant's natural resistance to disease. They do not act directly on the pathogen. These elicitors (or activators) may be natural, synthetic or even biological. Many recent studies suggest that Si can activate plant defence mechanisms, yet the exact nature of the interaction between Si and biochemical pathways leading to resistance remains unclear (Fauteux *et al*. 2005), although it has been shown to promote the production in plants of phenolics, phytoalexins, chitinases, peroxidases, glucanases in response to fungal infection. Most work has been carried out on rice, grain crops and tomatoes. Dann and Muir (2002) showed that potassium silicate can significantly increase the activity of plant resistance proteins in peas and reduce disease caused by the foliar pathogen *Mycosphaerella pinodes.*

The aim of these experiments was to evaluate fruit disease control using the defence promoter potassium silicate both pre- and postharvest.

5.5.2 Materials and Methods

Experiment 1: Silicon preharvest dip trial at Duranbah NSW (2004)

The aim of this experiment was to determine if dipping avocado fruit in Kasil (potassium silicate) one-week prior to harvest could decrease the development of postharvest fruit diseases.

This trial was conducted on a block of ‘Hass’/clonal ‘Velvick’ trees at Duranbah. The trial was randomised with two treatments and 60 single fruit replicates.

In May 2004, 60 fruit on two trees were selected for treatment. Fruit were tagged and then briefly dipped into 750ppm silicate solution (0.01% Tween 80). After a week, the 60 treated fruit plus 60 untreated control fruit were harvested, divided into 3 replicates of 20, packed into commercial cartons, ripened at 22°C (65% RH) and assessed for the development of disease as described in 5.2.2 (Expt 1).

Experiment 2: Preharvest dip trial at Hampton QLD (2004)

The aim of this trial was to evaluate the effect of two defence elicitors (potassium silicate/Kasil and acibenzolar-S-methyl/Bion) on the induction of antifungal dienes in avocado peel/leaves and on the suppression of anthracnose in fruit.

The field trial was conducted on 'Hass' avocado fruit on trees at Hampton QLD. Fruit were randomly selected with nine treatments and 3 single fruit replicates and 6 tree replicates. The following treatments were applied:

1. Untreated control
2. Pentra-bark - 1%
3. Pentra-bark + Kasil (potassium silicate) - 200ppm
4. Pentra-bark + Kasil - 1000ppm
5. Pentra-bark + Bion (acibenzolar-S-methyl; Novartis) - 100 ppm
6. Tween (wetting agent) alone – 0.1%
7. Tween + Kasil - 200ppm
8. Tween + Kasil - 1000ppm
9. Tween + Bion - 100 ppm

Applications were carried out in September 2004. Six trees were selected and on each tree, each treatment was applied to three fruit. One week after treatment, all fruit were harvested and ripened at 22°C (65% RH) and assessed for the development of postharvest disease as described in 5.2.2 (Expt 1).

Experiment 3: Branch injection trials at Duranbah NSW (2004)

The aim of this experiment was to determine the effect of branch injections of Kasil (potassium silicate) on postharvest disease development in ‘Hass’ avocado fruit.

This trial was conducted on a block of 4-year-old 'Hass'/clonal 'Velvick' at Duranbah NSW. Selected branches were injected with potassium silicate using the trunk injection method developed for phosphorus acid application. Four branch replicates were used for each treatment (potassium silicate and control). Each branch was injected with 20mL 750ppm silicon in early July 2004.

After 2 weeks, twenty fruit were picked from each branch, packed into commercial cartons and stored at 22°C and 65% RH. At eating ripe, the fruit were assessed for the development of postharvest diseases as described in 5.2.2 (Expt 1).

Experiment 4: Silicon injection trial 2004

The aim of this experiment was to determine the effect of Kasil® (potassium silicate) injections on the development of postharvest fruit diseases of 'Hass' avocado fruit harvested at different time intervals.

This trial was conducted on a block of 4-year-old 'Hass'/clonal 'Velvick' at Duranbah NSW. There were two treatments with three single tree replications. Treatments were:

1. Untreated control
2. Kasil injection

In May 2004, three trees were injected with 750ppm Kasil (20mL/m^3 canopy). After 2 weeks, two trays (count 20) were harvested from each of the three treated trees and the three matched untreated trees. Fruit samples were taken from each tree for dry matter analysis to determine maturity. The fruit were ripened (22°C and 65% RH) and assessed for the development of disease as described in 5.2.2 (Expt 1). Further harvests were conducted 8 and 12 weeks after treatment.

In July, leaf, pedicel, skin and flesh samples were taken from each of the 3 replicates of the control and silicon injected trees. Plant material was dried at 60°C, ground to a powder and then sent for mineral nutrient analyses (SGS Agritech, Toowoomba).

Experiment 5: Rates and timing trial at Duranbah NSW (2004/2005 season)

The aim of this experiment was to determine the best rate and timing of potassium silicate (Kasil) applied as an injection for postharvest fruit disease control. Phosphonate was included in the trial to determine if silicon treatments could be incorporated in the phosphonate injection program.

The trial was conducted on blocks of 'Hass' grafted to clonal 'Velvick' trees and 'Hass' grafted to seedling 'Edranol' at Duranbah NSW in the 2004/2005 avocado season. The trial was randomised with 7 treatments and six tree replicates for each treatment. The following treatments were applied:

1) Untreated control
2) Inject - 750ppm potassium silicate - Nov 04
3) Inject - 1500ppm potassium silicate - Nov 04
4) Inject - 750ppm potassium silicate - Mar 05
5) Inject - 1500ppm potassium silicate - Mar 05
6) Inject - 750ppm potassium silicate - Nov 04 and Mar 05
7) Inject - 20% H_3PO_3 + 750ppm potassium silicate - Nov 04 and Mar 05

Injections were carried out in November 2004 and March 2005. In July 2005, fruit were harvested, packed into commercial trays in the field and ripened for assessment. Fruit were ripened at 23˚C (65% RH) and assessed for maturity, shelf life (days to eating soft), anthracnose and stem-end rot as described in 5.2.2 (Expt 1).

Experiment 6: Trunk injections at different concentrations at Duranbah NSW (May 2006)

The aim of this experiment was to examine the effect of trunk injection with different concentrations of potassium silicate on the development of postharvest disease in 'Hass' avocado.

The trial was conducted on blocks of 'Hass'/clonal 'Velvick' trees at Duranbah NSW. Trees were blocked according to slope of the trial block. The trial was randomised with 4 treatments and 6 replicates. The following treatments were applied:

1. Untreated control
2. 2x 20mL needles of 750ppm Kasil
3. Needles (20mL/needle) of 750ppm Kasil injected at 20cm spacings around the trunk
4. Needles (20mL/needle) of 750ppm Kasil injected at 10cm spacings around the trunk

Treatments were applied in May 2006 and fruit were harvested 6 weeks later. One tray (count 20) each of fruit was harvested from the east and west sides of the tree and fruit were ripened at 22°C (65% RH). Fruit were assessed as described in 5.2.2 (Expt 1).

Experiment 7: Fertigation trial at Hampton QLD (2004/2005 season)

The aim of this experiment was to examine the effect of fertigation with potassium silicate on postharvest disease development of 'Hass' avocado fruit. The potential for fertigation was assessed due to the labour intensive nature of trunk injection.

The field trial was conducted on fourteen-year-old 'Hass' grafted to unknown seedling rootstocks at Hampton. The trial design was randomised with two treatments and 5 single tree replications. The following treatments were applied:

1. Untreated control
2. Kasil (potassium silicate) drench (0.05%)

In March 2005, 14 trees were selected for treatment on the basis of crop load. The trees were skirted to a height of 0.5m prior to treatment. Trees were paired on the basis of crop load and general health. Half of each pair was selected as untreated controls. The other half of the trees were received an application of potassium silicate. The potassium silicate was applied by watering can to each tree on the top of the mulch ($25m^2$ under the canopy). Treatments were reapplied after 2 months.

A month after the second treatment, four fruit from each treatment were selected for dry matter analysis to determine if fruit were mature enough for harvest and fruit were harvested another month after that. Fruit were ripened at 23ºC (65% RH) and assessed as described in 5.2.2 (Expt 1).

Experiment 8: Silicon formulation trial at Mt Tamborine QLD (2005/2006 season)

The aim of this trial was to determine the effect of soil applications of different formulations of silicon on the development of postharvest disease in ‘Hass’ avocado.

The field trial was conducted on a block of 4-year-old 'Hass’/seedling ‘Velvick’ trees on Charlie Eden's property at Mt Tamborine QLD. The trial was randomised with 7 treatments and 5 single tree replications. The following treatments were applied:

1. Untreated control
2. Kasil (potassium silicate) - trunk injection (750ppm)
3. Silvine (GrowForce; magnesium silicate) (750g per $20m^2$ split over three applications)
4. Wollastonite (supplied by Peter English; calcium silicate) (500g per $20m^2$ split over three applications)
5. Photofinish (Nutritech; potassium silicate with humic acid and fulvic acid) ($15mL/m^2$)
6. Stand SKH (Agrichem; potassium silicate with humic acid) ($15mL/m^2$)
7. Kasil (potassium silicate) ($15mL/m^2$)

Kasil was injected into the trees using the phosphorous acid injection method. The number of needles depended on the size of the tree. Silvine and Wollastonite were applied with 400mL of sand. The solutions were applied as the measured amount for selected trees (based on tree size) diluted into 9L of water and applied evenly around the base of the trees. After 2 weeks the liquids were reapplied. A month later, all treatments (except injections) were reapplied. Two months later, the drench treatments were reapplied. A month later, injections and drenches were applied. Two months later, drenches were reapplied.

Treatments were applied throughout the fruit growing season from when fruit were match head size (October 2005) until 12 weeks prior to harvest (May 2006). In late May 2006 leaves were sampled from each tree for mineral analyses. In September 2006 trees were harvested. Twenty fruit were harvested per tree. Fruit were packed into commercial cartons, ripened at 22°C (65%) and assessed for the development of disease as described in 5.2.2 (Expt 1).

Experiment 9: Silicon formulation trial at Hampton QLD (2005/2006 season)

The aim of this experiment was to examine the uptake of various silicon treatments applied to the soil/root zone of 'Reed' avocado trees and to determine the effect of the treatments on postharvest disease development.

The trial was conducted on a block of 'Reed' avocados grafted to 'Velvick' rootstocks at Hampton QLD. The layout of the trial was blocked across the slope. Trees were very uniform and the area under each tree was approximately $2m^2$ per tree. In each row every alternate tree received treatment (2.5m spacing between trees), rows next to each other were used (5m spacing between rows). Treatments (Table 25) were assigned to trees randomly in each block with 7 treatments and 6 single tree replications.

Table 25: Table of treatments applied in soil silicon application uptake and disease development trial at Hampton (2005/2006)

	Treatment	Dose
1	Untreated control	-
2	Inject Kasil (1000ppm)	2 needles/tree
3	Silvine	75g/tree
4	Wollastonite	50g/tree
5	Photofinish	30mL/tree
6	Stand SKH	30mL/tree
7	Kasil drench	30mL/tree

In November 2005 treatments were applied to each tree. Injected trees received 2 injections (20mL/syringe) potassium silicate. Silvine and Wollastonite were combined with 100g of sand and then scattered around the base of trees from the drip line inwards on top of the existing mulch and leaf litter. Photofinish, Stand SKH and Kasil were dissolved in 8L of water and applied around the base of each tree from the drip line inwards on top of the existing mulch and leaf litter.

All treatments (except injections) were repeated after 6 weeks and again after another 6 weeks. After a further 6 weeks, all treatments were reapplied (including injections). In November 2006, 16 fruit were harvested per tree. Twelve fruit were packed into commercial cartons for ripening and disease assessment as described in 5.2.2 (Expt 1). The skin and flesh from four fruit were dried for 5 days at 55°C and analysed for dry matter and mineral content.

5.5.3 Results

Experiment 1: Silicon preharvest dip trial at Duranbah NSW (2004)

There were no significant differences between the treatment and the untreated control. The silicon treatment had no effect on the number of days to eating ripe or disease development (Table 26). The fruit took a long time to ripen and there were low levels of disease.

Table 26: The effect of preharvest Kasil dip one week prior to harvest on the development of anthracnose and stem-end rot (n=6)

Treatment	Shelf Life (days)	% Anthracnose severity	% Anthracnose incidence	% Stem-end rot severity	% Stem-end rot incidence	Marketable Fruit* (%)
Untreated control	16.8	2.05	20	0.85	3.3	88.3
Kasil	16.7	1.23	10	1.77	8.3	86.7
P	0.483	0.258	0.116	0.600	0.349	0.802
lsd	ns	ns	ns	ns	ns	ns

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Experiment 2: Preharvest dip trial at Hampton QLD (2004)

It was found that Pentra-bark, the organosilicate bark penetrating surfactant, significantly reduced anthracnose disease severity and delayed ripening by an average of 24hrs, however, the defence activators Kasil (potassium silicate) and Bion (acibenzolar-S-methyl) showed variable results (Table 27).

Table 27: The effect of two defence elicitors (potassium silicate and acibenzolar-S-methyl) on the suppression of anthracnose in fruit (means with the same letter were not significantly different at a $P<0.05$) (n=18)

Treatment	Shelf Life (days)	Disease severity Anthracnose %	Stem-end rot %	Total disease severity (%)
Untreated control	12.39bcd	19.89abc	10.5	30.39ab
Pentra-bark	13.22b	9.78c	8.61	18.39b
Pentra-bark + Kasil (200ppm)	14.39a	8.56c	7.89	16.44b
Pentra-bark + Kasil (1000ppm)	12.67bc	11.44c	17.45	28.89ab
Pentra-bark + Bion (100ppm)	13.28b	31.67ab	16.67	48.33a
Tween (0.1%)	12.44bcd	13.28bc	17.33	30.61ab
Tween + Kasil (200ppm)	11.78cd	38.94a	14.89	53.83a
Tween + Kasil (1000ppm)	12.39bcd	36.28a	11.22	47.5a
Tween + Bion (100ppm)	11.56d	35.22a	15.11	50.33a
P	<0.001	0.001	0.693	0.02
lsd	1	19.21	ns	25.77

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Experiment 3: Branch injection trials at Duranbah NSW (2004)

There were no significant effects of silicon branch injections on the ripening rate or on the development of postharvest disease (Table 28).

Table 28: The effect of branch injections with Kasil (potassium silicate) on the development of postharvest diseases of 'Hass' avocado in 2004. Branches were injected two weeks prior to harvest (n=8)

Treatment	Shelf Life (days)	% Anthracnose severity	% Anthracnose incidence	% Stem-end rot severity	% Stem-end rot incidence	Marketable Fruit* (%)
Untreated control	14.32	3.6	17.5	0.54	6.2	83.8
Kasil	13.65	5.3	30	1.25	5.0	83.8
P	0.433	0.650	0.310	0.341	0.705	1.000
lsd	ns	ns	ns	ns	ns	ns

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Experiment 4: Silicon injection trial 2004

As found in the previous experiment, there was no effect on disease levels 2 weeks after injecting with Kasil (Table 29). However, it was found that postharvest anthracnose could be significantly decreased by using trunk injections of potassium silicate 8 and 12 weeks prior to harvest (Tables 30 and 31). Further experiments were then planned.

