# Improving yield and quality in avocado through disease management

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Department of Employment, Economic Development & Innovation

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**AV07000**

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# AV07000 Final Report (completed 30/11/2010)

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Queensland Government

**AV07000 -** Improving yield and quality in avocado through disease management

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The following report documents research for the Australian Avocado Industry in improving yield and quality in avocado through disease management.

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# Media Summary

Diseases of avocado continue to be identified by Industry as a key factor limiting productivity in most of the major production zones. Beyond the farm gate, postharvest diseases also account for significant losses in the supply chain. This project investigated options for more sustainable management of major root- and fruit-infecting diseases. A focus of the research was to reduce fungicide inputs, for the benefit of the environment and general public.

- Rootstock material with superior establishment and survival capacity under very high Phytophthora root rot pressure in the field was identified. Two new selections were better able to withstand the disease than most of the commercial cultivars used in the Industry today. The yield and fruit quality performance of these rootstocks is currently being assessed in a separate project, and potential for commercialisation and release to Industry is under discussion.
- Application rates and timing of potassium phosphonate for Phytophthora root rot management were optimised. The rate for foliar treatment was increased, and adopted by Industry. Injection application must be performed at a time when fruit is not an active metabolic 'sink'. Later-maturing fruit varieties such as 'Reed' require delayed injection so that phosphonate does not accumulate in developing fruit and residues in fruit are not excessive.
- Preliminary trials have indicated the potential of some alternative approaches or products for reducing postharvest disease in fruit. While some of these products are fungicides used in other horticultural industries, others have no pesticidal mode of action and rely on boosting calcium levels in peel or activating plant defences to limit the infection by fungi and development of disease symptoms. Further trials are necessary before recommendations can be made to Industry.
- Brown root rot has been identified as limiting productivity in avocados in some production areas. This fungus kills trees, and the only practical management option at this stage is tree removal. Further research will evaluate chemical and cultural options for minimising the impact of this disease to growers and Industry.

# Technical Summary

One of the key constraints to production of high quality avocados is their susceptibility to a range of diseases. These include soilborne diseases caused by the oomycete pathogen *Phytophthora cinnamomi* (Pc), and the relatively 'new' but insidious brown root rot caused by the basidiomycete fungus, *Phellinus noxius*. Fruit are also susceptible, and *Colletotrichum gloeosporioides* causes both pepper spot disease, which is observed on immature fruit often associated with sunburn or tree stress, and anthracnose, which is expressed visually as fruit ripen, although the fungus infects in the field, remaining latent or dormant, until ripening. Stem end rot disease also causes postharvest disease, and the main fungi involved are *Botryosphaeria* spp. and *C. gloeosporioides*. Several field and laboratory experiments and analyses were undertaken within the project to evaluate novel approaches, or to optimise existing management strategies, to reduce the damage and economic loss caused by these diseases.

Field studies comparing establishment, survival and growth of 'Hass' grafted to different rootstocks have identified material with superior resistance to Phytophthora root rot. There was significant variation in tree health amongst commercial rootstocks and material recently selected from parent trees which have survived for many years in the presence of Pc ("escape trees"). Selections 'SHSR-02', 'SHSR-04', ungrafted 'Hass' (rooted cuttings from clonal propagation), and the commercial rootstock 'Dusa™' were significantly healthier over time than other rootstocks, many of

which died during the trials, for example 'Reed' was consistently highly susceptible. Improved establishment and superior tree health was associated with increased tree height and trunk girth.

Potassium phosphonate is a very effective tool in the management of Pc if used correctly. Field experiments have shown that foliar spray applications and registered label rate of 0.1% a.i. phosphonate were ineffective, and that 0.5% a.i. was more effective, applied multiple times, at increasing phosphonate concentration in roots to levels adequate to arrest infection by Pc. Our data on root and fruit residues after 4 sprays of 0.5% a.i. supported an application by Agrichem P/L to the Australian Pesticides and Veterinary Medicines Authority (APVMA) for an emergency use permit (and subsequent extension to the permit) for the increased rate.

Trunk injection with potassium phosphonate continues to be the most effective method of application (compared with foliar sprays and bark or trunk paints or sprays) to reliably increase and maintain feeder root phosphonate concentrations above the suggested critical level of 40mg/kg for the Pc-avocado pathosystem. Results obtained in this study show that in later-maturing 'Reed' fruit, trunk injections should be delayed until fruit are not a priority 'sink' for photosynthates (and thus, injected phosphonates) otherwise the compound will accumulate in the canopy and fruit, and not in the roots where it is required. This will also reduce the risk of high fruit residues, which are not acceptable to some export markets. For example, the MRL of phosphonate in fruit destined for the USA is 25 mg/kg (or 25 ppm).

Several novel approaches and new products have been tested for their efficacy in reducing postharvest disease. Exposure of harvested avocado fruit to ultraviolet-C radiation did not reduce the incidence and severity of postharvest diseases anthracnose and stem end rot. In fact, analyses demonstrated that anthracnose increased with greater UV-C exposure times. While UV-C may be a practical option for some fruits and vegetables, as suggested in abundant literature, it does not warrant further investigation or investment for avocado. Postharvest applications with fludioxonil fungicide, naturalGreen and EcoCarb were somewhat effective in reducing disease, and field applications with mancozeb and another product reduced disease but not to the same extent as the standard fungicide applications of regular copper protectants and 2 sprays of azoxystrobin prior to harvest.

Brown root rot is now considered to be a disease impacting on yield and productivity of avocado in some growing regions, primarily Atherton Tablelands and Bundaberg/Childers. It has also been confirmed on orchards in the Sunshine Coast hinterland, QLD, and northern NSW areas. Symptoms include rapid leaf wilting and tree death, often sequentially along a row, but pattern of death can be sporadic or patchy within a block. An infection stocking at the base of the trunk is not always present. Host range and basic biology, and management options were reviewed from the literature and published in "Talking Avocados".

# Introduction

Diseases of avocado continue to be identified by Industry as a key factor limiting productivity in most of the major production zones. Beyond the farm gate, postharvest diseases also account for significant losses in the supply chain. The general aim of the project was to investigate options that the Industry could adopt which have the potential to improve yield and quality in avocado through reducing the impact of the major diseases. The three areas of focus in the project were Phytophthora root rot, postharvest fruit diseases and brown root rot.

Phytophthora root rot, caused by the oomycete pathogen *Phytophthora cinnamomi* (Pc) is ubiquitous within avocado production areas in Australia and overseas, and is considered the most destructive and important disease (Pegg, Coates *et al.* 2002). It's impact is currently reduced using an integrated approach including cultural (mulching, adequate drainage and optimal nutrition), chemical (potassium phosphonate) and genetic approaches (breeding and selection of resistant or tolerant rootstocks). Two approaches have been examined in this project. Firstly, recent selections, identified and developed from trees which have survived for some years in the presence of Pc, have been included in field trials at three sites, known to have high Pc populations. Their growth and survival was monitored over time. The majority of this work has recently been published (Smith, Dann *et al.* 2011) and the reader is referred to the publication for full details. The second approach was to investigate alternative methods of potassium phosphonate application, and optimisation of this compound in terms of rates, uptake, time of application and longevity of activity. Most studies with phosphonate to date have been with 'Hass', however, our research demonstrated that the later maturation of 'Reed' fruit required delayed injection of phosphonate to minimise translocation to developing fruit, so that fruit residue levels were not excessive. More efficient phosphonate applications and Pc resistant rootstocks as well as reinforcing beneficial cultural practices will reduce the impact of this serious root rot disease across the whole Industry.

Postharvest anthracnose and stem end rot diseases of avocado fruit are caused primarily by anthracnose and stem end rot fungi, *Colletotrichum gloeosporioides* and *Botryosphaeria* spp. and are expressed in the later stages of ripening, long after fruit have left the orchard. Pepper spot disease, also caused by *C. gloeosporioides*, is seen on unripe fruit in orchards and at harvest and is often exacerbated by sunburn of fruit. These fruit diseases causes significant crop losses due to unmarketable fruit and have a negative impact on consumer confidence due to an inconsistent product standard. While field and postharvest fungicides (copper formulations, azoxystrobin and prochloraz) provide a level of control of these diseases when used correctly, there are mounting concerns about copper contamination of soils, and the use of pesticides generally. With the list of pesticides used in production of fruit acceptable to European markets and others shrinking, it is pertinent for Industry to be aware of advances in technology and novel approaches to disease management which may be applicable to avocados. Our research has evaluated some of these approaches and new products for their efficacy in avocado.

Brown root rot caused by *Phellinus noxius* was first positively identified as causing avocado tree death in 2002 in the Sunshine Coast hinterland. The orchard was adjacent to a stand of natural rainforest known to have trees infected with the fungus. *P. noxius* has been reported to cause disease in avocado in Taiwan (Ann, Chang *et al.* 2002), and has an extremely wide host range, including *Ficus* spp., hoop pine, and other tropical and subtropical fruit and forest species. Death of avocado trees along rows was first noted on the Atherton Tablelands, QLD, in 2001, and the destruction of orchards by Cyclone Larry in March 2006 brought attention to this disease that was weakening trees. Within this project extensive surveys of the Atherton Tablelands and Bundaberg/Childers areas confirmed the widespread occurrence of tree deaths caused by brown root rot. It has also been confirmed on orchards in northern NSW. An extensive report has been prepared and published in Talking Avocados (Dann, Smith *et al.* 2009). The awareness of the disease has increased substantially among growers in Phellinus-prone areas, and the project team confirms suspected cases reported by growers.

Project activities undertaken within AV07000 will be extended in Phase 2, AV10001, which has been approved by the Industry Advisory Committee, and awaits final HAL approval and contracting. It is anticipated that greater adoption and awareness of practical outcomes of the disease management projects will occur in the next phase. Industry will benefit through healthier trees and better quality fruit produced more sustainably.

# Materials and Methods

## Management of Phytophthora root rot

### Resistant rootstock selections

All details of field trials conducted to assess establishment, survival and performance of a range of rootstock material are described in a recent publication of this work, and will not be repeated in detail here. See paper by (Smith, Dann *et al.* 2011). Very briefly, 3 sites were chosen on commercial avocado orchards which had a history of severe Phytophthora root rot in trees prior to bulldozing the block. The sites were at Duranbah, northern NSW, Hampton, south-east Queensland and Childers, central Queensland. Several trees of each rootstock (with 'Hass' scions) were planted at each site. Trees were sourced from our collaborator, Dr Tony Whiley, and also from Anderson's Nursery and Birdwood Nursery. Rootstocks included those recovered from 'escape' trees, that is, those which have survived for long periods despite high *P. cinnamomi* pressure. Trees were treated with phosphonate and metalaxyl for the establishment period, to allow vigorous growth and favourable root:shoot ratio such that they had the opportunity to express resistance once Pc protection measures were discontinued. Trees were assessed regularly for canopy health.

### Optimisation of phosphonate applications

<u>Efficacy of phosphonate applied as a trunk spray with bark penetrant or as a trunk injection, Hampton 2006-7</u>

This trial was established in June 2006 to follow on from the findings of the AV04001 project aiming to further determine the uptake, re-distribution and decline of potassium phosphonate in avocado trees when phosphonate was applied as either a trunk injection or a bark spray with penetrant. Twenty healthy three year old 'Reed' on seedling 'Velvick' rootstock trees, approximate canopy diameter 2.5-3 $m^2$ were selected on a commercial orchard at Hampton. On 20$^{th}$ June 2006 10 trees were trunk-injected at two points evenly distributed by first drilling injection holes (5mm drill bit) below the graft union with a cordless driver drill and then screwing Chemjet$^{TM}$ syringes spring-loaded with 20mL of 20% a.i. phosphonate into the injection holes. The syringes were released and the phosphonate solution forcibly ejected into the vascular tissue over time. (Note. the Industry recommends injecting 15ml of 20% a.i. phosphonate per $m^2$ canopy diameter). On the same day, the other 10 trees were sprayed with 80mL of a solution of 10% a.i. phosphonate with 2% Pulse, a commercial bark penetrant. The solution was applied to the bark of the trunk up to 1.5m above ground level using hand held misters. Untreated guard trees were left between each treated tree.

One month after treatment application, white feeder roots were collected from approximately one metre out from the trunk below injection sites in injected trees and from a similar zone in bark treated trees. Leaves were also sampled at this time with four newly mature leaves collected from each quadrant of the tree for a total of 16 leaves collected per tree. Samples were sent to SGS Agritech in Toowoomba for analysis of phosphonate content.

Root and leaf sampling of trial trees was repeated on the 2$^{nd}$ October 2006 with flowers also collected at this time. Sampling occurred again on the 13$^{th}$ December 2006 with three developing fruitlets collected from each quadrant of trees for a total of 12 fruitlets per tree.

On the 19th January 2007, trees that had received the bark spray treatment were retreated with 80mL of 20% a.i. phosphonate with 2% Pulse applied as previously mentioned. Leaf and root samples were taken for analyses on the 28th March and 13th June 2007 as previously outlined. A single fruit per tree was also collected in June and fruit from each treatment pooled for analyses.

The trial suffered a heavy frost in August 2007 with trees losing all fruit and foliage and no further sampling was done from the trial.

Analyses of phosphonate concentration in roots after foliar sprays with 0.2% a.i potassium phosphonate, Hampton 2007

A small trial was initiated in May 2007 to assess the uptake of potassium phosphonate when applied as a foliar spray at a concentration of 0.2% a.i. Ten trees were randomly selected for observation in a block of four year old 'Reed' on seedling 'Velvick' rootstock trees at Hampton that had not previously been treated with potassium phosphonate. Trees in the block received three foliar applications of approx. 5L of a 0.2% a.i. solution of potassium phosphonate applied with commercial spray equipment. Trees were initially treated on the 31st May 2007 and then again on the 15th June 2007 and 2nd July 2007. Ten days after each application, white feeder roots were collected from each tree selected for observation and analysed for phosphonate levels by SGS Agritech.

Further investigation of phosphonate trunk sprays with penetrant, Hampton 2007

This trial was established in 2007 to compare the rate of potassium phosphonate uptake and decline in trees treated with bark sprays of different concentrations of potassium phosphonate and bark penetrant Pulse® as an extension of the 2006-7 potassium phosphonate bark application work. Trees in the same block of now 4 year old 'Reed' on seedling 'Velvick' rootstock at Hampton that had not previously received any potassium phosphonate were selected to be treated with one of the potassium phosphonate solutions listed in Table 1.

**Table 1 Summary of treatments in phosphonate trunk spray trial, Hampton 2007**

| Treatment | Potassium phosphonate solution |
|---|---|
| 1 | 80mL of 10% a.i. potassium phosphonate bark sprayed |
| 2 | 80mL of 20% a.i. potassium phosphonate bark sprayed |
| 3 | 80mL of 10% a.i. potassium phosphonate and 1% v/v Pulse bark sprayed |
| 4 | 80mL of 10% a.i. potassium phosphonate and 2% v/v Pulse bark sprayed |
| 5 | 80mL of 20% a.i.potassium phosphonate and 1% v/v Pulse bark sprayed |
| 6 | 80mL of 20% a.i. potassium phosphonate and 2% v/v Pulse bark sprayed |
| 7 | 80mL of 20% a.i. potassium phosphonate injected |

Bark sprays were applied to tree trunks up to 1.5m above ground level using handheld spray bottles. Injections were carried out as previously described. An untreated guard tree was left between each treated tree.

Treatments were applied on the 13th June 2007 and root and leaf samples were collected one month after treatment on the 16th July 2007 as previously described and analysed for phosphonate levels by SGS Agritech. Sampling was to occur again at six months after treatment however the trial suffered a heavy frost in August 2007 that severely affected trees and the trial was abandoned.

Support for increased rates of foliar phosphonate application, Duranbah 2008

Following the granting of the emergency use permit (PER10722) by the APVMA for an increased foliar rate of application of potassium phosphonate (from 0.1% to 0.5% a.i.), a trial was conducted to compare application methods and demonstrate the effectiveness and provide confidence in the new recommended application rates. Thirty two healthy, three year old 'Reed' on seedling 'Edranol' rootstock trees were selected for the trial on an orchard at Duranbah in northern New South Wales. These trees had not previously received treatment with potassium phosphonate. On the 15th May 2008 trees received one of four treatments as listed in Table 2. Foliar treatment was reapplied on the 6th June, 10th July and 29th August 2008. Root and fruit samples were taken from each tree as previously described, approximately one month after the final foliar application and sent to SGS Agritech for analysis of phosphonate levels. Roots were sampled for analysis again on the 18th December 2008.

**Table 2 Method and rate of application of potassium phosphonate, Duranbah 2008.**

| | |
|---|---|
| 1 | Untreated control - no phosphonate applied |
| 2 | Two 20mL syringes of 20% a.i. phosphonate applied on opposite sides of trunk. (Rate of 500mL Phos 400 + 500mL $H_2O$). |
| 3 | Bark application of 80mL of 20% a.i. phosphonate and 2% v/v Pulse applied to trunk up to one meter above ground level using a paint brush. (Rate of 500mL Phos 400 + 500mL $H_2O$ + 20mL Pulse or 500mL Phos 600 + 1000mL $H_2O$ + 30mL Pulse) |
| 4 | Foliar application of 0.5% a.i. phosphonate adjusted to pH7.2 (Rate of 12.5mL/L of Phos 400 or 8.3mL/L of Phos 600). |

Timing of phosphonate injection in 'Reed', Hampton 2009

As a result of the findings from the trial at Duranbah in 2008 a further trial was initiated in 2009 to determine the most appropriate timing of potassium phosphonate injection in the later maturing 'Reed' variety to ensure optimum movement of phosphonate into roots and minimise movement into developing fruit. Forty 'Reed' trees were selected at each of two commercial orchards, one in Duranbah in northern New South Wales and the other at Hampton in southeast Queensland. Trees at both sites were approximately six years old. There were 8 tree replicates for each injection time of May, June, August and September, or uninjected as controls. Each treated tree received 2 or 3x 20mL syringes of 20% a.i. potassium phosphonate.

Root samples were collected from control, May, June and August injection treatments in September, and analysed for phosphonate levels. Flowering for the following season's crop had not commenced however there was early bud formation. Root and fruit samples were taken from each tree at the time of commercial harvest, around the end of November 2009 (10 weeks after the final September injection). Root samples were sent to SGS Agritech for analysis of phosphonate

levels. Six fruit were sampled per tree and transported to Indooroopilly Research Centre (IRC) where approximately 100g fresh weight of flesh per tree sample removed from under the peel and dried at 60°C for five days. The fresh weight of each sample was recorded and the dry weight measured after drying to calculate the percentage dry matter of fruit from each tree. Dried flesh samples from each tree were then ground and sent to SGS Agritech for residue analysis of phosphonate levels.