The Kasil injections did not increase the levels of silicon in the leaves, pedicels, skins or flesh sampled from treated trees (Table 32) nor did they have any effect on the mineral content of leaves or pedicels harvested from the treated trees. The concentration of magnesium and sodium were significantly higher in the skins of fruit from silicon injected trees. The concentration of manganese was significantly higher in the flesh of fruit from silicon injected trees.

Table 29: The effect of trunk injections of potassium silicate on the development of anthracnose and stem-end rot on 'Hass' avocado fruit **two** weeks after treatment. Fruit were harvested from Duranbah in May 2004 (n=6)

Treatment	**Shelf Life (days)**	**% Anthracnose**		**% Stem-end rot**		**Marketable Fruit* (%)**
		severity	**incidence**	**severity**	**incidence**	
Untreated control	13.77	8.3	29.2	1.74	9.2	75.8
Kasil	13.77	13.3	31.7	1.45	5.0	74.2
P	1.00	0.273	0.797	0.857	0.191	0.830
lsd	ns	ns	ns	ns	ns	ns

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Table 30: The effect of trunk injections of potassium silicate on the development of anthracnose and stem-end rot on 'Hass' avocado fruit **eight** weeks after treatment. Fruit were harvested from Duranbah in July 2004 (means with the same letter were not significantly different at a $P<0.05$) (n=6)

Treatment	**Shelf Life (days)**	**% Anthracnose**		**% Stem-end rot**		**Marketable Fruit* (%)**
		severity	**incidence**	**severity**	**incidence**	
Untreated control	13.28 b	17.7 a	52.5 a	1.49	9.2	63.3
Kasil	15.15 a	3.7 b	24.2 b	1.76	10.0	78.3
P	<0.001	0.014	0.004	0.836	0.852	0.153
lsd	0.644	10.4	16.81	ns	ns	ns

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Table 31: The effect of trunk injections of potassium silicate on the development of anthracnose and stem-end rot on 'Hass' avocado fruit **twelve** weeks after treatment. Fruit were harvested from Duranbah in August 2004 (means with the same letter were not significantly different at a $P<0.05$) (n=6)

Treatment	**Shelf Life (days)**	**% Anthracnose**		**% Stem-end rot**		**Marketable Fruit* (%)**
		severity	**incidence**	**severity**	**incidence**	
Untreated control	8.9	53.2 a	92.3	0.43	5.3	15.3 b
Kasil	9.1	29.2 b	69.9	0.14	4.3	45.7 a
P	0.261	0.016	0.098	0.250	0.783	0.044
lsd	ns	18.37	ns	ns	ns	29.39

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Table 32: The effect of injection with potassium silicate (Kasil) on the mineral content of leaves, pedicels, skins and flesh harvested from 'Hass' avocado trees at Duranbah in July 2004 (means with the same letter were not significantly different at a $P<0.05$) (n=6)

Treatment	**Si (mg/kg)**	**B (mg/kg)**	**Ca (% DW)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (% DW)**	**Mg (% DW)**	**Mn (mg/kg)**	**Na (% DW)**	**P (% DW)**	**S (% DW)**	**Zn (mg/kg)**	**N (% DW)**
Leaf													
Untreated control	1443	53.7	2.12	437	133.3	1.39	0.457	1177	0.018	0.170	0.2667	71.7	2.4
Kasil	1357	51.0	2.60	500	133.3	1.29	0.447	1433	0.020	0.173	0.2933	70.3	2.6
P	0.892	0.792	0.291	0.067	1.000	0.678	0.823	0.141	0.718	0.815	0.073	0.887	0.471
lsd	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Pedicel													
Untreated control	15933	49.3	0.12	47.0	90.3	1.81	0.077	31.3	0.040	0.15	0.047	32.3	1.3
Kasil	12433	41.7	0.12	41.7	78.3	1.59	0.063	35.7	0.049	0.12	0.040	31.7	1.1
P	0.705	0.109	0.830	0.502	0.368	0.068	0.552	0.541	0.059	0.447	0.374	0.862	0.527
lsd	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Skin													
Untreated control	1193	79.0	0.05	112	50.3	1.60	0.07 b	16.00	0.016 b	0.07	0.05	30.3	0.93
Kasil	720	72.0	0.06	97	44.7	1.52	0.08 a	20.33	0.023 a	0.07	0.05	29.7	0.93
P	0.082	0.621	0.275	0.550	0.411	0.403	<0.001	0.080	0.027	1.000	1.000	0.729	1.000
lsd	ns	ns	ns	ns	ns	ns	0.0009	ns	0.0054	ns	ns	ns	ns
Flesh													
Untreated control	803	115.7	0.03	16.3	32.0	1.92	0.0733	11.33 b	0.058	0.2	0.09	34.7	0.87
Kasil	283	116.7	0.04	17.3	35.7	1.73	0.0767	13.67 a	0.048	0.2	0.10	37.0	0.90
P	0.180	0.943	0.116	0.652	0.434	0.475	0.519	0.008	0.375	1.000	0.288	0.554	0.830
lsd	ns	ns	ns	ns	ns	ns	ns	1.309	ns	ns	ns	ns	ns

Experiment 5: Rates and timing trial at Duranbah NSW (2004/2005 season)

Silicon treatments tended to be variable in control of anthracnose, but 750ppm in November 2004 and 1500ppm in March 2004 were most effective (Table 33). Generally, treating with silicon decreased the severity and incidence of anthracnose. However, some treatments were not statistically different to the untreated control. Treatments had no effect on the shelf life, severity or incidence of stem-end rot or percentage of marketable fruit. The potassium silicate and potassium phosphonate combined treatment was not significantly different to the untreated control.

Table 33: The effect of trunk injections of potassium silicate as well as potassium phosphonate on the development of anthracnose and stem-end rot on 'Hass' avocado fruit at Duranbah NSW. Fruit were harvested in August 2004 (means with the same letter were not significantly different at a $P<0.05$) (n=42)

Treatment	**Shelf Life (days)**	**% Anthracnose**		**% Stem-end rot**		**Marketable Fruit* (%)**
		severity	**incidence**	**severity**	**incidence**	
Untreated control	11.61	9.47 a	45.1 a	1.93	14.3	67.9
Kasil - 750ppm - Nov 04	11.53	3.41 b	25.4 d	0.93	6.2	85.4
Kasil - 1500ppm - Nov 04	12.02	5.62 ab	27.9 cd	2.25	13.4	76.8
Kasil - 750ppm - Mar 05	12.36	5.92 ab	42.5 ab	1.98	17.5	69.2
Kasil - 1500ppm - Mar 05	11.98	2.89 b	29.6 bcd	1.68	15.4	76.3
Kasil - 750ppm - Nov 04 & Mar 05	11.57	5.92 ab	40.8 abc	1.81	12.1	72.1
20% HPO3 + 750ppm – Nov 04 & Mar 05	12.34	9.50 a	46.8 a	2.38	15.5	64.9
P	0.564	0.028	0.011	0.775	0.165	0.094
lsd	-	4.605	14.49	-	-	-

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Experiment 6: Trunk injections at different concentrations at Duranbah NSW (May 2006)

Treatments had no significant effect on the development of postharvest disease (Table 34) or on maturity (data not shown). Aspect from which the fruit was picked had a significant effect on the severity of anthracnose (Table 34) with the eastern side of the tree having more severe anthracnose.

Table 34: The effect of injections with varying concentrations of potassium silicate (Kasil) on the development of postharvest disease in 'Hass' avocado at Duranbah. Fruit were harvested in June 2006 (means with the same letter were not significantly different at a *P*<0.05) (n=6)

Treatment	Shelf Life (days)	% Anthracnose severity	% Anthracnose incidence	% Stem-end rot severity	% Stem-end rot incidence	Marketable Fruit* (%)
Untreated control	11.26	6.7	32.9	0.58	6.94	78.7
Kasil - 2 needles	10.97	9.6	36.8	0.63	6.05	79.0
Kasil - Needles every 20cm	10.68	12.1	49.5	0.53	5.09	69.0
Kasil - Needles every 10cm	11.32	10.1	35.6	0.57	6.48	73.1
P	0.711	0.797	0.7	0.995	0.951	0.799
lsd	ns	ns	ns	ns	ns	ns
Aspect						
East	11.11	12.0 a	41.3	0.43	5.34	71.9
West	11.00	7.2 b	36.1	0.73	6.94	78
P	0.427	0.034	0.159	0.196	0.373	0.076
lsd	ns	4.403	ns	ns	ns	ns

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Experiment 7: Fertigation trial at Hampton QLD (2004/2005 season)

Across the trial there were moderate to high levels of disease (Table 35). There were no significant effects of treatment on disease development. There was very little stem-end rot, hence moderate levels of marketable fruit. There was no significant effect of aspect on postharvest disease but there was an effect on shelf life. Fruit harvested from the eastern side of the tree had a slightly longer shelf life (11.8 days for fruit from the east side, 11.1 for fruit from the western side). Although the effect of treatment on fruit maturity was not significant, the average dry matter of fruit harvested from silicon treated trees was 26.01%, whilst for fruit harvested from untreated trees it was 23.24%.

Table 35: The effect of fertigation with potassium silicate on the development of postharvest disease in 'Hass' avocado at Hampton. (means with the same letter were not significantly different at a $P<0.05$) (n=7)

	Shelf Life (days)	% Anthracnose severity	% Anthracnose incidence	% Stem-end rot severity	% Stem-end rot incidence	Marketable Fruit* (%)
Treatment						
Untreated control	11.4	20.1	64.0	2.9	13.8	53.3
Kasil drench	11.5	21.0	67.4	2.2	12.0	50.4
P	0.776	0.818	0.634	0.408	0.459	0.694
lsd	ns	ns	ns	ns	ns	ns
Aspect						
East	11.8 a	18.2	66.7	2.7	9.9	56.1
West	11.1 b	22.9	64.7	2.4	16.0	47.5
P	0.320	0.145	0.737	0.773	0.156	0.122
lsd	0.66	ns	ns	ns	ns	ns
Treatment x Aspect						
East						
Kasil drench	12.1	19.7	68.9	2.1	9.5	54.9
Untreated control	11.5	16.7	64.5	3.3	10.2	57.4
West						
Kasil drench	10.8	22.3	66.0	2.2	14.6	45.8
Untreated control	11.3	23.5	63.5	2.5	17.5	49.2
P	0.109	0.497	0.873	0.721	0.798	0.934
lsd	ns	ns	ns	ns	ns	ns

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Experiment 8: Silicon formulation trial at Mt Tamborine QLD (2005/2006 season)

There were no significant differences between silicon levels in leaves from different treatments (Table 36). Interestingly the highest levels of calcium were in leaves from the untreated control trees and the Kasil drench trees. Treatment had no effect on fruit maturity (data not shown). There was no effect of silicon treatment on the development of side anthracnose or stem-end rot or on the percentage of marketable fruit (Table 37). Fruit from Kasil injected trees had the highest levels of stem anthracnose and, although not significant, they had the third highest level of stem-end rot.

Table 36: Leaf mineral nutrient concentrations in leaves harvested from 'Hass' trees treated with different types of silicon at Mt Tamborine. Leaves were harvested in May 2006 (means with the same letter were not significantly different at a *P*<0.05) (n=5)

Treatment	**Si (mg/kg)**	**Al (mg/kg)**	**B (mg/kg)**	**Ca (% DW)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (% DW)**	**Mg (% DW)**	**Mn (mg/kg)**	**P (% DW)**	**S (% DW)**	**Zn (mg/kg)**
Untreated control	528	2.023 c	9.55 d	0.922 ab	116.5	6.55	0.90	0.013 ab	30.02 ab	0.057	0.263	3.2
Kasil injection (750ppm)	714	1.894 c	10.62 cd	0.127 d	91.2	1.15	0.89	0.005 c	5.09 c	0.020	0.251	7.6
Silvine	712	6.070 a	11.06 bcd	0.433 c	107.3	4.99	0.78	0.004 c	24.72 bc	0.023	0.246	12.5
Acidulated Wollastonite	494	5.702 ab	12.82 ab	0.755 b	134.6	8.87	0.88	0.010 abc	25.87 abc	0.051	0.261	8.6
Photofinish	664	7.293 a	12.06 abc	0.681 bc	130.2	8.90	0.92	0.007 bc	28.04 ab	0.056	0.261	16.8
Stand SKH	549	6.689 a	13.76 a	1.100 a	122.5	9.12	0.84	0.015 a	46.34 a	0.055	0.248	10.6
Kasil	516	2.738 bc	9.52 d	0.838 ab	110.8	5.96	0.84	0.008 abc	16.49 bc	0.043	0.267	7.1
P	0.13	0.002	0.002	<0.001	0.146	0.095	0.44	0.041	0.023	0.201	0.313	0.077
lsd	ns	3.087	2.139	0.273	ns	ns	ns	0.007	21.13	ns	ns	ns

Table 37: The effect of different silicon treatments on the development of postharvest disease in 'Hass' avocado at Mt Tamborine. Fruit were harvested in September 2006 (n=5)

Treatment	Shelf Life (days)	% Anthracnose severity	% Anthracnose incidence	% Stem-end rot severity	% Stem-end rot incidence	Marketable Fruit* (%)
Untreated control	9.8	48.8	87.8	1.33	15.6	26.7
Kasil injection	9.5	52.5	88.9	1.48	13.3	27.8
Silvine	10.0	41.3	77.8	0.51	6.7	35.6
Wollastonite	9.7	41.6	83.3	1.82	15.6	32.2
Photofinish	9.5	55.6	88.9	1.2	10	22.4
Stand SKH	9.7	45.3	80	0.72	6.7	37.8
Kasil drench	9.6	43.4	74.4	0.93	8.9	32.2
P	0.881	0.934	0.665	0.721	0.46	0.944
lsd	ns	ns	ns	ns	ns	ns

*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Experiment 9: Silicon formulation trial at Hampton QLD (2005/2006 season)

There were significant differences in fruit maturity from different treatments (Table 38). When fruit were harvested it was noted that the level of fruit drop from Silvine treated trees was higher than other trees. This was unexpected, since they were the least mature fruit.

Table 38: The effect of silicon treatment on maturity (measured as % dry matter) of 'Reed' avocado harvested in November 2006 (analysis performed after discarding outliers) (means with the same letter were not significantly different at a $P<0.05$) (n=38)

Treatment		Dry matter (%)
Untreated control		21.4 a
Kasil injection		19.9 bcd
Silvine		18.6 d
Wollastonite		20.4 abc
Photofinish drench		21.1 abc
Stand SKH drench		19.7 cd
Kasil drench		21.3 ab
	P	0.006
	lsd	1.48

Dry Matters were determined only for the first four replicates of Silvine treated fruit
There were insufficient fruit for reps 5 and 6

None of the treatments provided good control of anthracnose at firmness 3 (between sprung and eating ripe or 4 (eating ripe) (Tables 39 and 40). Across the whole experiment there was a high incidence of anthracnose but symptoms were not always severe. There was very little stem-end rot.