Due to poor orchard management and chronic decline of trial trees, the trial site at Duranbah was abandoned in October 2009.

Current Trial Hampton, 2010

An extension of the 2009 trial at Hampton with 'Reed' is currently underway and results will be reported within the new project, AV10001 - Improving yield and quality in avocado through disease management, Phase 2. This trial is investigating further optimisation of phosphonate application in 'Reed' by testing efficacy and phosphonate root and fruit residues after reduced rates of injection.

## Management of postharvest fruit diseases

### Effect of UV light exposure to harvested fruit

This component of the project was undertaken by an undergraduate honours student at the University of Queensland, Ms Janelle Trott, during August 2007 to February 2008. Janelle's UQ supervisor was Dr Elizabeth Aitken and the work was primarily undertaken at Indooroopilly under the guidance and co-supervision of Dr Elizabeth Dann and Ms Jay Anderson (DEEDI), with assistance from others in the Fruit Pathology team as required. The results presented here are by permission from Janelle Trott.

There are several reports in the literature of reduced postharvest disease developing on fruit which had been exposed to ultraviolet C (UV-C, short-wave 200-280nm) after harvest, for example mango naturally infected with the anthracnose pathogen (Gonzalez-Aguilar, Wang *et al.* 2001; Gonzalez-Aguilar, Zavaleta-Gatica *et al.* 2007; Zainuri 2006). The aim of this work was to investigate the potential of UV-C to reduce postharvest disease in two avocado cultivars.

Avocado fruit cultivars Hass and Reed were harvested at the mature-green stage from a commercial property at Duranbah, northern New South Wales. Three or four fruit from each of five replicate trees were used for each treatment. Fruit were clipped from the trees leaving a short 5mm pedicel on the fruit, packed into tray-lined cardboard boxes and transported to the laboratory facilities at the Department of Primary Industries and Fisheries, Indooroopilly (DPI&F) within 4h of harvest. The avocados were labelled with a treatment code, tree and replicate number and stored overnight at ~24ºC. There were two trials with each cultivar.

Fruit were exposed to UV-C light for various time intervals to determine the effects on the development of postharvest disease and fruit quality (Table 3). An experimental packing line (Figure 1A) fitted with brushes and rollers (Figure 1B) to rotate the fruit was modified and fitted with a UV-C light source (two 88cm UV-C germicidal tubes, Gelman Sciences) ~40cm above the brushes. Peak emission from the tubes was 254nm. The fruit were placed onto brushes directly below the UV-C light source. Black plastic was then pulled down to protect the user from the UV-C light radiation. The brushes continually rotated the fruit without fruit advancing along the line, allowing for a uniform coverage of UV-C light. Various energy receipts (a function of intensity and time of exposure) were applied to each of the UV-C treatment groups and dosages were measured

in kJ/m2, using a UV radiometer model IL1400 BL with a UV-C sensor model SEL 240 (International Light, USA), and these are reported in Table 3.

In the first experiment with 'Hass' the fruit were rotated at a constant speed of 60rpm as the brush speed could not be varied. The fast speed caused damage to the skin, and thus fruit in 'Hass' Experiment 2 were placed in a laminar flow cabinet approximately 40cm directly below the UV-C light source and individually turned once during UV-C irradiation. The experimental packing line motor was replaced with a new motor containing a variable brush speed dial. The brush speed was thus reduced to 5rpm for experiments with 'Reed' avocados.

In each experiment, control groups were subjected to brushing only (ie no UV-C treatment) for the following durations: 'Hass' Expt.1 = 5 min; 'Reed' Expt. 1 = 2.5, 5, 7.5 and 10 min; 'Reed' Expt 2 = 10, 15 and 20 min


**Figure 1 Experimental packing line (A), that was fitted with brushes and rollers (B) to rotate the fruit evenly during UV-C exposure.**

**Table 3 Summary of UV-C exposure time, total energy receipts and brush speed for the four avocado experiments**

| | UV exposure time (min) | Energy receipts (kJ/m2) | Brush speed (rpm) |
|---|---|---|---|
| 'Hass' Expt 1. | 0, 2.5, 5, 7.5, 10 | 0, 2.3, 4.7, 7.1, 9.4 | 60 |
| 'Hass' Expt. 2 | 0, 1.2, 2.5, 5, 7.5 | 0, 0.9, 1.8, 3.3, 5.4 | n/a (laminar flow) |
| 'Reed' Expt. 1 | 0, 2.5, 5, 7.5, 10 | 0, 2.3, 4.7, 7.1, 9.4 | 5 |
| 'Reed' Expt. 2 | 0, 10, 15, 20 | 0, 9.4, 14.1, 18.8 | 5 |

Fruit were stored in cardboard boxes in a dark ripening room at 23℃ and 65% RH. Each fruit was assessed daily for UV-C burn, brush damage, disease development, and skin colour and firmness changes until they reached the 'eating ripe' stage.

In 'Hass' eating ripe stage was reached when fruit turned from green to purple black and softened. The pedicel was removed and the skin was scored into four quarters (~3mm deep) and peeled off the fruit flesh. Anthracnose and stem end rot disease incidence (percentage of affected fruit in each treatment group) were recorded. Anthracnose disease severity was determined by estimating the percentage surface area of brown/black lesions covering the inside of the fruit skin. Stem end rot disease severity was assessed by cutting through the fruit flesh starting at the stem end to determine the percentage volume of flesh discolouration.

Assessment in 'Reed' was similar except that eating ripe was determined as the time when the dried residual peduncle dislodged easily from the fruit. As the Reed cultivar stays green when ripe, anthracnose disease severity was assessed without peeling the fruit. Stem end rot disease severity was assessed as for 'Hass'.

Isolations from the diseased stem end of fruit were made to confirm causal organisms. A small piece of tissue, ~1-2mm$^3$, was excised from lesion margins and placed onto streptomycin amended potato dextrose agar (SPDA). The agar plates were then placed under near UV light (Phillips TL40W/08, 300-380 nm) to encourage sporulation (12h light: 12h dark cycle) for 2-4 weeks. The resulting fungal colonies were identified on the basis of colony colour and microscopic morphology (size, shape and appendages of the conidia).

Treatments were arranged in a randomised complete design for all experiments. Statistics were analysed using GraphPad Instat Version 3.05 and R statistical computing software (R Development Core Team 2007). In selected experiments, beta, negative binomial and Dirichlet regressions were performed by Dr Simon Blomberg, Biological and Chemical Sciences Faculty Biometrician, The University of Queensland. Incidence and severity of anthracnose and stem end rot were compared between treatment groups for significance using Fisher's Exact Test and one-way analysis of variance, respectively, if the data was normally distributed. Where data sets were not normally distributed, eg. where there were large numbers of fruit with 0% disease, the Kruskal-Wallis test with Dunn's 14 Multiple Comparison was used. The unpaired t-test and Mann Whitney test were used to compare individual treatment groups. Beta regression was used to analyse relationships between the effects of length of brushing and UV-C exposure on disease severity.

## Treatment of harvested fruit with traditional and non-traditional chemicals

Acidified prochloraz dipping trials 2008

Two trials were conducted to investigate the efficacy of acidified prochloraz (Sportak®) postharvest dip treatment in reducing postharvest disease. These trials were initiated after a report that acidified lower rates of prochloraz and hydrochloric acid alone effectively controlled disease in mango and persimmon caused by *Alternaria alternata* (Prusky, Kobiler *et al.* 2006). The low concentrations were apparently effective because more of the active ingredient was available (soluble) in acidified solutions. One trial was completed on 'Hass' fruit from Green Pigeon, northern NSW, in August 2008, and a second trial on 'Reed' from Duranbah also in northern NSW, was completed in mid-November 2008.

There were 6 treatments as outlined below, with a tray of fruit (usually 20 pieces) being sourced from 4 replicate trees per treatment. Extra fruit from each tree was harvested for pulp dry matter assessments as a measure of maturity. Dipping was carried out in plastic laundry baskets inserted into 40L garbage bins containing the treatment solution prepared with tap water at room temperature for 30 seconds. Fruit were air-dried on racks before being repacked into trays and ripened at 22-23C, 65% RH in a controlled environment room. Fruit were checked daily and individual pieces removed when they had reached the 'eating ripe' stage. When ripe, the peel of 'Hass' fruit are a purple/black colour so it was necessary to peel fruit to determine % of surface area affected by postharvest disease. % volume flesh area affected by stem end rot was also recorded where present, and isolations from the diseased stem end of fruit from one replicate were made to confirm causal organisms. As 'Reed' are a green-skinned variety it was not necessary to peel the fruit to determine disease severity. Stem end rot was assessed as described for 'Hass'.

Treatments:

1. Water control
2. HCl (acid) alone 0.55 mL/L for 30 sec
3. Sportak standard concentration, 0.55 mL/L (450 g ai /L prochloraz) for 30 sec
4. Sportak low concentration, 0.11 mL/L (90g ai /L prochloraz) for 30 sec
5. Sportak standard + HCl, 0.55 mL/L (450 g ai /L prochloraz) for 30 sec
6. Sportak low concentration + HCl, 0.11 mL/L (50 g ai /L prochloraz) for 30 sec

Data were subjected to general analyses of variance in Genstat Release 11.1 (VSN International Ltd., 2008) statistical software.