Mineral analyses were variable with significant differences between treatments for silicon, aluminium, calcium, iron, magnesium and phosphorous (Table 41). There were no correlations between mineral data and disease levels (data not shown).

Table 39: The effect of silicon treatments on the development of postharvest disease in 'Reed' avocado at Hampton rating 3 for firmness. Fruit were harvested in November 2006 (n=42)

Treatment	**Shelf Life (days)**	**% Anthracnose**		**% Stem-end rot**		**Marketable Fruit* (%)**
		severity	**incidence**	**severity**	**incidence**	
Untreated control	7.2	9.0	100.0	0.21	4.2	54.2
Kasil injection	6.8	6.8	100.0	0.00	0.0	58.3
Silvine	6.7	7.2	98.2	0.04	1.4	55.9
Wollastonite	6.8	8.1	100.0	0.00	0.0	43.1
Photofinish drench	6.8	8.4	98.6	0.14	5.8	47.7
Stand SKH drench	7.1	8.0	96.6	0.04	1.4	64.1
Kasil drench	7.0	7.6	100.0	0.02	1.4	48.0
P	0.358	0.913	0.373	0.144	0.145	0.788
lsd	ns	ns	ns	ns	ns	ns

^ Transformation did not improve residuals
*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Table 40: The effect of silicon treatments on the development of postharvest disease in 'Reed' avocado at Hampton at eating ripe stage. Fruit were harvested in November 2006 (n=42)

Treatment	**Shelf Life (days)**	**% Anthracnose**		**% Stem-end rot**		**% Anthracnose (%)**
		severity	**incidence**	**severity**	**incidence**	
Untreated control	7.7	15.0	100.0	0.15	2.8	25.0
Kasil injection	7.4	16.7	100.0	0.15	5.6	25.0
Silvine	7.4	14.8	100.0	0.07	2.8	33.0
Wollastonite	7.4	16.6	100.0	0.00	0.0	13.9
Photofinish drench	7.4	17.4	100.0	0.07	8.7	21.5
Stand SKH drench	7.7	13.1	100.0	0.07	1.4	39.1
Kasil drench	7.5	13.6	100.0	0.04	1.4	26.2
P	0.459	0.973	ns	0.414	0.411	0.335
lsd	ns	ns	ns	ns	ns	ns

^ Transformation did not improve residuals
*marketable fruit is the percentage of fruit with ≤ 5% anthracnose and no stem-end rot

Table 41: Mineral analyses of leaves from silicon treated trees at Hampton. Leaves were sampled in May 2006 (means with the same letter were not significantly different at a *P*<0.05) (n=42)

Treatment	Si (mg/kg)	Al (mg/kg)	B (mg/kg)	Ca % DW	Cu (mg/kg)	Fe (mg/kg)	K % DW	Mg % DW	Mn (mg/kg)	P % DW	S % DW	Zn (mg/kg)	Ca+Mg/K ratio
Untreated control	1636 a	9.7 a	26.7	0.400 bc	141.6	25.0 a	1.256	0.215 a	42.1	0.079 a	0.244	14.6	0.494 a
Kasil injection	1495 ab	8.0 ab	28.5	0.346 c	137.1	22.1 a	1.32	0.159 a	36.3	0.062 ab	0.250	16.4	0.391 ab
Silvine	911 c	3.5 d	29.3	0.609 a	199.7	5.2 b	1.378	0.023 b	25.5	0.057 abc	0.249	7.8	0.463 ab
Wollastonite	1201 bc	4.9 cd	30.4	0.504 ab	165.3	4.4 b	1.37	0.016 b	25.5	0.036 bc	0.238	15.1	0.382 ab
Photofinish drench	1588 a	2.9 d	30.5	0.336 c	157.4	3.4 b	1.292	0.010 b	23.4	0.026 c	0.246	8.5	0.273 bc
Stand SKH drench	1776 a	5.4 bcd	30.9	0.154 d	194.0	3.5 b	1.376	0.017 b	16.3	0.029 bc	0.254	14.6	0.125 c
Kasil drench	1548 ab	8.0 abc	24.8	0.376 bc	147.7	18.9 a	1.359	0.150 a	31.2	0.060 abc	0.247	16.3	0.388 ab
P	<0.001	<0.001	0.304	<0.001	0.227	0.003	0.52	0.001	0.189	0.044	0.972	0.106	0.008
lsd	376.5	3.13	ns	0.150	ns	13.7	ns	0.114	ns	0.036	ns	ns	0.19

5.5.4 Discussion

Application of potassium silicate by fruit dipping probably gave insufficient uptake. If any silicon was taken up by the fruit it did not reduce disease levels compared to the untreated controls. While undertaking these trials, it was found that the bark penetrating surfactant, Pentra-bark, seemed to reduce anthracnose levels in fruit. The reason for this is not understood. The product could act as a barrier to further fungal penetration or it is possible that the product is acting directly on the fungal cells causing injury or death. At this stage, further investigations are pending.

Branch injections of potassium silicate applied prior to harvest were ineffective. However, when trunk injections were carried out 8 weeks and 12 weeks prior to harvest, control of both anthracnose and stem-end rot was achieved. In addition, fruit ripening was delayed by the 8 week treatment. From the mineral concentration data it appears that the potassium silicate injections have no effect on the mineral balance of the trees. Previous avocado studies have found that any effect on mineral concentration levels can be strongly correlated with disease development (Willingham *et al.* 2001). There were significant differences between treated and untreated trees between Mg and Na (fruit skins) and Mn (fruit flesh), but there was no correlation with disease development. In these trials there was no evidence that the differences in mineral concentrations between the potassium silicate treated trees and untreated trees have led to the differences in days to eating ripe and disease data.

It is suggested that the potassium silicate is acting as a defence activator rather than having a direct effect (e.g. by strengthening cell walls). There was no obvious accumulation of silicon in the fruit skin or flesh which could have a structural effect by reinforcing cell walls. The volume of potassium silicate injected into each tree was relatively small and would possibly not contribute greatly to the total silicon content in the treated trees.

When phosphonate was combined with potassium silicate, there was no reduction in the incidence or severity of anthracnose. The pH of the phosphonate/silicon solution used in this study was 6.3. In their review of the chemistry of silicon, Knight *et al.* (2001) indicate that as the pH of the solution falls below 9 the amount of silicic acid in solution decreases. In our work, due to the low pH of the phosphorous acid/silicon solution very little soluble silicon would have been available to the avocado tree. This probably explains why there were no differences in disease levels between the treated and untreated trees.

Applying potassium silicate by fertigation did not control the development of postharvest disease under our field conditions. Silicon is taken up by the roots of plants from the soil solution as monosilicic acid (Ma *et al.* 2001). As avocado is not a high silicon accumulator, the uptake of silicic acid is possibly limited to passive uptake. It is also possible that insufficient irrigation was applied to these trials during the season. Also, more regular applications of potassium silicate to the soil during fruit development may have been necessary.

In previous studies, rootstock has been found to affect the development of postharvest anthracnose (Willingham *et al.* 2001). 'Hass' fruit from 'Velvick' rootstocks developed less anthracnose than 'Hass' from 'Duke 6' rootstocks. We tested if the silicon injections could interact with ‘Velvick’ and ‘Duke 6’ to improve disease control in ‘Hass’. There were, however, no significant differences between treatments but high disease levels may have made treatment difference difficult to observe. Also, there was no rootstock effect on anthracnose and we believe this may be due to the differences in disease control between the rootstocks decreasing as trees age.

When data was analysed from the Mt Tamborine trials comparing various silicon formulations, it was found that fruit from Kasil injected trees had the highest levels of stem anthracnose and, although not significant, they had the third highest level of stem-end rot. It is thought that perhaps the injections adversely affected the water conducting vessels making fruit from injected trees more prone to stem-end anthracnose and stem-end rots. Applications of silicon as potassium silicate, magnesium silicate, calcium silicate and potassium silicate with humic and fulvic acid in the form of fruit dips or soil applications did not control fruit diseases.

In a further silicon formulation trial at Hampton, a large number of fruit from the Silvine treated trees abscised prior to harvest which was unusual as they were the least mature. The silicon treatments did not increase the levels of silicon in leaves in treated trees compared to leaves from untreated trees. It appears that the treatments applied to the trees may have disrupted the uptake and balance of nutrients in the trees.

6. Scoping study of the Australian avocado industry

6.1 Introduction

On a global scale, the Australian avocado industry is small, producing less than 2% of the world's avocados. Current Australian production is approximately 41 000 tons (Talking Avocados 18(2):22) with a gross value of well over $110M (Cotterill, Weinert and Kernot 2006, DPI&F Avocado Industry Report). The industry is growing rapidly and set to increase by 20% in the coming year as new plantings come on line. Already, production threatens to exceed local demand and in the near future it will become increasingly difficult for growers to remain profitable. Furthermore, the changing climatic conditions throughout Australia and rapidly depleting water supplies are creating new challenges for growers. In view of this, a scoping study of the Australian avocado industry was undertaken in 2007. The aim of the study was two fold: for the researcher (a newcomer to the Australian avocado industry) to become familiar with the industry; and to determine the changing research needs of the growers. The study involved a series of structured personal interviews and was undertaken in three major avocado producing regions: Western Australia, Northern Queensland and South East Queensland. It was not possible to obtain accurate statistics for each region regarding the number of avocado growers, tons produced, area under production, or the value of the crop. No industry wide survey has been conducted in recent years. Industry statistics noted in this report are based on estimates obtained from industry representatives in the region surveyed.

6.2 Regions, orchards and facilities visited

6.2.1 Western Australia

The Western Australian (WA) avocado industry, currently worth in excess of $20M, is set to triple in the next tree years with mass plantings of up to 400 000 trees planned for the region (The Western Australian, 17th Jan 2007). There are approximately 150 avocado growers in WA with over 1000ha of trees in production. Although WA produced only 10% of Australia's avocados, it remains a very lucrative industry. A large part of the avocado fruit growth period and all of the harvesting season extends over the very dry hot summer months. Pest and disease pressure is minimised resulting in superior fruit quality. The WA avocado industry is unique in that it enjoys a summer harvesting season whereas most other avocado producing countries harvest their crop over the winter months. Being counter season to the rest of the Australia's avocado industry means that WA can deliver avocados when supply is low and demand high. As a result fruit storage times are minimised, fruit quality maximised and high market prices are achieved. Two main avocado producing regions of WA were surveyed: Carabooda, north of Perth, and the Pemberton area in the south. The survey was undertaken while on tour of the WA avocado industry together with 20 Queensland and New South Wales avocado growers. Horticulture Australia Limited contributed towards the cost of the tour (AV06013).

Perth Market, Canning Vale, WA

The present market site was developed in 1989 and is situated on 50ha in Canning Vale, 16km south of the Perth CBD. The market handles over $350M of fresh produce annually. Twenty-three primary wholesalers and over thirty secondary wholesalers, distributors and food processing facilities operate from the market. The market boasts 100 000m^2 of shed space and 4 600m^2 of cool chain trucking warehouse which is fully utilised. Expansion of the cold storage warehouse facilities is planned.

Eighty four percent of avocados traded at the Perth Market are from WA, 4% from Victoria, 8% from Qld, and 4% from NSW. The market handles East Coast avocados during winter months. Transport to the Perth Market from East Coast takes approx two days. During the summer months, 15% of the WA avocados traded at the Perth Market is sold to Eastern and Southern State retailers and markets. The major retailer stores such as Coles and Woolworths purchase avocados directly from the Perth Market in black generic boxes. The market deals mainly with Hass avocados since Hass is the dominant variety produced in WA and is favoured by consumers. However, at the time of our visit there was early season Shepard avocados from Childers, Qld, on the market floor as well as Fuerte from WA. Hass was selling at approximately $50 / tray and organic Hass avocados were trading at $40 / 6.5kg tray. The market adheres to a Mandatory Code of Conduct and is presently developing a Standard Terms of Trade.

Carabooda area

Carabooda, approximately 45km north of Perth, has a population of 378 with agriculture being the main industry in the region (http://www.wanneroo.wa.gov.au).

Two avocado farms were visited in this area: Avowest, owned by Dr Washer and managed by Alan Blight, and The Avocado Grove, owned and managed by Helen and David Duncan (Appendix 1 and 2). The topography around Carabooda is relatively flat and the soil sandy. It's a winter rainfall area with hot dry summers and wet winters. Frost doesn't commonly occur in this area. Irrigation water is artesian being filtered through limestone bedrock. The ground water is replenished during the winter rainfall season but due to the lower than average rainfall encountered over the past decade, water quality is declining. Salt burn was evident on avocado leaves in most orchards visited in this area. According to the local growers, salt burn is always at its worse at the end of the dry summer season and the problem is alleviated with the onset of winter rains. Pulse irrigation is commonly practiced in the area with trees receiving approximately 800L of water per tree per day. Thick mulch is used in younger plantings and older trees are left to self mulch. The two avocado farms visited were 13 ha and 20 ha with trees ranging in age from newly planted to 31 years old. Hass was the dominant cultivar on a variety of rootstocks many of which are unknown. Insect pest and disease are not of major concern to avocado growers in this area and few, if any, chemicals are applied. Given the well drained sandy soils, phytophthora rootrot is not a notable problem in this region. One of the major areas of concern to growers is canopy management. Major limb removal and tree stumping is practiced as a means of controlling tree size but the results are not very satisfactory. John Leonardi of Avocado Australia Ltd is currently conducting canopy management trials on one of the farms visited.

The avocado fruit harvesting season in this area extends from September to November. Both farms visited pack their own fruit. AvoWest also markets its own fruit while The Avocado Grove, markets its fruit through the Avonova group.

Manjimupu and Pemberton Area

Manjimup, situated approximately 310 km south of Perth, and Pemberton a further 30 km south, is in the hilly Darling Range. The soil varies from sandy to gravel clay, to a richer gravel loam. The climate is milder than that of Perth with wet, cool winters and regular winter frost. Manjimup has a temperate climate while Pemberton is more Mediterranean. In the Pemberton area minimum winter temperatures drop as low as minus 7^{o}C. Summers are dry and windy with temperatures occasionally reaching 40^{o}C and relative humidity being very low. The regions receive between 1000mm–1800mm of rain per year but the past few seasons have been exceptionally dry with less than 500mm of rain being recorded on several of the farms visited.