Alternative fungicide and non traditional chemicals dipping trials 2009-10

There are a large range of products available on the market which may be effective in reducing postharvest fruit disease of avocado. One of those tested in these dipping trials is a fungicide (not currently registered in avocado) shown to effectively reduce anthracnose and stem end rot diseases in mango, which are also the predominant fruit diseased in avocado and caused by similar fungal organisms. Additionally, there are many products available which are claimed to have 'soft' modes of action, ie. are not directly fungicidal and not harmful to the environment, but yet supposedly increase plant yield and health etc. via other mechanisms like enhancing natural plant defences. There has been little or no experimentation done to confirm these claims. The dipping and spray trials in this project tested a number of these products to determine their effect in managing post harvest disease with the hope of being able to recommend effective compounds for further testing, or for suggested incorporation into disease management strategies. The ultimate aim is to deliver to Industry options for more targeted and/or reduced fungicide application, in line with its goals of more sustainable and profitable production.

Two trials were conducted in 2009, and one in 2010 to assess effects of dipping fruit in two rates of a previously untested fungicide, or 4 other products, on development of postharvest disease upon ripening. Fludioxonil, (Scholar®, Syngenta), is a Group 12 fungicide (a phenylpyrrole) and is thus unrelated to any others currently used in avocado or mango production. Due to the withdrawal of carbendazim as a postharvest treatment, the mango industry attained a permit (in force July 2010 to June 2013) to use Scholar as a postharvest hot dip or spray, after several preliminary trials have shown it to be extremely effective in reducing anthracnose and stem end rot. Hot dips are not an option for avocado postharvest treatment, so this fungicide was tested at two rates in solution at ambient temperature.

Acibenzolar-S-methyl (Bion®, Syngenta) is a known plant defence activator and has been commercialised in many countries for use in specific plant/pest target systems. While Bion has been effective in some mango trials in reducing postharvest disease (eg. Zainuri, 2006), previous work in our group has failed to demonstrate its efficacy as a treatment which reduces disease in avocado (unpublished).

NaturalGreen® (naturalGreen GmbH, Germany) is composed primarily of calcium carbonate ($CaCO_3$) approx. 79%, and magnesium carbonate ($MgCO_3$) 4.6%, and is high in silicon and trace elements such as iron, copper, manganese, selenium and zinc. It's manufacturers claim a wide range of benefits, including improvement of natural resistance against plant diseases, improvement of yield and quality, and continuous supply of calcium to the plant aiding cellular stability and ionic exchange. It is certified by BioGro New Zealand for organic production. We were interested to determine if this product could increase Ca and Mg levels in fruit peel, as related research in our group has shown that high Ca and Mg (and associated lower N), correlates with less postharvest disease and superior fruit quality.

Aminogro® (Organic Crop Protectants, Sydney) is claimed to be a 'plant crop biostimulant' based on chitosan derived from prawn shells, and other marine sourced materials which are converted in a unique industrial digestion process into amino acids, polypeptides, proteins and fortified with a range of trace minerals and vitamins. The amino acids are rapidly absorbed by the plant and help the plants immune system to minimise insect and fungal attack/damage to correct minor stress and nutrient deficiencies to maximise premium quality fruit flowers and produce.

EcoCarb (Organic Crop Protectants, Sydney), is a plant fertiliser containing activated potassium bicarbonate, with demonstrated efficacy against anthracnose, mildews as well as botrytis and a number of black spot diseases.

For the first trial, four replicate trays of 'Hass' fruit per treatment were selected from a bulk sample of fruit harvested from the rootstock trial (T. Whiley's AV08000 - Rootstock Improvement for the Australian Avocado Industry - Phase 3 project) at Duranbah in July 2009. ie. there were no single tree replicates. For the second trial, one tray of 'Reed' fruit was harvested from each of 40 trees at Hampton in November 2009, and five trays were randomly assigned to each of the treatments outlined below. For the third trial, 8 trays of 'Hass' fruit were harvested from each of 5 trees at Hampton in July 2010, ie. 5 single tree replicates.

Fruit were ripened and assessed as described previously.

Treatments:

1. Water control
2. natural green (0.5% w/v) for 1 min
3. EcoCarb (4g/L) for 1 min
4. Aminogro low (5 mL/L) for 1 min
5. Bion (25g product/100L, 12.5 g a.i./100L) for 1 min
6. Scholar high (500mL/100L, 230 g a.i./L) for 30 sec

7. Scholar low (250mL/100L, 230 g a.i./L) for 30 sec
8. Sportak standard (0.55 mL/L, 450 g ai /L prochloraz), for 30 s

Data were subjected to general analyses of variance in Genstat Release 11.1 (VSN International Ltd., 2008) statistical software.

## Effect of field sprays with traditional and non-traditional chemicals 2009-2010

As well as some of the non-traditional products trialled in postharvest dipping experiments, there were some additional products included as field sprays applied several times through fruit development.

Serenade Max (Agraquest, USA and supplied locally by Nufarm Australia), is a biocontrol agent based on a patented strain of *Bacillus subtilis* (QST 713), with claimed superior antimicrobial activity via 3 classes of antimicrobial compounds and efficacy against a broad range of bacterial pathogens, as well as activating plant defence responses. It is supposedly synergistic with fungicides (eg. strobilurins and triazoles), as cell membranes are damaged by the lipopeptide compounds giving fungicides improved access to fungal cells. Serenade Max was not effective in reducing anthracnose in avocado when applied several times as a field spray (Everett, Pushparajah *et al.* 2008), or once as a postharvest treatment (Everett, Timudo-Torrevilla *et al.* 2008).

Potassium silicate (Kasil) has been shown (inconsistently) to reduce postharvest disease when applied as a trunk injection (Anderson, Pegg *et al.* 2004) however, it's efficacy as a foliar spray with surfactant to aid penetration into leaf cells has not been adequately examined. The disease-reducing effect of silicon has been shown for many plant/pathogen systems, where it is particularly effective in annual crops (eg. Dann and Muir 2002) ; Whan 2009).

Dithane Rainshield™ (Dow AgroSciences Aust. Ltd.) is a formulation of the protectant fungicide mancozeb with claimed improved rainfastness and more uniform distribution upon application. It is currently registered in mangoes and other fruit crops but not avocados.

An initial trial was established at Duranbah, northern NSW to ensure 'new' products were not phytotoxic when applied as sprays to trees at the nominated concentrations. The treatments were naturalGreen, EcoCarb, Aminogro (2 rates) and GF13 (a Chinese preparation of burdock fructooligosaccharide). Six year old 'Reed' trees were sprayed 4 times (twice for naturalGreen treatment) between 30 April and 19 August, 2009. None of the treatments caused obvious phytotoxic effects on the trees. However, the orchard had not been well managed for some years, and health of the trees declined considerably due to water stress (drought), Phytophthora pressure etc., and a decision was made to abandon the trial without harvesting fruit for postharvest disease assessment.

A further two trials in 'Hass' were conducted in the 2009-10 fruiting season on commercial orchards in south east Queensland. Site 1, located on an orchard in the Glass House Mountains region of the Sunshine Coast in south east Queensland, consisted of five year old 'Hass' trees grafted on 'Dusa' rootstock. Trees had a lighter crop load compared to the previous season though were still bearing well. The trial at Site 2, located at on an orchard near Childers in south east Queensland, was run by Dr John Leonardi, and consisted of two year old 'Hass' trees grafted to seedling 'Velvick' rootstocks. Trees had been treated with the growth regulator Sunny® (uniconazole) at flowering in September 2009 to reduce the spring growth flush and increase fruit size and set. Trial trees at both sites were excluded from the growers' regular fungicide spray program but were subject to all other regular orchard management practices including pesticide treatments and irrigation.

Over the 2009/2010 growing season trees were treated with the trial chemicals as listed in Table 4. All trial chemicals were applied five times through the season at both sites, commencing at early fruit set. Treatments 1 and 7 also received two applications of the systemic fungicide chemical Amistar® at three weeks and one week prior to harvest. Trees were sprayed to ensure thorough coverage of foliage, with 2-6 L per tree depending on size.

At the Glass House Mountains site the trial commenced on the 1st November 2009. Treatments 2, 3, 4, 5, 6 & 8 were applied on the 1st November 2009, 17th December 2009, 11th February 2010, 7th April 2010 and 26th May 2010. The protectant chemicals in treatments 1 and 7 were applied at the time of initial application on 1st November repeated on the 3rd December, 11th January, 12th February and 7th April. Amistar® was applied to treatments 1 and 7 on the 26th May and 11th June. Treatments were applied using a vehicle mounted spray rig.

At the Childers site treatments 2, 3, 4, 5, 6 and 8 were applied initially on the 28th October 2009 and repeated on the 24th December 2009, 18th February, 15th April 2010 and 1st June. Treatments 1 and 7 were applied on a monthly basis from the 28th October 2009 to the 15th April 2010 followed by applications of Amistar on the 17th May and 1st June. Treatments were applied with a motorised backpack mounted rig.

Fruit were harvested from the trials once they had reached 24% dry matter and final treatment application had been made (harvest dates were 7th and 17th June, 2010, for Childers and Glass House Mountains, respectively). Twenty fruit per tree were harvested and transported to Indooroopilly Research Centre before being stored in a controlled environment room set at 22°C and 70% relative humidity. Fruit were monitored for ripeness and assessed for disease development at eating ripe. A further five fruit from each tree were harvested for measurement of dry matter levels and sampling for nutrient analysis. Untreated fruit and those from the natural green treatment were selected and peel samples taken for Ca, N analyses to determine effect of treatments.

**Table 4 Summary of treatments to developing fruit on trees at Childers and Glass House Mountains 2009-2010**

| Treatment | | Rate and timing of application |
|---|---|---|
| 1 | Industry standard | Amistar (80mL/100L 250SC) – 2 applications (3 weeks before harvest and 7 days before harvest).<br>Norshield (copper) WG (105g/100L)- 5 applications at approx. monthly intervals |
| 2 | naturalGreen | 30g/100L – 5 applications (6-8 week intervals, harvest 1 week after final application) |
| 3 | Serenade Max | 200g/100L – 5 applications (6-8 week intervals, harvest 1 week after final application) |
| 4 | Kasil 2040 (1000 ppm) | 260mL/100L + Du-wett 15mL/100L per tree – 5 applications (6-8 week intervals, harvest 1 week after final application) |
| 5 | EcoCarb | 300g/100L plus + Du-Wett 15g/100L per tree – 5 applications (6-8 week intervals, harvest 1 week after final application) |
| 6 | Aminogro | 150mL/100L– 5 applications (6-8 week intervals, harvest 1 week after final application) |
| 7 | Rainshield | Amistar (80mL/100L 250SC) – 2 applications (3 weeks |

| | | |
|---|---|---|
| | | before harvest and 7 days before harvest).<br>Rainshield (mancozeb) 200g/100L – 5 applications at approx. monthly intervals |
| 8 | Product a | 60g/100L – 5 applications (6-8 week intervals, harvest 1 week after final application) |
| 9 | Untreated control | No sprays |

## Scoping study on brown root rot caused by *Phellinus noxius*

A scoping study into brown root rot was included as a component of AV07000 due to the increased awareness among growers and Industry of the damage to trees and productivity loss that this disease had been causing. Orchards on the Atherton Tablelands and Bundaberg/Childers areas of Queensland were visited and inspected for *Phellinus noxius* (Pn) in May 2008 and February 2009, respectively. Orchards in northern New South Wales, and on the Sunshine Coast hinterland (QLD) were also visited, where death of trees due to Pn was suspected. A report was presented to Industry and was subsequently published in 'Talking Avocados' (Dann, Smith *et al.* 2009). It includes a review of literature, host plants affected, current distribution on avocado within Australia, potential control options and ideas for further research. Thus, the reader is referred to this report, and details will not be repeated here, besides a brief summary of findings, and update on spread.

A new project funded by HAL/AAL (AV10001: 'Improving yield and quality in avocado through disease management, Phase 2') will commence in January 2011, and will have a significant *Phellinus* component, particularly trialling some management options identified from the literature and presented in (Dann, Smith *et al.* 2009). Action is required to reduce the impact of this disease.

# Results

## Management of Phytophthora root rot

### Resistant rootstock selections

Full details of this work are available in Smith et al, 2011, DOI: 10.1007/s13313-010-0011-0, and for copyright reasons, will not be duplicated here. Briefly, two selections 'SHSR-02' and 'SHSR-04', as well as ungrafted 'Hass' and the commercial rootstock 'Dusa™' were significantly better survivors and were healthier over time than other rootstocks including 'Velvick' (from various sources), 'Duke 7', A8, A10, 'Reed', 'Latas™', 'Rigato' and 'Barr Duke'. 'Reed' was consistently highly susceptible and most of these trees had died within the 4 year assessment period. Superior tree health was often associated with increased tree height and trunk girths (Smith, Dann *et al.* 2011). The study demonstrated variation in establishment of trees under high disease pressure, for example at the Duranbah, NSW site (Figure 2) tree health after 2 years ranged from 2.7 to 8.5,

(on a scale where 10 = dead), compared with under a lower disease pressure at the Childers QLD site 3 years after planting where tree health ranged from 0 (healthy) to 2.2. In other words, trees thrived in the relative absence of Pc at Childers.

Fruit numbers and weights per tree were obtained from trees at the Childers site in 2009 and 2010 (not included in above mentioned publication). Crop weight and numbers of fruit per tree were highly significant among treatments in both years assessed. In 2009, the greatest yields were from 'A8', 'Velvick' clonal (Whiley) and 'Velvick' seedling (Simpson) rootstocks, which were significantly greater than from 'Velvick' seedling (Anderson), 'Dusa'™, 'Latas'™ and 'Reed' (

Table 5). Four months earlier, trees had been assessed for canopy health, and only 'Reed' was significantly less healthy than all other rootstocks (Smith, Dann *et al.* 2011), which could in part explain its poor yield performance. In 2010, the highest yielding trees were on 'Velvick' seedling (Simpson) rootstock, which was significantly higher than from 'Velvick' seedling (Anderson), 'Velvick' clonal (Whiley) and 'Reed' rootstocks (

Table 6). Fruit were also rated for postharvest disease in 2010, and although disease levels were high (34-66% anthracnose severity), there were no significant differences among rootstocks for anthracnose or stem end rot severity or incidence, or on fruit marketability[i]. However, there was a trend for 'Velvick' seedling (Simpson) trees having the best quality fruit, in terms of lower anthracnose and highest marketability (Table 6). 'Dusa™' and 'Reed' had the highest severity and incidence of anthracnose which translated to less than 10% marketable fruit from these rootstocks. 'Reed' also yielded poorly. Stem end rot was also more severe in 'Dusa™' and 'Latas™' compared to all other rootstocks.


**Figure 2 Rootstock trial at Duranbah, NSW, demonstrating healthy tree on 'SHSR-04' selection among less thrifty trees**

**Table 5 Numbers and weights of 'Hass' fruit per tree from different rootstocks (Childers, July 2009)**

| Rootstock | Crop Weight (kg) | | # Fruit | |
|---|---|---|---|---|
| A8 | 31.7 | a | 137.4 | a |
| Velvick clonal (Whiley) | 29.9 | a | 110.8 | a |
| Velvick seedling (Simpson) | 26.5 | a | 112.0 | a |
| A10 | 24.6 | ab | 105.1 | ab |
| Velvick seedling (Anderson) | 14.3 | bc | 58.9 | bc |
| Dusa™ | 12.9 | bc | 46.7 | c |
| Latas™ | 10.1 | c | 36.5 | c |
| Reed | 6.56 | c | 26.3 | c |

within each column means followed by the same letter are not significantly (P<0.05) different

**Table 6 Numbers and weights of 'Hass' fruit per tree from different rootstocks (Childers, July 2010)**

| Rootstock | Anthracnose severity (%) [y] | Stem end rot severity (%)[y] | Fruit market-ability (%)[y] | Crop Weight per tree (kg) [z] | | Pieces of Fruit/tree [z] | |
|---|---|---|---|---|---|---|---|
| Velvick seedling (Simpson) | 33.9 | 4.14 | 40.8 | 80.0 | a | 329 | a |
| Latas™ | 46.7 | 7.88 | 19.5 | 70.4 | ab | 268 | ab |
| A8 | 40.8 | 5.76 | 32.1 | 68.2 | ab | 289 | ab |
| Dusa™ | 62.6 | 8.31 | 9.4 | 64.7 | ab | 240 | abc |
| A10 | 34.4 | 5.47 | 30.8 | 56.9 | abc | 250 | abc |
| Velvick seedling (Anderson) | 38.2 | 3.74 | 27.6 | 46.3 | bcd | 191 | bcd |
| Velvick clonal (Whiley) | 44.5 | 3.63 | 26.7 | 35.2 | cd | 144 | cd |
| Reed | 65.9 | 5.44 | 7.5 | 23.9 | d | 97 | d |

[y] Fruit disease assessments are means from 6 trees (replicates) per rootstock (n=6), while
[z] Yields are means from 10 trees per rootstock (n=10), except for Velvick clonal (Whiley) where there were 9 trees (n=9).
within each column means followed by the same letter are not significantly (P<0.05) different

## Optimisation of phosphonate applications

Efficacy of phosphonate applied as a trunk spray with bark penetrant or as a trunk injection, Hampton 2006-7

At one month after treatment phosphonate levels were significantly higher in both the roots and leaves of trees that had been injected however these levels had dropped by the time of the second

sampling in October to be almost equal to the level in trees treated with the bark spray (Table 7). At the third sampling in December phosphonate levels in leaves and fruit of injected trees had increased and were significantly greater than levels in bark spray treated trees where leaf levels had remained constant and root levels had dropped. Phosphonate levels in flowers collected in October and fruitlets collected in December were significantly higher for injected trees.

In March 2007 following reapplication of the bark spray treatment, root and leaf phosphonate levels were not significantly different between the two treatments and this trend was the same at sampling in June 2007.

Phosphonate levels in the roots of injected trees varied through the sampling period, peaking in July 2006 and were lowest in October 2006. Levels increased again over the December 2006 and March 2007 sampling periods before decreasing again at the June 2007 sampling. Root phosphonate levels of injected trees were not significantly less in June 2007 than at the first sampling in July 2006. Leaf phosphonate levels of injected trees were significantly higher at the July 2006 sampling than at any proceeding sampling time.