Appadene Park (appendix 3), an avocado producing farm owned and managed by Robyn and Tom Winfield, and Applewood Packshed (appendix 4) managed by Vic Grozotis were visited in Manjimup. In the Pemberton area four farms were visited (appendix 5-9). Large irrigation dams are evident on all farms visited, the water being collected from run off during the winter rain season. Artesian water is not commonly used for irrigation in this area. Most of the growers visited pulse irrigate their trees using micro-sprinklers. During the flowering and fruiting season trees receive approximately 150 - 350L of water per tree per day. All of the growers visited schedule their irrigation according to the soil moisture content with the majority making use of tensiometers. The WA growers are very aware of soil health issues and use a thick layer of mulching around their younger trees. Chipped Karri bark, which is readily available in the Pemberton area, is commonly used for mulching. Delroy Orchard, owned by Russel Delroy and managed by Rob Dimitrio, utilise some rather unconventional management practices. They apply a thick but narrow band of Karri bark mulch almost one meter deep around young trees and irrigate only in the mulched area. They restrict the irrigation zone to 0.5 - 1m radius from the base of the tree in an attempt to limit the tree's root zone. According to Russel Delroy limiting the root zone contributes to a smaller tree size. The soil outside of the mulching zone is heavily compacted which discourages root development. Furthermore, the Delroys have used Hass as a rootstock since they believed that Hass has dwarfing qualities. Rob Dimitrio warned that although Hass on Hass does result in smaller trees, cropping is delayed till the tree reached its fifth year. All harvesting on the Delroy farm is done from the orchard floor. No cherry pickers are used. Most of the other growers visited utilise cherry pickers for harvesting. In general, due to the cooler ambient conditions in the Pemberton area avocado trees tend to remain relatively small as compared to trees on the East Coast.

As in the Carabooda area, pest and disease management did not appear to be of major concern to the avocado growers in Pemberton. On a few of the farms visited the garden weevil (*Phlyctinus callosus*) can on occasion become problematic and warrants chemical intervention. According to the growers the weevils shelter in soil and emerge to feed on avocado foliage close to the orchard floor. The weevil only appears to be problematic in young trees. Throughout the Pemberton area in lower lying blocks and in the heavier soils, phytophthora rootrot can result in tree decline.

Growers use chemical intervention for rootrot control. Both foliar applications of phosphorous acid and tree injections are commonly used on ailing trees. However, very few phytophthora affected trees were observed on the farms visited. Growers belonging to the Avonova group utilise regular root analyses to test the levels of phosphonates in the avocado roots. They generally apply phosphorous acid preventatively rather than curatively in accordance to the results of the root analyses. Furthermore, a few of the growers in the Pemberton area had occasionally encountered Armillaria rootrot in their orchards. Armillaria is an endemic fungus commonly found in gum tree roots. The fungus is only problematic if orchards are established in newly deforested soil especially if de-stumping was poorly undertaken. If the block is allowed to lie fallow for a few years after de-stumping, the problem usually does not occur. The Armillaria fungus grows in the cambial zone of the avocado tree and eventually girdles and kills the trees. In affected orchards orange Armillaria fruiting bodies are visible at the base of the ailing trees and mycelium growth between the bark and the hardwood. According to Tom and Faye Backhouse, avocado growers in the area, the best method of preventing the spread of the fungus is to remove the affected trees and all its major accompanying roots and to excavate the surrounding soil. Clean, uninfected soil is then placed in the excavation site before replanting can occur. The fungus is borne on larger tree roots and possibly in soil.

The dominant cultivar grown in the Pemberton and Manjimup area is Hass. The harvesting season follows that of the Carabooda area, i.e. November to early April. Some of the growers visited pack and market their own fruit and several pack and market through the Avonova group. Most of the growers visited practice mixed agriculture. Several own large cattle herds while others have diversified into kiwi fruit, tamarillo, macadamias, and even truffle production. As with the Carabooda avocado growers, despite the smaller tree size, canopy management is of major concern to most growers. Many of the growers visited are uncertain as to the best method of controlling tree height. Selective limb removal is commonly practiced, while tree removal and mechanical hedging is also used. John Leonardi, a researcher working with the AAL, has extended his canopy management research to include the Pemberton area. Furthermore, frost damage is of concern to many growers in the area. Growers utilise over head irrigation to protect younger trees. The automated irrigation systems are activated when ambient temperatures drop below $2^{o}C$. Despite all efforts, severe crop losses and even tree losses are common occurrences in this region. Growers have identified frost management control as an area needing research investment.

6.2.2 Northern Queensland

The major growing area in Northern Queensland extends from Ravenshoe in the south to Mareeba in the north and Dimbulah in the west (appendix 10). The climate varies across the region with the Great Dividing Range strongly influencing climatic conditions. Rainfall increases and temperatures decrease from the northern to the southern areas of the highlands. Elevation and climatic conditions of the major avocado growing areas in the region are shown in Table 42. This is a predominantly summer rainfall area with regular cyclonic events.

Table 42: Elevation and climatic conditions of the major avocado producing areas in Northern Qld

Area	Elevation (m)	Annual rainfall (mm)	Avg temp range (^{o}C) January	July
Mareeba	404	903	34-22	25-10
Dimbulah	460	721	36-21	26-8
Atherton	761	1308	30-18	23-6
Ravenshoe	920	842	31-16	23-3

DeFaveri and Tonello, 2004, An Agricultural profile of Cairns Highlands 2004. DPI&F, Mareeba Centre for Tropical Agric.

There are 46 AAL levy paying avocado growers in Northern Qld and a dozen new growers not yet in production. It is estimated that there is presently 1300 hectares of avocados in the region and approximately 8250tons of avocado fruit was sent to markets from the region in 2007 (production figures obtained from J. Kochi, AAL director for Northern Qld, pers comm). This represents 20% of the total Australian avocado production and is worth between \$20M – \$30M (Cotterill, Weimert and Kernot, 2006, Industry report, unpublished DPI&F document). Shepard and Hass are the main varieties grown in the region with the harvesting season extending from February to June. Peak production occurs from March to April, and competes with large fruit volumes entering the markets from the Bundaberg and Childers areas. A marketing group, Shepard Australia, was established in 1991 to coordinate the marketing of the green skin avocado from this region. The company has proved most successful in their coordinating efforts.

Dimbulah area

Two farms were visited in the Dimbulah area (appendix 11 and 12), one organic in transition, and the second, a conventional farm. Each farm had between 10 and 20 hectares of established avocado orchards. The soil in this area is sandy loam with an underlying clay layer. The main rainfall occurs in February and March with the rest of the year being relatively dry. Water logging can occur in the lower lying reaches of orchards during these wet months. The sandy soils in the upper reaches, being well drained, lent themselves to more frequent irrigation and the growers surveyed irrigate multiple times per week. Irrigation is automated and scheduled using C-probes or tensiometers. Irrigation scheduling is varied according to the trees' phenological stage and soil moisture. In these poorer soils growers emphasised the importance of good mulching. Mulching is applied at least once a year and more frequently in younger orchards. Given the relative harshness of this area, i.e. poorer soils and high ambient temperature, tree size management does not appear to be problematic for these growers. Canopy management is based on selective limb removal and selective tipping using pneumatic pruners. Mechanical hedging is not generally practiced on the farms visited. Apart from a small water logged area on one of the farms visited, phytophthora rootrot did not appear to be a major concern in this area. Foliar applications of phosphorous acid are used preventatively for the control of rootrot and tree injections are not often warranted. The major concern of growers in the Dimbulah area is insect pest management. Fruit spotting bugs cause considerable crop losses and the existing control methods are not deemed satisfactory. The organic grower is particularly concerned about the control of this pest species. Leaf roller and looper caterpillars were also mentioned as major pests in this area. The growers feel that research in pest management & IPM is urgently needed.

Mareeba – Walkamin Area

Two farms were visited in the Mareeba -Walkamin area (appendix 13 and 14). The farms visited had between 20-30 hectares of avocado trees and were amongst the oldest plantings in the region. The deep red ferrosol soils in this area are probably the best avocado growing soils in Northern Qld. Soil moisture monitoring devices are used to schedule irrigation and water is applied daily on one of the farms visited. In these good soils trees are highly vigorous and the growers are concerned at the escalating cost of harvesting very big trees. While rootrot can be a problem in these heavier soils, good control is achieved through phosphorous acid tree injections. As with the Dimbulah farmers, insect pest management is a major concern. However, the growers expressed their research needs not as that of pest management but rather of increasing farming profitability. Despite the good growing conditions, escalating production costs are marginalising profits. Growers see the need for a 'bench marking' exercise similar to that recently done in the mango industry. The question was raised as to when does a block becomes no longer viable to manage. As orchards age, management costs increase and yields decrease as does fruit quality. According to one of the growers surveyed, although individual block production data is recorded on many farms, production costs per block is rarely, if ever, monitored. The development of a good bench marking system in which production costs and resulting profits on a block basis would be greatly beneficial to growers. Integrated pest managing and the management of older orchards appear to be other major concerns for growers in this area.

Atherton Area

An 80 hectare farm with 10 000 avocado trees was visited in Atherton (appendix 15). This is a high rainfall area with regular cyclone events and occasional winter frosts. The farm visited was severely affected by two cyclones in 2006, Larry and Monica, and many avocado trees were blown over. The trees were not righted but pruned back and allowed to regrow. Their recovery is remarkable. The soil in this area is a rich deep volcanic ferrosol, ideal for avocado production. Given the fertile soils and good growing conditions, tree vigour is high and trees are spaced 12 x 6m. The tree size is controlled through mechanically hedging and topping every year. Approximately 1.5m of regrowth occurs per year. Despite the annual heavy pruning and vegetative vigour, these trees achieve on average over 27 tons of fruit per hectare. Fruit size and quality is excellent. According to the grower, north-south orientated rows are constant producers while rows orientated east-west tends to alternate in bearing. Both Hass and Shepard are grown on the farm visited and are grafted on Guatemalan rootstocks. In these heavier soils phytophthora rootrot can occur but is seldom problematic. Affected trees are treated with a foliar application of phosphorous acid. As with the other growing areas in the Northern Qld region, insect pests appear to be of major concern. Fruit spotting bug, leaf roller, thrips looper, etc. require regular control. The grower feels that the development of a sustainable Integrated Pest Management (IPM) program is required for this area.

Ravenshoe Area

A farm in Toumoulin in the Ravenshoe area was surveyed (appendix 16). The farm has 8 hectares planted to avocados at a tree spacing of 8 x 11m. Ravenshoe is at 920m above sea level and has a cool climate with occasional frosts. Despite the lower rainfall in this region, as compared to Atherton, fruit disease is problematic and growers are required to apply several sprays of fungicides per season. Irrigation is applied twice a week and on the farm visited soil moisture monitoring is not used as an irrigation scheduling tool. The soils are not as ideal as those in Atherton or Walkamin but are none the less good volcanic soils. Phytophthora rootrot is a major concern for the grower visited and despite injecting trees three times a year; good control has not been achieved in some areas of the orchard. Pest management is of major concern for the grower surveyed with red spider mite, spotting bug and leaf roller being important pests in this area.

6.2.3 South east Queensland

The South East Queensland avocado industry, comprising the Bundaberg and Childers areas, produces approximately 40% of the country's avocados (Talking Avocados, 18(1):15). The climate is subtropical with most of the rain fall occurring in the summer months. Temperatures are mild with an average annual maximum of 26.7°C and an average minimum of 15.5°C. The area is becoming increasingly dry with current annual rain fall below 1000mm (http://www.bom.gov.au/). Bundaberg is at an elevation of approximately 27m above sea level and Childers is at 109m. Although soil types vary greatly throughout the region, the avocado plantings in Childers tend to be on rich deep red volcanic soils while the Bundaberg farms are predominantly on grey sandy soils. The Bundaberg region produced approximately 10 000 tons of marketable fruit in 2006 (J. Lovatt, 2006 DPI&F, Bundaberg, crop statistics survey, unpublished data) yet only has 39 levy paying growers. Some of the largest avocado farms are found in this region. Timbercorp Ltd, a management investment scheme company, produces 30% of Australia's avocados and has 955 hectares in the Bundaberg Region, some of which are newly planted. In 2005 it was estimated that the region had 1 200 hectares of avocado but many new plantings have since been established (J. Lovatt, 2006 DPI&F, Bundaberg, crop statistics survey, unpublished data).

Bundaberg Area

Three avocado farms were visited in the Bundaberg area, two privately owned and one belonging to Timbercorp Ltd (appendix 17- 19). The avocado plantings on these farms ranged in size from 8 – 160 hectares and tree age from newly planted to 25 years old. The dominant varieties grown are Hass and Shepard with some Sharwil, Wurtz, Lamb Hass and Fuerte also being produced. This region appears to be ideally suited to avocado production with most of the growers surveyed achieving average yields in excess of 20 tons per hectare. They are innovative growers who utilise technology to maximise their farming effectively. Some of the growers surveyed have established orchards on newly imported or developed rootstocks with improved yield efficiencies and disease tolerance. These growers are keen to try new techniques such as fully automated irrigation systems and novel methods of irrigating (refer to appendix 19). Although severe water restrictions are currently being imposed on the growers in this area the growers interviewed did not emphasise optimising water utilization as a high research priority. They are confident in their existing water management practices and in general believe that the necessary information for optimising water use is available. Given the good growing conditions in the Bundaberg area tree vigour is high. Canopy management is done mainly through selective limb removal and John Leonardi, of Avocado Australia Ltd, has established canopy management trials on some of these farms. The tree nutrition program is scheduled according to leaf analysis which is carried out several times a year, pest and disease management is done both through calendar spraying and through scouting and phytophthora rootrot is control mainly through phosphorous acid tree injections. The growers' research priorities were found to be varied; declining water quality and the need to research water quality remediation techniques; the potential threat of *Phellinus noxius* to the avocado industry and the need to find an alternative control method for Phytophthora root rot other than tree injections.

Childers Area

Three growers were surveyed in the Childers area two of which are private growers and one managing farms which belong to Timbercorp Ltd (appendix 20-22). The avocado planting varied in size between 50 – 900 hectares. The 900 hectare planting belongs to Timbercorp Ltd and extending over four farms. As with the Bundaberg growers, the Childers growers were found to be excellent growers with many years experience. One of the farms surveyed was newly planted with trees under three years of age while the others were well established older farms. The older farms averaged yields of over 20 tons per hectare but up to 40 tons per hectare had been achieved in some blocks over the past few years. The dominant varieties grown on these farms are Hass and Shepard with some plantings of Reed, Lamb Hass, Pinkerton, Wurtz and Ettinger as pollinators. Most of the plantings are on Velvick and Guatemalan rootstocks. One of the growers surveyed has large plantings on a new South African rootstock, Dusa, which is reputed as being phytophthora tolerant. Several large rootstock trials are being undertaken on the Timbercorp farms in this area. Optimising water use is of prime importance to these growers and they all utilise multiple techniques to monitor soil moisture and the trees' water requirements. Enviroscans, tensiometers and even dendrometers are uses for irrigation scheduling. The dendrometers measures tree stem shrinkage and expansion as the trees go through daily cycles of water deficiency and replenishment. One of the growers surveyed pulse irrigates his trees. He is probably the only grower in the region to do so. His future plan is to fertigate with each irrigation event. As in the Bundaberg area, tree vigour is high and canopy size is controlled through mechanical hedging and selective limb removal. Due to the well drained soils in this area and the good farm management practices the incidence of phytophthora rootrot is not high on the farms surveyed. Only symptomatic trees are chemical treated and preventative treatments are not usually applied. Pest and disease management is done through both calendar spraying as well as through regular monitoring of pest populations. The growers surveyed in this area were found to be well informed on the latest research findings. Their research needs were visionary rather than addressing short term existing problems. Two of the growers surveyed export fruit to New Zealand and Asia. Their research needs were export orientated. They identified the probability of losing some of the older registered pest management chemicals, such as endosulfan, as a potential threat to the industry. This is most pertinent for export markets. They thought it essential that new chemicals be sought and tested before these older chemicals are lost. Also, the continuous use of large volumes of copper and its effect on soil health was seen as a treat. It was felt that alternatives to copper must be researched. Identifying new markets was seen as an important research priority. In the very near future supply will exceed Australian local demand for avocados and if new markets are not found, profitability will be threatened. New markets must be explored. These may include export markets, processed avocado and 'value adding' products such as avocado oil, fresh cut avocado, avocado salads, organic avocado, etc. According to these innovative growers surveyed research should focus on increasing profitability of the industry rather than solving short term problems.