Root phosphonate levels of trees receiving the bark spray application were stable at the July and October 2006 sampling dates before decreasing significantly at the December 2006 sampling. Levels following the second bark spray application were significantly higher than those following the initial application before decreasing slightly to levels not significantly greater than those recorded at the July 2006 sampling date. There were no significant changes in the phosphonate levels recorded in leaves during the trial period for trees receiving the bark spray application.

**Table 7 Effect of trunk injection or bark spray on phosphonate levels (mg/kg) in roots, leaves, flowers and fruit, Hampton 2006-7**

| Treatment[1] | Roots | | | | | Leaves | | | | | Flowers | Fruitlets |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jul 06 | Oct 06 | Dec 06 | Mar 07 | Jun 07 | Jul 06 | Oct 06 | Dec 06 | Mar 07 | Jun 07 | Oct 06 | Dec 06 |
| Inject | 65.8 a | 34.7 | 47.2 a | 63.3 | 48.1 | 114.8 a | 5.1 | 38.7 a | 5.0 | 5.0 | 44.4 a | 188.5 a |
| Bark spray | 30.3 b | 33.6 | 16.7 b | 48.7 | 46.2 | 5.7 b | 5.0 | 6.4 b | 6.2 | 5.0 | 7.5 b | 13.8 b |

[1] Trees first treated 20 June 2006 by trunk injection or bark spray as in materials and methods. On 19 Jan 2007 the bark spray was re-applied to those trees which received bark spray previously. Within each column values followed by the same letter are not significantly ($P<0.05$) different.

Analyses of phosphonate concentration in roots after foliar sprays with 0.2% a.i potassium phosphonate, Hampton 2007

There was a small increase in root phosphonate concentrations following the third foliar application of potassium phosphonate however the increase was not significant (Table 8). Root levels were low and arguably insufficient to provide protection from infecting Phytophthora, so an increase in the foliar rate to 0.5% a.i. was recommended.

**Table 8 Phosphonate concentrations in roots following foliar application of potassium phosphonate at 0.2% a.i. concentration**

| Sampling Date | Root phosphonate concentrations (mg/kg) |
|---|---|
| 13th June 2007 | 7.3 |
| 27th June 2007 | 7.3 |
| 16th July 2007 | 11.4 |

Trees were sprayed with 0.2% a.i. potassium phosphonate 31 May, 15 June and 2 July 2007

Further investigation of phosphonate trunk sprays with bark penetrant, Hampton 2007

The results for analysis of leaf phosphonate levels for three samples were abnormally high and must be viewed with caution. There were no significant differences in leaf phosphonate levels between trees treated with different bark spray treatments while trees treated with a trunk injection had significantly higher phosphonate levels (Table 9). Phosphonate levels in roots were not significantly different for any of the treatments. Sampling was to have occurred again at six months after treatment however the trial suffered a heavy frost in August 2007 that severely affected trees and the trial was abandoned.

**Table 9 Phosphonate concentrations in leaves and roots following trunk spray or injection application of potassium phosphonate with or without bark penetrant**

| Treatment | Phosphonate concentrations (mg/kg) sampled July 2007 | |
|---|---|---|
| | Leaves | Roots |
| 10% a.i. phosphonate | 121.0 b | 36.6 |
| 20% a.i. phosphonate | 90.0 b | 43.2 |
| 10% a.i. phosphonate + 1% Pulse | 135.0 b | 47.8 |
| 10% a.i. phosphonate + 2% Pulse | 87.0 b | 26.0 |
| 20% a.i. phosphonate + 1% Pulse | 284.0 b | 30.2 |
| 20% a.i. phosphonate + 2% Pulse | 117.0 b | 79.8 |
| 20% a.i. phosphonate injected | 788.0 a | 40.2 |

Trunk sprayed on 13th June 2007

Support for increased rates of foliar phosphonate application, Duranbah 2008

'Reed' trees received potassium phosphonate applications via single injection or single bark spray in May, or multiple (4x) foliar sprays from May to August. Roots and flesh were sampled in September and roots again in December, and analysed for phosphonate residues. At both sampling dates root phosphonate levels were significantly higher for injected trees compared to other treatments (Table 10). At the first sampling date in late September, root phosphonate levels were not significantly different between foliar and bark spray treatments although levels in the foliar treatment were significantly higher than in control trees while levels in the bark spray treatment were not. At the second sampling date there were no significant difference in root phosphonate levels between the foliar, bark spray and control treatments.

Phosphonate residue levels in avocado flesh from injected trees were significantly higher than in fruit from all other treatments, and exceeded 100ppm. Residue levels were also high in fruit which had received foliar applications of phosphonate, and were greater than in fruit from trees which had been bark treated or untreated (Table 10).

There were no significant differences in tree health between the treatments when assessed at the second sampling date (Table 10). There were also no significant changes in root concentrations for any of the potassium phosphonate treatments between the two sampling dates however levels were considerably higher at the second sampling date for control trees.

**Table 10 Phosphonate levels in roots and flesh after different methods of application of phosphonate in 'Reed' avocado, Duranbah 2008**

| Treatment | Phosphonate (mg/kg) at 26.09.08 | | | | Phosphonate (mg/kg) at 17.12.08 | | Tree Health[1] at 17.12.08 |
|---|---|---|---|---|---|---|---|
| | Roots | | Flesh | | Roots | | |
| Injection | 65.3 | a | 118.6 | a | 60.0 | a | 1.88 |
| Foliar (4x) | 40.5 | b | 76.9 | b | 30.3 | b | 1.75 |
| Bark | 23.3 | bc | 6.5 | c | 32.8 | b | 2.25 |
| Control | 6.38 | c | 6.84 | c | 17.8 | b | 3.5 |

[1] based on a scale where 1 = healthy canopy and 10 = tree death

Agrichem Australia sought permission from DPI&F and HAL to use this data to support an extension of the Emergency Use Permit. We provided the data to Agrichem, and the Permit was extended until March 2011.

Timing of phosphonate injection in 'Reed', Hampton 2009

'Reed' trees were injected with phosphonate in May, June, August or September to determine optimum time of injection to maximise phosphonate residues in roots while minimising levels in fruit. At sampling in September 2009 root phosphonate levels were highest in trees that had been injected in May with levels significantly greater than in un-injected control trees or in those injected in August (Table 11). (NB. Control trees had been injected with phosphonate in previous seasons by the grower as part of a Phytophthora management plan).

There were no significant differences among treatments in phosphonate levels measures in roots sampled at the time of commercial harvest in November. However, root phosphonate levels were greatest in trees injected in May and lowest for trees injected in August. Root phosphonate levels in all treatments including the control were greater than the arbitrary critical level of 40 mg/kg. Fruit phosphonate residue levels were significantly greater for trees injected in May than for trees injected at any other time (Table 11). Residues in fruit from trees injected June, August or September were not significantly different but exceeded the MRL of 100 mg/kg. Fruit residues harvested from trees not injected in the 2009 season were minimal at nearly 6 mg/kg. This may demonstrate that root phosphonate levels from previous seasons may remain high enough to protect trees from Phytophthora. A trial in 2010 is assessing whether reduced rates of phosphonate in 'Reed' is sufficient to carry trees through the season with adequate root levels.

**Table 11 Effect of timing of injection of phosphonate on residue levels in roots and fruit, Hampton 2009**

| Treatment | Phosphonate (mg/kg) at 15.09.09 | Phosphonate (mg/kg) at 30.11.09 | |
|---|---|---|---|
| | Roots | Roots | Flesh |
| Control | 73.3 b | 67.3 | 5.9 c |
| May | 138.8 a | 101.7 | 219.3 a |
| June | 114.6 ab | 76.9 | 140.6 b |
| August | 72.1 b | 58.4 | 103.1 b |
| September | | 88.7 | 113.9 b |

means followed by the same letter are not significantly ($P<0.05$) different

## Management of postharvest fruit diseases

### Effect of UV light exposure to harvested fruit

Assessments were made at 'eating ripe' stage. In 'Hass' Expt. 1, the speed of the brush rollers could not be varied and brush damage was observed after 2.5-10 min of brushing. At 6 days post UV-C treatment, the colour was still green where the brushes had marked the fruit, whereas the extremities had begun to 'colour up' (Figure 3A). The brushed areas seemed to be more prone to developing anthracnose lesions (Figure 3B).


**Figure 3 Avocado cv. Hass in the 10 min brushed control group, showing the delayed ripening effect caused by excessive brushing (A). Large coalescing anthracnose lesions (arrow) caused by *C. gloeosporioides* over the area where brush damage was observed (B).**

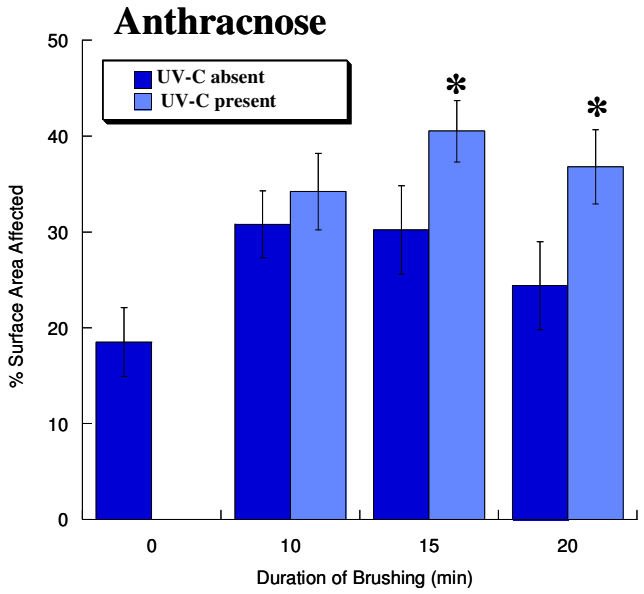
In 'Hass' Expt. 1 anthracnose incidence was significantly greater in the 5 min ($P$=0.027), 7.5 min ($P$=0.0025) and 10 min ($P$=0.0025) UV-C treatment groups (data not shown) compared to the unbrushed control, however disease incidence was still high in the 5 min brushed control (66.7%). There were no significant differences in the incidence of stem end rot between the treatment groups. Anthracnose severity increased when the duration of treatment was equal to or greater than 5 min (data not shown). However, due to the large variation within the treatment groups, only the 7.5 min ($P$<0.01) and 10 min ($P$<0.05) UV-C treatment groups were significantly greater than the unbrushed control. Stem end rot severity was lower in the UV-C treatment groups compared to the unbrushed and 5 min brushed controls, but this was not significant. *Dothiorella spp.*, *Phomopsis* spp. and *C. gloeosporioides* were isolated from stem end rot lesions.