6.3 Discussion

Growing conditions in the WA avocado industry are notably different to those of the East Coast. While Queensland growers are faced with a lack of irrigation water and high pest and disease pressure, the WA growers face challenges of tree size management and coping with regular frost events. The WA growers harvest their crop in the summer months which is counter season to the rest of the Australian avocado industry. During their harvesting season avocado fruit volumes are low and domestic market prices high. Although increasing volumes of avocados are being imported from New Zealand in the summer months, the market remains very lucrative for the WA growers. This is reflected in their research priorities. They favour research addressing short term farm management issues such as tree size management. Growers in Northern Queensland have identified pest management as a major concern for that region. They recognise the need for the development of a sustainable IPM program and several growers requested training courses be offered in insect pest scouting and IPM technology. The growers in South East Queensland tend to be well established experienced growers with innovative research needs. They identified as their research needs increasing farm profitability through sustainable farming practices, securing 'softer' or new chemicals for pest and disease control and identifying new markets for the ever growing supply of avocados.

7. Discussion

The rootstock program initiated in this project has so far yielded significant results. So far, it has been found that clonal rootstocks are superior in root rot tolerance to seedling rootstocks in their first twelve months since planting out in the field. Different sites have different disease pressure and it has been found that even the more tolerant rootstocks will still fail where disease pressure is very high. In addition to the trials established within the disease management program, there is also potential for data collection through the collaboration with the Rootstock Improvement Program run by Dr Tony Whiley. This project has long term trials around Australia. These trials will continue for several years into Project AV07000 and rootstocks will be included as they become available. In addition to root rot tolerance, other characteristics of the trees will be measured as they become productive.

After several years of monitoring by avocado grower and consultant Graham Thomas, it was his theory that a single injection of phosphonate applied at the appropriate time of the year could provide sufficient levels of phosphorous acid in the roots to maintain root rot control for at least twelve months. Our studies have found that injecting trees just after autumn root flush can provide sufficient phosphonate in the roots to maintain disease control for a year. This applies only to healthy trees as a protective treatment and will be an improved strategy for growers looking to reduce cost, labour and trunk wounding in their orchards.

Based on methods developed in the United States using the organosilicate bark translocating product Pentra-bark to deliver phosphonate to the roots of oak trees to control *Phytophthora ramorum*, experiments were established to study the effects of Pentra-bark mixed with phosphonate on the control of *P. cinnamomi* in avocado trees. After some adjustments, which included the use of the more compatible translocation product, Pulse, it has been found that phosphonate can be delivered into the phloem of the tree giving adequate levels in the roots to maintain disease control. Trials are continuing in Project AV07000 as we investigate the persistence of the chemical over time as well as the optimisation of rates of both the phosphonate and the translocating agent.

The results from the silicon treatment trials were extremely variable and further work is required to answer fundamental questions before recommendations could be made to growers regarding the use of soluble silicon to control fruit diseases. The mechanisms by which silicon reduces disease are not fully understood. There is some evidence to indicate that silicon must be in the soluble form to induce defence reactions (Fawe *et al.* 2001). Optimisation of the timing of application seems to be the critical factor.

The new pyraclostrobin fungicide Cabrio has shown positive results in preliminary trials and work will be continuing into the future.

Avocado scoping studies undertaken by Danielle Le Lagadec have provided considerable feedback from growers in Western Australia, northern Queensland and south-east Queensland. Avocado canopy management is currently being addressed by John Leonardi's project (AV04008). Most of the WA growers are aware of the work being done and their research needs are being, or will be, met. The Northern

Queensland growers' request for a sustainable IPM system is warranted since such a program is lacking in the Australian avocado industry. Developing an IPM program for all major avocado pest species is an enormous task. Since fruit spotting bug appears to be one of the dominant pest species it is suggested that attention could be focused on this pest first. Fruit spotting bug is an economic pest for many subtropical crops, e.g. mangoes, macadamia, litchis, etc. Although several studies have focused on this pest (including AV06001) a good IPM program has not yet been developed. It is suggested that several grower organisations could pool their resources in order to fund such a project. Once a good understanding of the fruit spotting bug has been achieved, the IPM program could then be expanded to include other avocado insect pest species. Simon Newett's project 'Study Groups to Achieve Global Competitive Avocado' (AV06003) could be used as a vehicle for relaying IPM principles and insect scouting methods to growers in the Northern Queensland region. Additional research in scouting techniques and relaying information to growers is probably not necessary.

The Bundaberg region growers' request for research into improving farming profitability is more difficult to achieve but essential for the industry's long term survival. Although growers can probably reduce their production costs somewhat by operating more cost effectively, the obvious way of increasing profitability is by achieving higher market prices. This will not easily be realised unless new outlets are found for the ever increasing volumes of avocado fruit being produced. It is recommended that a study be conducted into the cost benefits of developing avocado 'value adding' products such as frozen slices, guacamole, avocado oils, organic fruit, etc. Such technology has been developed in other countries and would not have to be reinvented for the Australian industry. The development of new export markets will become essential in the very near future. Each new market has its own requirement of which biosecurity and chemical residues is often of prime importance. In order to penetrate these new markets it will become essential to identify and register new or softer chemicals for the control of many of our current insect pest and disease. At present the industry relies heavily on the use of organo-phosphates and other old broad spectrum chemicals for the control of insect pests. Few first world markets tolerate the use of such chemicals and before new export markets can even be contemplated, alternative chemical control strategies will have to be developed.

8. Technology Transfer

Articles in grower newsletters:

Anderson J.M., Pegg K.G., Coates L.M., Dann E.K., Cooke A.W., Smith L.A. and Dean J.R. 2004. Silicon and disease management in avocados. *Talking Avocados* 15 (3): 23-25.

Pegg G.S., Giblin F.R. and Pegg K.G. 2004. Brown root rot caused by *Phellinus noxius* can lead to losses in avocado orchards. *Talking Avocados* 15 (3): 21-22.

Giblin F.R. 2005. Visitor from Israel. *Talking Avocados* 16 (1): 21.

Giblin F.R. 2006. Pepper spot on 'Hass' avocado fruit. *Talking Avocados* 17 (3): 14-16.

Giblin F.R. 2006. Silicon and the control of Phytophthora root rot in avocado seedlings. *Talking Avocados* 17 (4): 22-26.

Pegg K.G. and Giblin F.R. 2007. The avocado replant problem. *Talking Avocados* 18 (1): 30-31.

Publications:

Giblin F.R., Pegg K.G., Willingham S.L., Anderson J.M., Coates L.M., Cooke A.W., Dean J.R. and Smith L.A. 2005. *Phytophthora* revisited. New Zealand and Australian Avocado Growers' Conference "Profit Together", Tauranga, 19-23 September 2005.

Giblin F.R., Coates L.M. and Irwin J.A.G. 2005. Avocado fruit responses to *Colletotrichum gloeosporioides*. Conference Handbook, 15th Biennial Conference of the Australasian Plant Pathology Society, Geelong VIC, 26-29 September 2005.

Anderson J.M., Pegg K.G., Dann E.K., Cooke A.W., Smith L.A., Willingham S.L., Giblin F.R., Dean J.R. and Coates L.M. 2005. New strategies for the integrated control of avocado fruit diseases. New Zealand and Australian Avocado Growers' Conference "Profit Together", Tauranga, 19-23 September 2005.

Anderson J.M., Pegg K.G., Coates L.M., Cooke A.W. and Dean J.R. 2005. Silicon and postharvest anthracnose of 'Hass' avocado. (Poster) Conference Handbook, 15th Biennial Conference of the Australasian Plant Pathology Society, Geelong VIC, 26-29 September 2005.

Willingham S.L., Pegg K.G., Anderson J.M., Cooke A.W., Dean J.R., Giblin F.R. and Coates L.M. 2006. Effects of rootstock and nitrogen fertiliser on postharvest anthracnose development in 'Hass' avocado. *Australasian Plant Pathology* 35: 619-629.

Reports:

HAL Milestone reports
HAL Annual Reports

Presentations at growers field days:

2006 Giblin F.R. NFC Field Day: Atherton Tablelands, NQ: Improved management of avocado diseases, Management of avocado diseases caused by the fungus *Colletotrichum gloeosporioides*.

2006 Giblin F.R. and Pegg K.G. NFC Field Day: Alstonville, NSW: Improved management of avocado diseases, Management of avocado diseases caused by the fungus *Colletotrichum gloeosporioides*.

Presentations at conferences:

Giblin F.R., Pegg K.G., Willingham S.L., Anderson J.M., Coates L.M., Cooke A.W., Dean J.R. and Smith L.A. 2005. *Phytophthora* revisited. New Zealand and Australian Avocado Growers' Conference "Profit Together", Tauranga, 19-23 September 2005.

Anderson J.M., Pegg K.G., Dann E.K., Cooke A.W., Smith L.A., Willingham S.L., Giblin F.R., Dean J.R. and Coates L.M. 2005. New strategies for the integrated control of avocado fruit diseases. New Zealand and Australian Avocado Growers' Conference "Profit Together", Tauranga, 19-23 September 2005.

Giblin F.R., Coates L.M. and Irwin J.A.G. 2005. Avocado fruit responses to *Colletotrichum gloeosporioides*. 15th Biennial Conference of the Australasian Plant Pathology Society, Geelong VIC, 26-29 September 2005.

Poster Presentation:

Anderson J.M., Pegg K.G., Coates L.M., Cooke A.W. and Dean J.R. 2005. Silicon and postharvest anthracnose of 'Hass' avocado. (Poster) 15th Biennial Conference of the Australasian Plant Pathology Society, Geelong VIC, 26-29 September 2005.

Radio Interview:

NFC Field Day: Atherton Tablelands: ABC Mareeba: Avocado Research Update - Fiona Giblin

Workshops, Meetings and Seminar Presentations:

2004	AAGF R&D Workshop, Brisbane
2004	DPI&F (APPS) Seminar Series, Dec 2004 Presentation
2005	Avocados Australia R&D Workshop, Brisbane
2006	DPI&F Avocado R&D workshop, Nambour, QLD
2006	Avocados Australia R&D Workshop, Brisbane
2006	DPI&F Professional Development Workshop: Avocado Presentations (Phytophthora root rot and Pepper spot)
2007	DPI&F Avocado R&D Workshop, Indooroopilly
2007	Hosted visiting plant pathologist, Lungi Mavuso, from Westfalia Technological Services, South Africa - tour of DPI&F research centre, Anderson's Nursery and orchard, Duranbah, tour of Bundaberg farms with Danielle Le Lagadec
2007	Avocados Australia R&D and Promotions Workshop, Brisbane
2005	Sydney University student study tour of Anderson's Nursery
2006	Sydney University student study tour of Anderson's Nursery
2007	Sydney University student study tour of Anderson's Nursery

9. Recommendations

Key project outcomes

Rootstock studies

- Clonal rootstocks are superior to seedling rootstocks in their tolerance to Phytophthora.

Phosphonate application studies

- Recommendation is to apply an injection of phosphonate to healthy trees once a year at the end of the summer leaf flush and the end of the autumn root flush, but prior to floral bud development, to maintain adequate levels for tree health.
- Injections twice a year following maturity of spring and summer flushes are needed to restore health in root rot affected trees.
- Trunk applications of phosphonate plus a bark penetrating surfactant show promise for maintaining tree health.

Fruit disease studies

- Silicon cannot be recommended for the control of fruit disease as results are inconsistent.
- The strobilurin fungicide Cabrio shows promise against anthracnose and stem end rot. Cabrio is a protectant but can penetrate to some extent into the host to provide 'kick-back' activity.

Avocado scoping studies

- Important information was attained from growers from several areas concerning their key issues and this information will be used for future R&D.

Further research and industry activities to enhance adoption of recommendations

Rootstock studies

- Evaluation of new clonal rootstocks for their root rot tolerance should continue.
- Evaluation of rootstocks for Phytophthora tolerance and impact on fruit diseases should include more rootstocks of West Indian origin (based on recent data comparing postharvest disease development in 'Hass' where fruit from 'Velvick' (WI) rootstocks developed significantly less disease).

Phosphonate application studies

- Trunk application work shows promise and rates need to be optimised
- High volume foliar applications of phosphonate (0.1%) gave inadequate levels to feeder roots for disease control. A concentration of 0.5% is required to provide satisfactory root levels. Changing current label rates needs urgent attention.

Fruit disease studies

- Cabrio shows promise against anthracnose and stem end rot and further testing in field trials is necessary.

Avocado scoping studies

- Continued canopy management program for WA.
- IPM program required for N. QLD, especially addressing fruit spotting bug.
- Recommended that a study be conducted into the cost benefits of developing avocado 'value adding' products such as frozen slices, guacamole, avocado oils, organic fruit etc, to improve grower profits.

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12. Appendices

Appendix 1

AVOWEST, Carabooda
Manager: Alan Blight
Owner: Dr Washer, Parliamentarian & GP
Address: 4 Prospector Gardens, Edgewater, WA 6027
Tele: 0417 179 127

Area under avocado: 20 ha
No. trees: 8000 trees
Tree spacing: 7x3.5m, with the intention of removing every second tree as they reach maturity.
Tree age: 1-25 yrs old, approx 500-600 replants / yr, Alan believes that the life span of an avocado tree is only 15-20 yrs thereafter the trees should be removed & replanted, mature trees get too tall to harvest & yield decreases.
Scion: mainly Hass & a few Lamb Hass. Lamb Hass is very late yielding (December) but according to Alan a poor yielder, fruit drops as soon as tree stresses.
Rootstocks: old trees are on Mexican rootstocks, according to Alan, Mexican rootstocks produce excellent yields but are very sensitive to salt burn & tend to result in biannual bearing; later plantings are on Velvick & some A8 & A10.
Irrigation: micro-sprinklers wetting 6-7m radius, pulse irrigates hourly to increase fruit retention; Alan believes that only the top 10mm of soil water feeds roots, thus the tree stresses quickly if insufficient irrigation occurs; water source is subterranean from huge underground aquifers; salt content of the irrigation water is an ever increasing concern as the aquifer is depleted & not replenished fast enough; Alan has tried various irrigation scheduling methods, e.g. tensiometers, enviroscans, etc. Of major concern to Alan is the salt loading in soil, Alan flushes the soil regularly to avoid salt burn, salt burn is at its worst in Autumn as salt gathers in the avocado leaves over the dry summer months & reaches maximum levels just before the winter rain. Alan is experimenting with CSIRO 'Full stop" system (device buried in the soil which collects leached H_20, EC is checked twice weekly).
Nutrition: fertilisers applied through irrigation system, except gypsum, which is broadcast; leaf analyses done in May-June on hardened summer flush; Alan acidifies soil a bit by adding iron sulphate; water pH is close to 7 & contains a lot of calcium carbonates (high buffering capacity); there is no boron deficiency in these soils.
Canopy management: windows are pruned into the canopy through major limb removal, this is done in February – March; all pruning is done from orchard floor, smaller branches are mulched while larger ones are burned; mechanical hedging has been tried but found to result in severe crop loss next season; the ideal time to do limb removal is during a heavy cropping year, despite removing a limb a big crop load still remains.
Pest & disease control: no major issues, chemical intervention for insect pests or disease is rarely needed; leaf roller is an occasional problem; no more than 20% of entire farm is sprayed per year; no calendar spraying is done only very selective blocks are treated; anthracnose rarely occurs and is only a problem if fruit are allowed to hang too long on trees; Phytophthora is not a problem, no rootrot treatments are applied.

Yields: in a good year yields average 17 tons/ha; this year will be an 'off' year i.e. 7 tons/ha; reason for off year: too high temperatures during flowering resulted in poor set, also high yield of 2006 resulted in 2007 being an off year for entire South WA; flowering occurs in September to October which overlaps with harvesting season.

Harvest method: cherry pickers are used; harvesting season extends from end August to mid November.

Packhouse: pack own fruit; excellent post-harvest fruit quality (based on agents' comments); fruit quality declines only if fruit are allowed to hang too long on the trees; Alan regulates leaf N levels to control fruit quality; ideal fruit size count 20-25, there is very little market for big fruit; Alan doesn't use Sunny® since he prefers smaller sized fruit

Market: Avowest does its own marketing; most fruit go to the Perth market, about 40% goes to East Coast markets; sells some fruit directly to Coles & Woolworths; most markets which they supply prefers counts 23-25 even up to count 30; Sydney & Melbourne markets will accept bigger fruit; Alan does pack some 2nd grade fruit for local & East Coast markets; transport cost to Melbourne market = $1.50 / tray & to Perth market = $1 / tray; no avocado processing plant or oil factory in WA therefore lower quality fruit are dumped.

Problem areas: Salt burn is a problem on leaves especially in Autumn, Alan manages salt issue through rootstock & irrigation; according to Alan canopy management needs research attention, he also states that attention should be given to PGR to control vegetative regrowth after pruning, flower physiology needs urgent work especially in understanding flower induction.

Comments: This is a very harsh area for growing avocados, poor sandy soil with hot dry summers. However, the dry summers do result in low pest & disease pressure, which equates to good fruit quality. Furthermore, being counter Qld & NSW avocado season good marketing opportunities exist.

Appendix 2

THE AVOCADO GROVE, Carabooda
Manager & owners: Helen & David Duncan
Address: P.O. Box 105 Wanneroo, WA 6065; or 89 Bailey Rd, Carabooda WA 6033
Tele: 08 9407 5383

Area: 13 ha
No. trees: 2500
Tree spacing: 9 x 6m
Tree age: newly planted to 34 yrs old
Scion: Mainly Hass
Rootstocks: old trees are on unknown seedling rootstocks, later plantings are on seedling Velvick
Irrigation: micro-sprinklers watering 10m radius, 200L/hr; schedule: 30 minutes at night & from 10h00-17h00 pulses every 15 minutes = 800L / day / tree during flowering & fruiting season.
Nutrition: apply all fertilisers through the irrigation system using fertigation tank; on new plantings a thick layer of wood chip mulch is applied & also composted chicken & pig mature as well as mushroom compost; older trees are self mulching.
Canopy management: trees are cut back to stumps (1m - 1.5m high); stumped trees are back bearing within 2 yrs; usually entire blocks are stumped but sometimes alternate trees are stumped; stumping trees allows light into the orchard; personal observation: when stumping alternate trees very long spindly limbs tend to develop with fruit being born 5 m up, apparently lower area of trees will regain canopy in time.
Pest & disease control: no spraying for pest & disease is required; phytophthora rootrot can be a problem & ailing trees are inject with Phosjet & Ausphos is applied as a foliar spray.
Yields: in good a year 20tons / ha.
Harvest method: cherry pickers are used, harvesting period is end August to mid November, pick selectively for 1st three weeks (pick for size) thereafter strip pick, harvesting is done in pairs (2 cherry pickers working together), fruit placed into 300kg trailers hitched to quad bikes & taken to the packshed.
Packhouse: own, small but very modern, fully computerised system, 9 lane size sorter, general fruit size packed is count 23-25, pack in standard 6.5kg boxes; excellent fruit tractability system, can trace a fruit from a packed box back to the block where it was grown.
Market: market through the Avonova Group.
Problem areas: salt burn on leave was prominent but not considered a problem; canopy management is a major area of concern, John Leonardi has a canopy management trial site on this farm.
Comments: Sunny® is not used on the farm because larger fruit size is not required.

Appendix 3

APPADENE PARK, Manjimup

Manager & owner: Tom & Robyn Winfield, 4^{th} generation on this farm
Address: RMB 320, Seven-day Rd, Manjimup, WA 6258
Tele: 08 9771 2067

Soil: gravel clay to gravel loam, heavier soil, more fertile soil than in the northern avocado producing areas, soil pH=7
Area: 2 farms totalling 88 ha but not all under avocados, also have a few macadamia trees, limes, persimmons, and a few hectares of vegetable crops.
No. avocado trees: 3000
Tree spacing: varies, 8x5m, 7x5m, 10x4m
Tree age: newly planted – 8yr olds
Scion: Hass
Rootstocks: mostly seeding Velvick, a few other unidentified Guatemalan rootstocks, A8, A10, Reed, intends to plant Dusa & Latas for phytophthora control.
Irrigation: 150L/tree/day during peak growth season; schedules irrigation using tensiometers; micro-sprinklers with spray radius about 3m; doesn't pulse irrigate existing irrigation system is not designed for pulse irrigation.
Nutrition: broadcasts all fertilisers, applies fertilisers weekly during spring & summer, follows a fertiliser program as recommended by consultant.
Canopy management: selective limb removal but trees are still young & small; considering mechanical hedging as tree size increases.
Pest & disease control: not a problem, doesn't spray for disease or insects, has occasional garden weevil (*Phlyctinus callosus*) out breaks which feed on the leaves close to soil surface; phytophthora rootrot is a problem in some of the lower blocks; ailing trees are injected with phosjet (50% dilution); no preventative spray action it taken against rootrot; injects very young ailing trees; verticillium wilt also occasionally occurs but no treatment is applied, the trees either recover or die, no action is taken.
Yields: 14 000 trays per season = 80 tons from 6 ha; = 13.3 tons / ha for young trees (7 yr old).
Packshed: packs through the Avonova group.
Market: market through the Avonova grower group and trades under the name Premium Choice Produce; supplied fruit to Coles in WA & South Aus, also supplied markets in Sydney, Melbourne & Brisbane.
Problem areas: Frost damage appears to be of major concern, last season winter temperatures dropped to -7^{o}C for 12 hrs causing severe stress & tree losses, during summer several days of temperatures over 40^{o}C caused these frost, weakened trees to stress further resulting in severe sunburn damage to stems & fruit, affected trees have strange appearance (abnormal growth shape), an automated irrigation system programmed to come on when temperatures drop below 2^{o}C has been installed to combat frost damage.

Appendix 4

APPLEWOOD PACKHOUSE, Manjimup
Owner / manager: Vic Grozotis

Packs mainly apples but has recently started packing avocados in the summer months to keep packhouse working 12 months of the year. Packs all fruit on the same line; has ability to wax fruit if necessary; has long wash line with brushes which results in very shinny avocados; no fungicides used on the line (disease pressure is low in this area), has 10 drop points (packing stations); employs 8-10 ladies working the line. The ultimate aim is to create a brand name class called 'Ultra Premium' as well as to retain generic premium grade.
The growers are charged not for tonnes delivered but for cartons packed: costs are $4.75/ carton (6.5kg) & $4.70 for bulk packing (10kg); doesn't handle transport to markets at all, that's the growers' responsibility. Avocados get around $20-$30 / tray at the markets.
Seconds (2nd grade fruit) are also packed in trays & marketed as A-grade (no one wants a 2nd grade fruit). Grading standards are maintained by the packhouse & growers do not determine grading standards. Very little reject grade fruit is sent to the packhouse. Packout for avocados is about 98%, if packout drops to below 60% the packhouse runs a serious risk of making a financial loss.
Transparency is of prime importance to growers. This is a new packhouse, 2 years old, and is relatively big. They pack 200 000 trays of apples/year. The standard packing rate is 3000 trays in an 8hr working day. The fruit (apples & avocado) are pre-cool before being cold stored. The packhouse has several cold rooms which allows for flexibility.
Vic selects who he packs for, all growers must be ICA & Freshcare accredited. The packhouse will not accept fruit from a grower unless that grower can supply a minimum of 15 bins. It is too labour intensive to keep switching between growers.
Main problem – distance to markets, transport costs $1.30 – $1.80 / tray depending on which market the fruit go to.

Appendix 5

DELROY ORCHARDS, Pemberton
Manager: Rob Dimitrio
Owner: Russel Delroy
Address: P.O. Box 128 Pemberton, WA 6260
Tele: 08 9776 1463

Soil: sandy loam
Area: 80 ha planted to avocado, also has some kiwi fruit & is the biggest tamarillo grower in Australia
No. trees: 45 000
Tree spacing: 3x7m with the intention of forming hedge rows.
Tree age: newly planted to 9yrs old; farms philosophy is that the life span of avocado trees is only 15-18 yrs thereafter the trees should be removed & replaced.

Scion: Hass
Rootstocks: Hass (Hass on Hass) Russel believes Hass is a dwarfing rootstocks, trees are very small but apparently they don't bear until they're 5 yr old, trees grow very slowly in this cooler climate.
Irrigation & nutrition: 35L/hr micro-sprinklers, irrigates only at night for 10hrs (350L/tree/day), wetting area is small (about 50-100cm radius) & wets only the mulch at the base of the tree; applies thick layer of mulch (about 70cm) in long bands at base of trees; mulch consisting of composted Karri bark (sawmill waste); irrigates only in the mulch, no wetting inter-rows, soil in inter-rows is as hard as concrete, root growth in the mulch is very good; fertigates monthly.
Canopy management: mechanical hedges & also removes tops, optimum height of trees is 4m; post-pruning regrowth is very slow in this area due to cool conditions.
Pest & disease control: copper is applied occasionally, very rarely sprays any insecticides, occasionally needs to spray for garden weevils.
Yields: no detail available, next season will apparently be very poor crop.
Harvest method: no cherry pickers used, only use ladders, max tree height 4 m.
Packhouse: pack all their own fruit at Donnybrook. The Donnybrook packhouse is owned & managed by Russel Delroy.
Market: market directly to Woolworths & markets in Melbourne, & South Australia, Russel handles all the marketing.
Problem areas: frost control needs research, lost 40% of crop in 2006 due to frost damage.
Comments: According to Eric Skipworth, Delroy Orchard produce 400 tons of avocado / year. They also control 70% of Australian tamarillo market and have 10 ha of kiwi fruit; Russel looks for gaps in the market & fills them; he is a visionary with very alternative farming methods.

Appendix 6

Marron Brooks Partners, Pemberton
Manager: Tom & Faye Backhouse
Owner: Tom & Faye Backhouse & Marron Brooks Partners
Address: P.O. Box 206, Pemberton, WA 6260
Tel: 08 9776 1472

Soil: approx 5 soil types on the farm, red loam to white sand to coffee rock, was originally a sandy swamp with underlying clay layer, soil pH 4.5 – 7.
Area: 35.6 ha, but not all planted to avocados.
No. trees: 2000 but will remove 500 this year .
Tree spacing: older trees 10x10m, younger plantings 5x5m.
Tree age: 21 yrs, 15 yrs & 6 yrs
Scion: Mainly Hass, 40 Reed trees, a few Sharwil & 1 Hazard
Rootstocks: older plantings are on Guatemalan rootstocks, newer plantings are on Reed & a few on Zutano.
Irrigation: 2 x 75L/hr/ micro-sprinkler per tree; irrigate 1-2 hrs / day depending on tensiometer reading (150-300L/tree/day).
Nutrition: fertigate weekly & broadcast fertilisers fortnightly, apply lots of fowl manure

Canopy management: Intend to remove trees as part of canopy managing, planning on removing every 2nd row of trees in older orchards, older orchards have a very dense canopy; have done a little bit of selective limb removal.
Pest & disease control: No insecticide spray needed; there is a severe phytophthora problem in some blocks & trees are injected & spray with phosjet, Armillaria rootrot is also a problem, it's a natural fungus which grows in gum tree roots, affects tree crops if planted into virgin forest soil, occurs if all natural wood is not removed from orchard & land left fallow before planting to avocados, causes avocado trees to yellow & die, orange fruiting body visible at tree base; solution: to remove tree & all surrounding soil, replace soil before replanting; fungus is soil borne.
Yields: in a good year 30 000 trays are packed from 35 acres, excellent crop last season, in poor year they pack 12 000 trays.
Packhouse: very neat little on farm packing facility, pack in a generic box.
Market: Perth
Comments: Very beautiful, neat farm could probably produce fruit organically with only minor management changes, excellent root mat growth, cannot move the mulch due to the thick root mat. No frost in this area, they are a little higher than other farms. Tom is growing truffles, planted oak trees & inoculated roots with spores, can harvest (if it takes) in 7 yrs.

Appendix 7

D & D ROACHE, Pemberton
Manager: Trish & Mark Roache
Owner: Roache family
Tele: 08 9776 1098

Soil: heavier soils than seen previously.
Area: 15ha of avocados, 20ha potatoes & about 50ha cattle.
No. trees: 4000
Tree spacing: 10x4m, 7x8m, 9x5m.
Tree age: 22 yrs, 7 yrs, 6 yrs, 3yrs.
Scion: Hass
Rootstocks: Guatemalan
Irrigation : 95L/hr micro-sprinklers, irrigate 2 hrs/tree/day = 190L/tree/day; uses tensiometers for scheduling.
Nutrition: broadcasts every 3 weeks.
Canopy management: selective limb removal but doesn't cut limbs flush with main stem, leaves reasonably long piece of limb which allows regrowth off severed limb; paints all cut surfaces white, all prunings are mulched; takes 10hrs to prune 80 trees; John Leonardi is doing trials here.
Pest & disease control: none necessary but does spray trees preventatively for phytophthora; has a bit of verticillium wilt in some trees but doesn't apply any corrective measures.
Yields: 33 tons/ha in good year (7 yr old trees).
Harvest method: strip picking, using cherry pickers, harvest December – March.
Packhouse: pack off farm through the Avonova group.