In 'Hass' Expt. 2, UV-C treatment was undertaken in a laminar flow cabinet, with fruit turned once by hand. All treatment groups showed a high incidence of anthracnose (≥90%) and no significant differences in severity of anthracnose (range 24.9-48.5%) or stem end rot (range 11.7-16.7%) were demonstrated between treatment groups by one-way analysis of variance. *Lasiodiplodia/Dothiorella* spp., *Phomopsis* spp. and *C. gloeosporioides* were isolated from stem end rot lesions.

In 'Reed' Expt. 1, no significant difference between treatment groups was demonstrated for either anthracnose or stem end rot disease severity (not shown). However, stem end rot disease severity was significantly greater in the 10 min UV-C group when individually compared to the 10 min brushed control group ($P$=0.043). This reflected a trend that with increased UV-C exposure,

disease severity for both anthracnose and stem end rot was greater in all UV-C treatment groups compared with brushed controls. In the absence of UV-C treatment, a brushing duration of 2.5 min also significantly decreased the severity of stem end rot when individually compared to the unbrushed control ($P$=0.046), and whilst the 5, 7.5 and 10 min brushed control groups also had reduced disease severity compared to the unbrushed control, none showed significance. Beta regression was used to analyse for correlation between length of brushing alone and length of brushing plus UV-C exposure. This confirmed the trend of increasing disease severity with length of UV-C exposure as the slopes of the curves generated for anthracnose ($P$=0.006) and stem end rot ($P$=0.015) were significantly different (not shown).

In 'Reed' Expt. 2, treatment times were extended to 15 and 20 min to further investigate trends in disease severity with increased brushing and/or UV-C exposure. Compared to the first 'Reed' experiment, disease severity was greater in the late season fruit. Anthracnose severity was significantly greater in the 15 min ($P$<0.01) and 20 min ($P$<0.05) UV-C exposure groups compared to the unbrushed control group (Figure 4). No significant differences in stem end rot disease severity between brushed and UV-C exposure groups were demonstrated (Figure 5). However, beta regression confirmed the trend of increasing disease severity with increased length of UV-C exposure (not shown). *Dothiorella* spp., *Phomopsis* spp., *C. gloeosporioides, Lasiodiplodia,* spp. and *Pestalotiopsis* spp. were isolated from stem end rot lesions.




* significantly greater than unbrushed control (P<0.05)

**Figure 4 Effect of UV-C exposure and brushing on anthracnose disease severity in 'Reed' avocado Expt. 2**

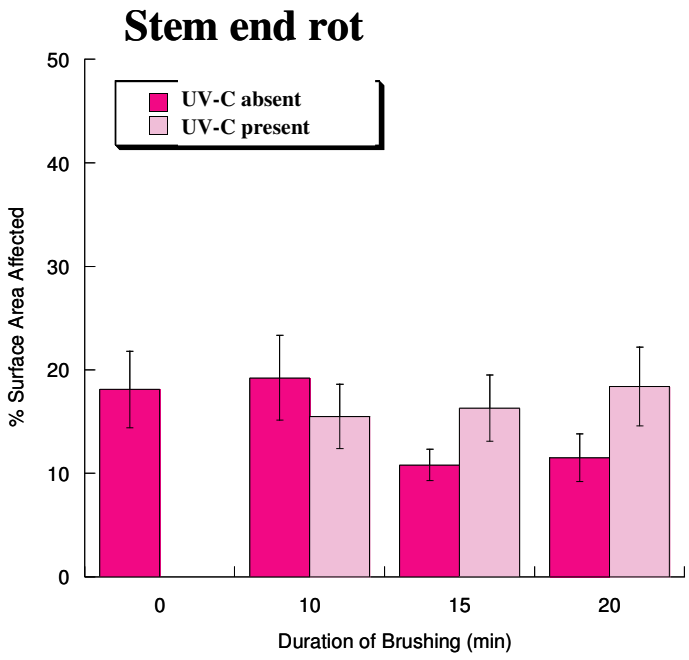



**Figure 5 Effect of UV-C exposure and brushing on stem end rot disease severity in 'Reed' avocado Expt. 2**

## Treatment of harvested fruit with traditional and non-traditional chemicals

The effect of treating with pyraclostrobin (Cabrio®) on severity of fruit disease was not examined in this project, despite it being included in the original project document. Cabrio®, Filan® (boscalid) and Pristine® (Pyraclostrobin + boscalid) were compared with standard Industry fungicides Amistar® (azoxystrobin) and prochloraz in a separate project MT 06055, which was not conceived when AV07000 was initiated. Thus, it was considered unnecessary to duplicate trials, and provided the opportunity to assess other options as discussed below.

Acidified prochloraz dipping trials 2008

Dipping fruit in prochloraz at the standard rate, or at 1/5$^{th}$ of the standard rate, significantly reduced anthracnose severity in 'Hass' fruit (Table 12) compared with dipping in water. Hydrochloric acid alone, or with standard or low rates of prochloraz did not reduce anthracnose severity. The incidence of anthracnose was greatest in fruit dipped in acid alone, and was significantly greater than in fruit dipped in prochloraz with or without acid at the standard rate, and low concentration prochloraz. Stem end rot severity was very low (0.2-2.7%) and there were no significant differences among treatments in severity (not shown) or incidence (Table 12), although incidence was reduce considerably compared with water-dipped controls. There were no differences among treatments in the number of days it took fruit to reach the eating ripe stage (not shown).

Postharvest anthracnose disease levels were low in the second trial with 'Reed', and there were no significant differences among treatments in severity or incidence. An additional symptom type on fruit peel was caused by a complex of *Colletotrichum* and *Botryosphaeria* (*Dothiorella*) spp., however, there were no significant differences among treatments in the severity of this symptom, although less severe disease and significantly fewer fruit with disease was from fruit dipped in acid alone (Table 13). This also translated into a higher percentage of more marketable fruit compared with all other treatments, although the effect was not significant.

**Table 12 Effect of concentration and acidification of prochloraz (Sportak®) postharvest dip treatments on anthracnose severity and incidence in 'Hass' fruit (Green Pigeon, August 2008)**

| Treatment | Anthracnose severity (%) | Anthracnose incidence (%) | SER incidence (%) | Fruit marketability[a] % |
|---|---|---|---|---|
| Water control | 51.8 a | 91.1 ab | 11.2 | 23.8 |
| Acid alone | 47.4 a | 98.8 a | 6.2 | 15.0 |
| Sportak standard conc. | 26.0 bc | 71.2 b | 0.0 | 52.5 |
| Sportak low conc. | 19.9 c | 76.2 b | 3.8 | 43.8 |
| Sportak standard + acid | 41.5 ab | 82.5 b | 1.2 | 33.8 |
| Sportak low conc. + acid | 43.8 a | 91.2 ab | 5.0 | 21.2 |

means followed by the same letter are not significantly ($P<0.05$) different

[a] Marketability is used as a measure of consumer acceptance (no stem end rot and less than 5% anthracnose)

**Table 13 Effect of concentration and acidification of prochloraz (Sportak®) postharvest dip treatments on anthracnose severity and incidence in 'Reed' fruit (Duranbah, November 2008)**

| Treatment | Anthracnose severity (%) | Anthracnose incidence (%) | Total side lesion[a] severity (%) | Total side lesion[a] incidence (%) | Fruit marketability %[b] |
|---|---|---|---|---|---|
| Water control | 3.56 | 37.5 | 11.0 | 91.3 a | 51.2 |
| Acid alone | 0.81 | 23.8 | 3.2 | 52.5 c | 81.2 |
| Sportak standard conc. | 1.62 | 40.0 | 19.6 | 80.0 ab | 51.2 |
| Sportak low conc. | 2.43 | 30.0 | 16.7 | 67.5 bc | 61.2 |
| Sportak standard + acid | 2.86 | 33.8 | 7.8 | 68.8 bc | 67.5 |
| Sportak low conc. + acid | 4.10 | 41.2 | 14.6 | 75.0 ab | 53.8 |

means followed by the same letter are not significantly ($P<0.05$) different

[a] Includes symptoms of lenticel spotting and limited surface lesions caused by *Colletotrichum/Dothiorella* complex, which was peculiar to this trial.