Marketing: done through Avonova; fruit sent to Melbourne, Sydney, South Australia & also direct to Coles.
Problem areas: the Roaches feel that canopy management needs research.
Comments: frost can be severe here & uses over head sprinklers for frost control; never uses any Sunny® due to good fruit size.

Appendix 8

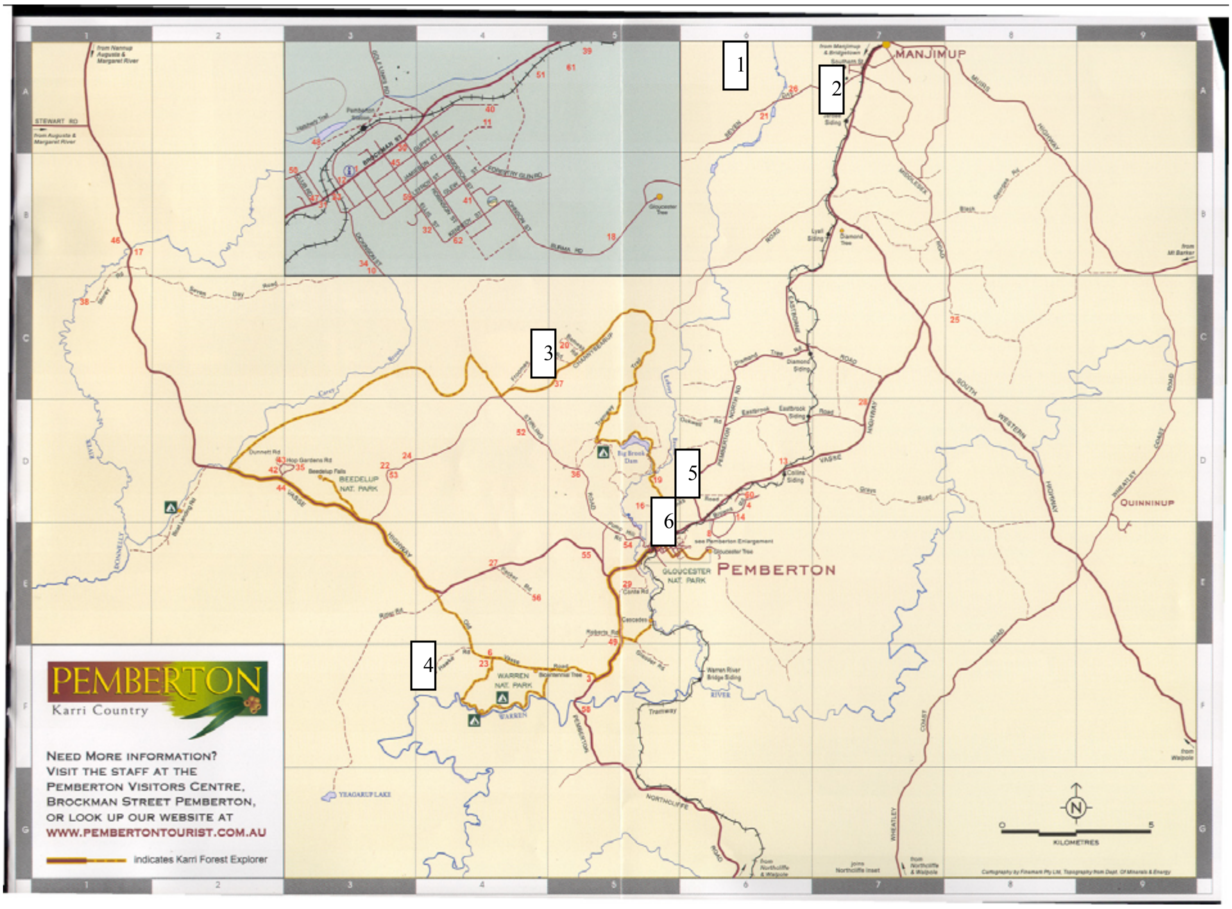
Bendotti, Pemberton
Manager & Owner: Joe Bendotti
Address: P.O. Box 29 Pemberton, WA 6260
Tele: 08 9776 1010

Soil: Deep Karri loam.
Area: 121.5 ha, 13 ha planted to avocados.
No. trees: 2700
Tree spacing: 5x10m.
Tree age: 6 yrs, 5 yrs, 2 yrs .
Scion: Hass
Rootstocks: Older trees are on seedling Guatemalan rootstock, new plantings are on Reed, Velvick, A8 & A10; Joe's observations: Reed results in very uneven tree heights, Velvick is a vigorous grower but results in very even tree size, A8 & A10 uneven growth.
Irrigation: 2 x 90L/hr micro-sprinklers/tree, irrigates 1.5hrs / day (=270L/day/tree)
Canopy management: will probably use selective limb removal, John Leonardi to advice, orchards are still very young.
Pest & disease control: does spray copper & very occasionally sprays for garden weevil; phytophthora rootrot is a problem in this area; root analyses are done in March for phosphernates & if needed phosjet is sprayed every 2 weeks.
Yields: harvested 105 bins (500kg each) from 13 acres = 3.9 tons/acre (5 & 6 year old trees).
Packhouse: packs off farm through Avonova.
Market: marketing is done by Avonova; main markets are Melbourne & Sydney, and direct to Coles.
Problem areas: frost is a major problem in this area.
Comments: Orchard looks excellent, very good tree health but growth is a bit uneven (explained by the various rootstocks).

Appendix 9

MAP OF PEMBERTON DISTRICT

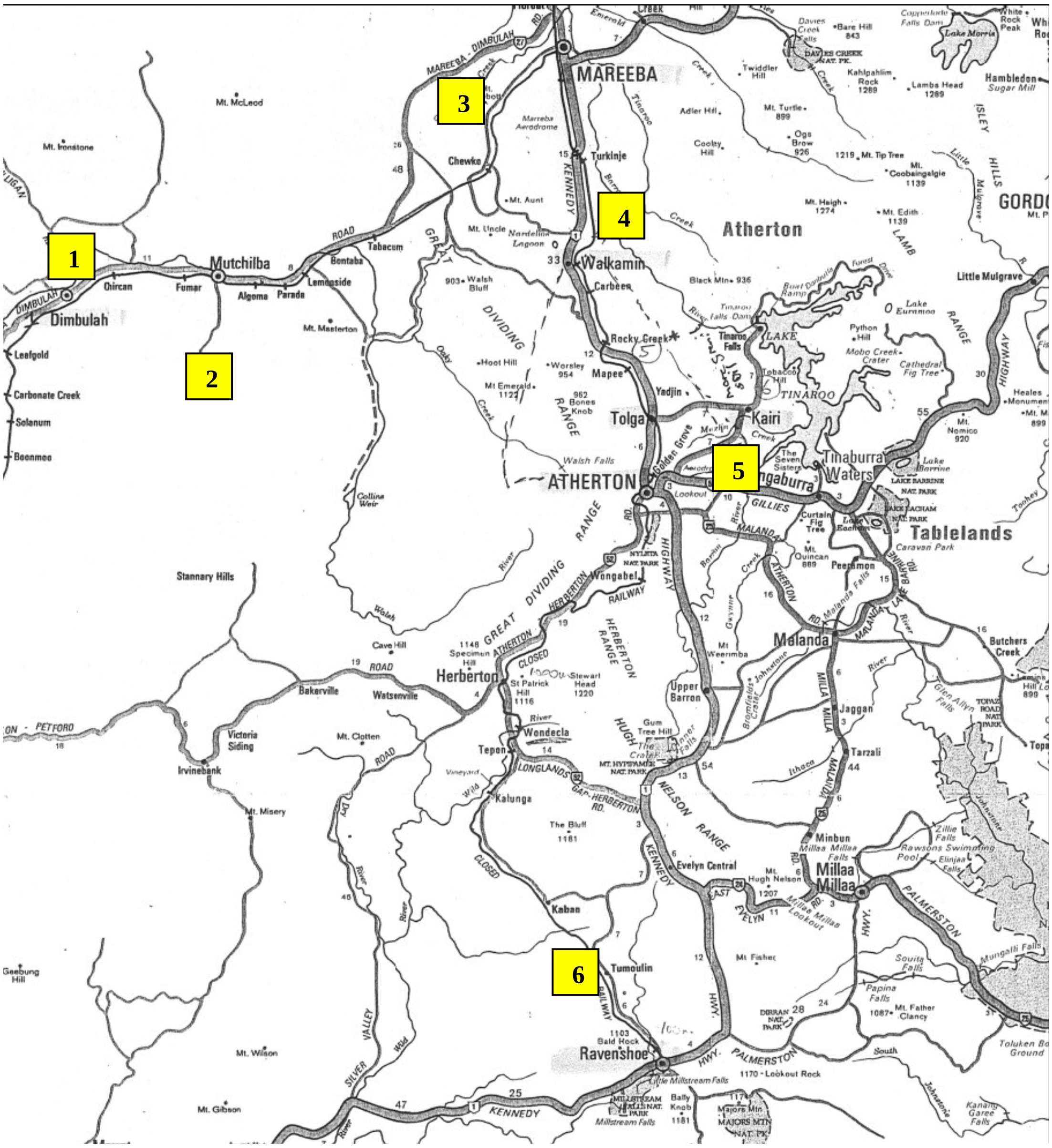
Key:
1. Appadene Park
2. Applewood Pack house
3. Delroy Orchards
4. Tom Backhouse
5. D & D Roache
6. Joe Bendotti



Appendix 10

MAP OF MAREEBA - ATHERTON DISTRICT

Key:
1. Blushing Acres
2. Kaimai Pty Ltd
3. Battistin Orchards
4. Lavers orchards
5. Jim Kotchi
6. Brice Turner



Appendix 11

Blushing Acres, Dimbulah
Manager/Owner: Sam & Kylie Collins
Tele: 0400 409 351 or 4093 5155

Soil: Granitic sand with clay layer at 400-600 mm depth; relatively poor soil with low organic matter content; flat table land; 460m above sea level
Climate: summer rain fall area, Feb-March being wettest months
Rainfall: 550mm / yr
Area: 133 ha of which 16 ha is under avocado (both organic & conventional)
No. trees: 2899
Tree spacing: 8.4x6m, 6.5x9.5m, 6x10m
Tree age: 14yrs – 9mnths
Scion: Shepard & Turner Hass
Rootstocks: Younger trees are on Velvick & Duke 7; older trees are on Guatemalan rootstocks
Yields: 12-14 tons/ha
Irrigation: Irrigation water obtained from Sun water scheme (Tinaroo dam), water quality is generally good but can have higher EC at times of drought, use 110L/hr microsprinklers, vary irrigation according to time of year, at present irrigate approx 40min / day. Use C probes to schedule irrigation, all automated data down loaded to a centre & recommendations made by consultant.
Ferigation: mulches heavily using rye grass, plants legumes in inter-rows to increase N levels in soil
Canopy management: skirts trees to facilitate mulch application & applies selective pruning, trees are still reasonably small, removes all dead wood, puts a lot of effort into pruning, all pruning done from a cherry picker; main pruning is done in July – selectively removes tops & protruding branches; & in October remove spring flush
Pest & disease control: main problem – fruit spotting bug, leaf roller & looper; uses chemical control in conventional blocks; anthracnose is not a problem, phytophthora is not a big problem on these sandy soils use foliar applications of Phosphorous acid on hardened flush just as roots are flushing
Harvest: Shepard harvested in Feb
Packhouse: Own
Market: Most fruit goes to Coles & Woolworths, 2nd grade fruit goes to local markets
Problem areas: Spotting bug control is going to be a problem for organic production
Comments: Hass fruit tends to be very small & need to use Sunny to increase fruit size; very neat farm, well mowed & well mulched, high tech grower.
According to other growers this area is very marginal for avocado or even mangoes.

Appendix 12

Kaimia PTY Ltd, Dimbulah
Manager: Joe & Clare Visini
Owner: Joe Taylor
Address: Dimbulah, P.O. Box 171 Mareeba
Tele: 4093 1145

Soil: Sandy gravel with clay intrusions
Climate: Tropical with summer rainfall, Temp range Jan: 34-22^{o}C; July: 26-8^{o}C
Rainfall: 721mm / yr
Area: 10 hectares
Tree spacing: 8.5 x 5m
Tree age: 9-7yrs old
Scion: Shepard, Sharwil, Pinkerton
Rootstocks: Velvick
Irrigation: Micro-sprinklers, 470ml / tree / day; irrigates 3 days a week
Canopy management: Mechanical hedging & topping; also selective tipping using pneumatic prunners
Pest & disease control: Insect pest are a major concern, Joe makes use of a pest scout; phytophthora rootrot is quite a serious problem in the lower reaches of the orchard, those are areas that are badly water logged, severe tree die back & some tree fatalities have occurred; the grower foliar sprays with phosphorous acid
Packhouse: Own, main fruit count is around 20
Market: Melbourne & Sydney, Joe & Vick do their own marketing
Problem areas: Insect pests are probably the biggest problems, i.e. fruit spotting bug, leaf roller & looper.

Appendix 13

Battistin Orchards, Mareeba
Owner & Manager: Eric & Tracy Battistin
Address: Mareeba, P.O. Box 517 Mareeba
Tele: 0417 784 489

Soil: Sandy loam, heavier soils than in Dimbulah
Climate: temp Jan: 34-22^{o}C; July: 25-10^{o}C
Rainfall: 903mm / yr
Area: 20 ha
Tree spacing: 8 x 6m & 11 x 6m
Tree age: 25-9 yrs
Scion: Shepard
Rootstocks: Guatemalan
Yields: 3.5 tons / ha packed (13 000 trays of 5.5kg)
Irrigation: irrigation scheduled using tensiometers
Pest & disease control: Calender spraying for pest & disease, no scouting or monitoring; injects with phosphorous acid for phytophthora control
Harvest method: Strips all fruit from trees, no selective harvest

Packhouse: own
Market: markets through the Shepard Group
Problem areas: Insects are a major concern, i.e. loopers & thrips; fruit spotting bug is not usually a problem; phytophthora can be a problem at times; encounters problem with fruit set, results in poor yield due to poor pollination; identified need for an IPM & scouting work shop
Comments: Uses Avoman as a record keeping system, fruit size is good, doesn't have any Hass

Appendix 14

Lavers Orchards, Walkamin
Owner & Manager: Don & Dell Lavers
Address: Walkamin; P.O. Box 205 Walkamin
Tele: 4093 3773

Soil: good red volcanic soils with underlying clay layer, probably the best soils in the district
Rainfall: 1000mm/yr
Area: 30ha of avocado & 30ha of mangoes
No. trees: 3500 avocado trees
Tree spacing: 6 x 10m
Tree age: 27 years - newly planted
Scion: Shepard, Hass & Sharwil
Irrigation: water supplied by Sunwater –Mareeba Dimbulah water scheme; has 2megL water storage on farm, applies on average 6.7megL/ha/yr, 110L/hr/tree, micro-sprinklers with 3.5-4m radius; varies irrigation according to tree phenology & climate; monitors soil moisture using latest technology, e.g. 'Full-stop' & enviroscans
Ferigation: ferigates according to leaf & soil analyses
Pest & disease control: uses pest scouts to monitor pest incidence
Packhouse: own, follows SQF2000 scheme
Market: markets through the Shepard group
Problem areas: Rootrot control still needs a lot of research; very concern about escalating costs of producing fruit, especially chemical costs; sustainable farming & developing an IPM program needs research; fruit spotting bug, leaf roller, & borer are becoming an increasing problem; researcher need to develop a benchmarking system similar to the one developed by DPI for the mango industry, growers need to realise their costs of production; keeps accurate records of yields / ha but production costs per ha have not been determined, needs a system of identifying costs per hectare; big question: when in a block no longer viable to maintain & should be replanted – bench marking system needs to be developed, yields is not the determining factor, production cost is almost more important than yield.
Comments: Has started an avocado nursery, will be commercial within 2 years; excellent growers, very innovative & heavily involved in soil health & irrigation research

Appendix 15

Jim Kochi, Atherton
Owner & Manager: Jim Kochi
Address: Atherton, P.O. Box 1408 Atherton
Tele: 0422 133 890

Soil: Red volcanic soil, free draining, excellent soils, rolling hills
Climate: wetter than Mareeba, frequently overcast, longer wet season, elevation: 761m, temp Jan: 30-18^{o}C, July: 26-6^{o}C
Rainfall: 1300mm/yr, monsoonal rains
Area: 80ha
No. trees: approx 10 000
Tree spacing: 12 x 6 m; cannot plant high density spacing since trees are too vigorous
Tree age: 29 - 2 yrs
Scion: Hass & Shepard
Rootstocks: Ploughman & Guatemalan
Yields: avg 195 kg / tree; 27.4 tons / ha; north-south orientated rows bear fruit consistently every year while east–west rows tend to alternate in bearing
Irrigation: approx 2megL / ha/ yr, uses bore water & reliant on rain events
Ferigation: fertigates regularly & mulches heavily; utilises approx 3000 bails / yr
Canopy management: mechanical hedging & topping every year, gets approx 1.5m growth / yr
Pest & disease control: some rootrot problems at times, foliar sprays phosphorous acid; during wet season applied Cu regularly for disease control; insect pests is a problem, does scouts for pests but some pests are controlled through calendar sprays
Packhouse: own
Market: Markets through Shepard group
Problem areas: Insect pests is one of the major problem areas (fruit spotting bug, thrips, looper, etc); wind rub on young fruit is a major concern
Comments: This farm holds some of the oldest commercial avocado blocks in the industry, cyclone Larry brought down a lot of trees, didn't right them just cut the major limbs & allowed the trees to regrow, regrowth is remarkable; high tree vigour is a major issue; uses Sunny to improve fruit size;

Appendix 16

Brice Turner, Tumoulin
Owner & Manager: Brice Turner
Address: Ravenshoe, Tumoulin
Tele: 0408 977 009

Soil: volcanic soil but not as rich as in areas further north
Climate: cooler & drier than further north, elevation 920m, temp Jan: 31-16^{o}C, July: 23-3^{o}C
Rainfall: 842mm / yr
Area: 8 ha

No. trees: approx 900
Tree spacing: 11 x 8 m
Tree age: 9, 8, 6 yrs
Scion: Hass
Rootstocks: Velvick, Duke 7 (seedlings), Guatemalan
Irrigation: doesn't use any soil moisture probes / monitoring system; schedules according to personal experience
Canopy management: mechanical topping & hedging
Pest & disease control: red spider mite is a problem in April, fruit spotting bug, leaf roller, hairy caterpillar are all problems, sprays several applications of Cu / yr; phytophthora rootrot is a problem in this area, injects with phosphorous acid 3 times a year but the results are not satisfactory
Packhouse: no, packs off site
Problem areas: Phytophthora is an area of research needing urgent attention, as well insect pest management
Comments: Unusual pepper spotting on fruit, looks very severe & getting worse as fruit are left to hang on the trees. Grower has delayed harvested due to poor market prices.

Appendix 17

Donovan Family Investments, Bundaberg & Childers
Manager / Owner: Lachlan Donovan
Address: Cullens Road, Bundaberg
Tele: 41 597 670

Soil: Deep red soils & gray gravely soils with underlying clay layer but good drainage
Area: 160 ha planted to avocado; 3 farms: 1 in Bundaberg & 2 in Childers
No. trees: 30 000
Tree spacing: 10 x 5m
Tree age: 0 – 25 years
Scion: Shepard, Hass, Sharwil, Wurts, Lamb Hass
Rootstocks: Dusa, Velvick, A_8, A_{10}, Reed & Guatemalan
Irrigation: schedules irrigation using eviroscans, crop sensors & tensiometers; irrigation system is automated; irrigates 2 x per week, obtains water from bores, Sunwater & own farms dams
Fertiliser: broadcasts & ferigates; fertilisers according to leaf analyses which are taken several times a year
Canopy management: selective limb removal & mechanical hedging; John Leonardi has trials on this farm
Pest & disease control: calendar sprays fungicides & fruit spotting bugs; all other insects are controlled when necessary as determined though monitoring
Yields: six year average is over 20 ton / ha; yields tend to alternate
Harvest method: first harvest is selective for fruit size, then threes are striped
Packhouse: Own
Traceability: Yes, from box back to block
Market: Does own marketing, Woolworth being a major client; doesn't export

Problem areas: Phellanius noxious, not a major problem at the moment but has the potential to become a big problem. Needs some research; need to identify / develop new markets
Comments: Sunny is being applied for fruit sizing in Hass & Shepard

Appendix 18

Oolloo Farm Management, One Harvest, Bundaberg
Manager: Kevin Smith
Owner: Timbercorp
Address: Ten Mile Road, Bundaberg
Tele: 4157 7211

Soil: sandy-loam to clay-loam, 3 dominant soil types, i.e. Alloway robur; Meadowvale; Oakwood, hard setting surface, well draining, soil pH = 5.5-6; slope 15%
Area: 165 ha of which 55 is planted to avocados (also grows mangoes & custard apples)
No. trees: 11 854 avocado trees
Tree spacing: 5 x 6.5 m - 6 x 12m
Tree age: 5 – 20 years
Scion: Hass, Shepard, Lamb Hass
Rootstocks: Guatemalan
Irrigation: schedules using eviroscans; uses an irrigation consultan; during flowering irrigate approximately 350 L/ tree / week, water being given 1 to 2 times per week
Fertiliser: fertigation & broadcasts; uses leaf analysis to determine fertigation program
Canopy management: trees are very tall & have not had a good pruning in some time, prune back very hard on one side of tree; Kevin is trying to bring the trees back into shape, despite removing half the tree 70% of flowering & set will still occur, tree compensates by having a heavier flowering in remaining half; pruning done by chain sew; planning to remove other half of tree in 2 years time; also toped some of the trees using mechanical hedger, trees are very tall & they are having difficulty harvesting the tops
Pest & disease control: uses pest scouts to monitor insect populations, spray according to scouts recommendation, phytophthora rootrot is an issue in some parts of the farm & trees are injected yearly in accordance to Tony Whiley's recommendations
Yields: 2007 season: Shepard 23 tons / ha (5 year old trees), Hass 19 tons / ha (8 year old trees), Lamb Hass is harvested late, early Aug to mid
Harvest method: strip
Packhouse: own
Traceability: yes, from box back to block
Market: Simpson Farms do all their marketing
Problem areas: Kevin is relatively new in this industry, would like to see more research done on rootrot control, would like to move away from injecting trees, to be replaced by penetrants; also canopy management is a problem on this farm

Comments: Uses Sunny for fruit sizing, is presently redoing the entire irrigation system

Appendix 19

Kachana, Bundaberg area
Manager/Owner: George Green
Address: Habermanns Road, South Kolan

Soil: deep red clay
Area: 46 ha of which 8ha is avocado; also grows figs & custard apples
No. trees: 1900
Tree spacing: 9 x 5 m
Tree age: 11-15 years
Scion: Shepard, Hass, Fuerte, Wurtz
Rootstocks: Guatemalan
Yields: 12 tons / ha on average
Irrigation: Schedules using tensiometers, during flowering provides approximately 35mm / ha / week, increases that to 60mm / ha / week during peak demand period (mid summer); irrigates entire orchard & encourages root growth in inter-rows; expansive feeder root growth is able to maximise utilisation of rain water; uses rotators (not micro-sprinklers) with wetting radius of 6m. Utilises Sunwater & bore water
Fertiliser : Fertigates according to leaf analysis, leaf analysis usually is done in April
Canopy management: Hedging & selective limb removal
Pest & disease control: calendar sprays for anthracnose & fruit spotting bug, all other insects are monitored & controlled accordingly; injects trees for rootrot control using passive injections
Harvest method: selective harvesting according to fruit size
Packhouse: Packs & markets through Nature Fruit Company in Nambour
Problem areas: Salt problems due to poor water quality; managing salt is a high research priority for George
Comments: Uses Sunny for fruit sizing; George has a excellent farm with some very innovative methods especially regarding irrigation; one of the most knowledgeable growers in the area

Appendix 20

Simpson Farms (Goodwood, Lynwood, Farnsfield, Promise Land), Childers
Manager: Simpson Family
Owner: Timbercorp Ltd
Tele: 41 268 200

Soil: deep red volcanic soils & some areas have high clay composition, but soil type varies given the diverse locations of the farms

Area: 900 ha of avocado plantings
No. trees: 167 000
Tree spacing: 6 x 10m & 5 x 11m
Tree age: 15yrs to new plantings
Scion: Hass, Shepard, Reed, Lamb Hass, Wurtz
Rootstocks: Velvick & Guatemalan
Irrigation: schedule using enviroscans; one enviroscan for every 10 ha; each farm has its own irrigation manager but is supervised by Simpson Farm Management; average irrigation rate during peak season is 900L / tree / week
Fertiliser: ferigates & broadcasts, schedules according to leaf analyses which are carried out in November & April
Canopy management: Hedging & selective limb removal
Pest & disease control: Calendar sprays for anthracnose & fruit spotting bug, all other insects / diseases are only controlled based on monitoring. Monolepta is occasionally a problem, phytophthora rootrot is a problem in some areas. In susceptible areas rootrot is controlled through tree injection, in less susceptible areas phosphorous acid is foliar applied preventatively
Yields: average 20 tons / ha, max production is around 40 tons / ha & poor bearing blocks produce around 15 tons / ha
Harvest method: first few rounds are selectively harvested based on fruit size, thereafter fruit is stripped
Packhouse: own
Traceability: yes, from box back to the block
Market: own marketing, supply big retailers; export to NZ & a bit to Asia
Problem areas: Research priority: alternative chemicals, softer chemicals, alternatives to Cu, IPM; also control strategies for monolepta including the insect's biology, Monolepta is responsible for 10-15% of all shed rejects but can be as high as 50% of all rejects
Comments: Very neat, well managed farms

Appendix 21

Avocado Ridge Farm, Childers
Manager/Owner: Jim Carney
Address: Morris Street, Childers
Tele: 41 261 174

Soil: deep red volcanic soils
Area: 64 ha of which 48ha is planted to avocado
No. trees: 9 355
Tree spacing: 5 x 10m
Tree age: 2.5 - 3 yrs old
Scion: Hass, Shepard, Pinkerton
Rootstocks: Dusa, Velvick & a variety of Birdwood Nursery rootstocks (Guatemalan)
Irrigation: 210L / tree every 3 days in mid summer (peak water demamnd)
Fertiliser: fertigation; schedules according to leaf analyses which are done in March and May

Canopy management: None yet but is planning to prune off ½ of the tree one year & the remaining ½ two years later
Pest & disease control: no phytophthora rootrot at all, so no prevention or control action taken, spray up to 3 rounds of Cu per year & only spray insecticides if scouting warrants it
Yields: expecting 7.7 tons per hectare next season
Harvest method: planning on harvesting at 23% DM
Packhouse: Pack through Nature's Fruit Company in Nambour
Market: through SunFresh
Problem areas: Jim would like to see research focusing on drought management, i.e. how much can you cut back on irrigation & still maintain a crop / tree health. Also, finding alternatives to the present harsh pesticides being used; would like to se more PGR research
Comments: This is a very neat young farm with huge potential. Jim observed that the clonal rootstock trees come into flower very evenly & at least 2 weeks earlier than the seedling trees; is keen to try Sunny for fruit size management but thinks that it may not be warranted for a few years still

Appendix 22

Rose Hill Farm
Manager/Owner: Jan & Zenta Toerien
Address: Bucher Road, Childers
Tele: 41 263 324

Soil: deep red volcanic where the avocado are planted & gray gravel soils for the litchis
Area: 53 hectares, 35 is planted to avocado
No. trees: 4 000 avocado trees
Tree spacing: 9 x 5m
Tree age: very old trees regrafted in 2001-03, some new plantings
Scion: Hass & a few Ettinger as pollinators (pollinators needed in the poor bearing years, in good years pollinators are not necessary)
Rootstocks: New plantings are on Velvick, old plantings are on unknown rootstocks
Irrigation: schedules using a combination of tensiometers, enviroscans & dendrometres (measures hydrostatic stress in trees, i.e. shrinking & expansion of tree trunk / stems), pulse irrigates 4 times a day, 7 days a week, 140 L per tree per irrigation event (560L / day) at peak water consumption times
Fertiliser: broadcasts but plans to fertigate, almost a hydroponic system, fertiliser program determined through leaf & soil analyses which are carried out several times a year
Pest & disease control: calendar sprays for fungicides & fruit spotting bug; all other pests are monitored & controlled accordingly
Harvest method: selective harvesting based on fruit size
Packhouse & Market: Packs & markets through Simpson Farms (Timbercorp)
Problem areas: Research should focus on methods to increase grower profitability. Present Australian avocado production is set to double in a few years, must find new markets for these fruit & also protect the Australian avocado market, i.e. biosecurity

issues need attention. There will be pressure placed on Australia to allow importation of fruit from Chilli, Peru, possibly Mexico & RSA. We must protect the market for Aus growers & protect it from foreign pests & diseases

Comments: According to Jan, present Aus avocado production is around 50 000 tons / yr & population is 21mil. Consumption per capita is 2.5-3kg making Australians the 3rd biggest consumers of avocado. Mexicans are the highest at 12-14kg / person / year, Chileans consume 4-5 kg / person, RSA eat approx 700g / person, & the Europeans consume 250g / person / year. Australian consumption will have to double to absorb the increased production or alternative markets have to be found. This could include processing & oil production. World avocado production in 2007 is around 4mil tons.