[b] Does not take lenticel spotting or *Colletotrichum/Dothiorella* complex into account (fruit marketability)

Alternative fungicide and non traditional chemicals dipping trials 2009-10

Several unregistered products, fungicidal and non-fungicidal have been tested in two postharvest dipping trials, with 'Hass' and 'Reed' avocados. There were significant differences among treatments in postharvest disease incidence and severity for the 'Hass' trials (Table 14 and Table 16) where disease levels were high (approximately 20-70% and 14-48% severity of anthracnose in 2009 and 2010 trials, respectively), but not the 'Reed' trial (Table 15) where anthracnose severity did not exceed 6% of surface area affected.

In the 2009 'Hass', trial dipping in Sportak as well as 2 rates of an unregistered fungicide (fludioxinil, Scholar), plus two non-fungicidal compounds (natural green and EcoCarb) resulted in significantly less severe anthracnose developing in fruit than in water treated controls (Table 14). Dipping fruit in Bion significantly increased severity of anthracnose compared to all other treatments. Anthracnose incidence was significantly reduced in fruit dipped in Sportak, natural green, EcoCarb and the high rate of Scholar, compared to the water-dipped fruit (Table 14). Scholar and Sportak fungicides significantly reduced stem end rot severity and incidence compared with water control, however, the other treatments had no significant effect, with the exception of Bion, which increased stem end rot (significantly for severity). The most marketable fruit were from the fungicide and natural green treatments.

Postharvest disease severity was low in 'Reed' fruit harvested and treated in November 2009, and there were no significant differences among treatments in any parameter measured (Table 15). Fruit marketability as a measure of consumer acceptance was greatest in fruit from EcoCarb and lowest in fruit from Bion dip treatments.

In the 2010 'Hass', trial dipping fruit in Sportak had the greatest effect on reducing anthracnose severity and stem end rot, although not significantly compared to the water control

Table 16). As in 2009, Bion treatment actually increased severity of anthracnose, significantly compared to EcoCarb, Scholar high and Sportak treatments. Both rates of Scholar significantly reduced stem end rot severity and incidence compared with water controls and Bion-treated fruit. There were no significant differences among treatments in fruit marketability, although the most marketable fruit were from the fungicide and EcoCarb treatments, and the least marketable from Bion treatment (Table 16).

**Table 14 Effect of several products applied as a postharvest dip on anthracnose and stem end rot disease in 'Hass' avocados (Duranbah, July 2009)**

| Treatment | Anthracnose severity (%) | Total stem severity (%) | Anthracnose incidence (%) | Total stem incidence (%) | Fruit marketability[a] % |
|---|---|---|---|---|---|
| Water control | 57.4 b | 6.22 bc | 93.8 ab | 66.3 ab | 8.8 d |
| natural green | 36.3 de | 6.47 c | 73.8 de | 51.3 b | 26.3 bc |
| EcoCarb | 43.8 cde | 7.44 bc | 80.0 cd | 56.3 b | 18.8 cd |
| Aminogro | 51.2 bc | 8.28 b | 92.5 abc | 65.0 ab | 11.3 d |
| Bion | 71.2 a | 14.1 a | 98.8 a | 83.8 a | 1.25 e |
| Scholar (fludioxonil) high | 30.9 e | 1.37 d | 80.0 de | 25.0 c | 40.0 ab |
| Scholar (fludioxonil) low | 44.2 cd | 1.73 d | 86.3 bcd | 22.5 c | 28.8 bc |
| Sportak (prochloraz) | 19.6 f | 1.17 d | 59.5 e | 12.5 c | 55.0 a |

means followed by the same letter are not significantly ($P<0.05$) different
[a] % marketability – no stem end rot and less than 5% anthracnose

**Table 15 Effect of several products applied as a postharvest dip on anthracnose and stem end rot disease in 'Reed' avocados (Hampton, November 2009)**

| Treatment | Anthracnose severity (%) | Total stem severity (%) | Anthracnose incidence (%) | Total stem incidence (%) | Fruit marketability % |
|---|---|---|---|---|---|
| Water control | 2.69 | 0.43 | 78.7 | 9.3 | 77.3 |
| natural green | 2.79 | 0.86 | 88.0 | 13.5 | 79.8 |
| EcoCarb | 2.36 | 0.35 | 87.1 | 2.9 | 87.4 |
| Aminogro | 3.81 | 1.45 | 85.1 | 27.4 | 70.1 |
| Bion | 5.51 | 1.41 | 86.5 | 13.4 | 60.7 |
| Scholar (fludioxonil) high | 4.04 | 0.03 | 86.5 | 1.3 | 80.8 |
| Scholar (fludioxonil) low | 2.79 | 0.62 | 83.2 | 4.2 | 81.6 |
| Sportak (prochloraz) | 4.56 | 0.78 | 78.3 | 5.3 | 73.1 |

**Table 16 Effect of fungicide and non-traditional products as fruit dip treatments on severity and incidence of postharvest disease in 'Hass' fruit (Hampton, July 2010)**

| Treatment | Anthracnose severity (%) | Total stem severity (%) | Anthracnose incidence (%) | Total stem incidence (%) | Fruit marketability % |
|---|---|---|---|---|---|
| Water control | 31.0 abc | 4.11 ab | 84.9 | 15.2 abc | 29.0 |
| natural green | 30.6 abc | 1.27 bc | 85.9 | 11.1 bc | 29.0 |
| EcoCarb | 23.1 bc | 2.11 abc | 89.0 | 13.0 bc | 36.0 |
| Aminogro | 34.4 ab | 3.22 abc | 92.0 | 17.0 ab | 27.0 |
| Bion | 48.1 a | 5.56 a | 93.0 | 26.0 a | 19.0 |
| Scholar (fludioxonil) high | 25.6 bc | 0.41 c | 87.0 | 4.0 c | 37.0 |
| Scholar (fludioxonil) low | 31.2 abc | 0.17 c | 87.0 | 4.0 c | 32.0 |
| Sportak | 13.8 c | 1.15 bc | 76.0 | 10.0 bc | 50.0 |

means followed by the same letter are not significantly ($P<0.05$) different

## Effect of field sprays with traditional and non-traditional chemicals

Trials at Childers and Glass House Mountains were conducted to determine the efficacy of spraying trees with several treatments throughout the fruit development phase on incidence and severity of postharvest disease. There were medium to high levels of anthracnose and stem end rot diseases at both sites. When data were analysed from the Glass House Mountains trial, there were no significant differences in anthracnose or stem end rot severity or incidence among treatments (Table 17), however there were some indications of treatment effects. Fruit from the Industry Standard fungicide (copper and Amistar) treatment had only 40% of the level of anthracnose severity of fruit from the untreated control trees, and fruit from the Product a and Rainshield (mancozeb fungicide) treatments had approx. 60% of the level of anthracnose severity compared with untreated fruit (Table 17). Fruit from these treatments also had lower incidences of anthracnose compared with untreated fruit. This translated to greater proportions of marketable fruit (fruit with less than 5% anthracnose and no stem end rot) from these treatments, although only fruit from the industry standard fungicide treatment were significantly more marketable than those from untreated trees (Table 17). *Botryosphaeria* (*Lasiodiplodia theobromae*) and *Colletotrichum gloeosporioides* were isolated from 71% and 15% of stem end rot lesions, respectively.

**Table 17 Effect of fungicide and non-traditional products as field spray treatments on severity and incidence of postharvest disease in 'Hass' fruit (Glass House Mountains, harvested June 2010)**

| Treatment | Anthracnose severity (%) | Total stem severity (%) | Anthracnose incidence (%) | Total stem incidence (%) | Fruit marketability % | |
|---|---|---|---|---|---|---|
| Untreated control | 53.0 | 4.87 | 87.0 | 25.0 | 20.0 | b |
| naturalGreen | 45.9 | 2.10 | 88.8 | 8.8 | 21.2 | b |
| EcoCarb | 41.8 | 2.39 | 90.9 | 20.3 | 21.3 | b |
| Aminogro | 53.9 | 4.84 | 85.8 | 18.9 | 21.2 | b |
| Product a | 31.9 | 4.53 | 76.0 | 29.0 | 34.0 | ab |
| Kasil | 44.4 | 1.45 | 84.0 | 14.5 | 22.0 | b |
| Serenade Max | 40.3 | 4.27 | 91.0 | 18.3 | 21.2 | b |
| Rainshield | 32.4 | 2.71 | 76.9 | 14.2 | 38.7 | ab |
| Industry Standard | 21.9 | 2.23 | 62.0 | 12.0 | 55.0 | a |

means followed by the same letter are not significantly ($P<0.05$) different

Postharvest anthracnose and stem end rot were extremely high in fruit from the Childers trial, however, there were some significant treatment effects on anthracnose severity and incidence and fruit marketability (Table 18). Fruit from Kasil treatment had the most severe anthracnose with more than 80% of the surface area affected. Fruit from EcoCarb, Aminogro and Serenade Max treatments had similar levels of anthracnose to Kasil. Fruit from Product a, natural green and Rainshield treatments had around 60% severity of anthracnose, and those from the Industry standard fungicide treatment around 40%, which was significantly lower than all other treatments (Table 18). Anthracnose incidence was significantly lower in fruit treated with the industry standard fungicides than all other treatments, and correspondingly had significantly higher proportion of fruit considered marketable. There were slightly more marketable fruit from Rainshield, Product a and natural green treatments compared to the remaining treatments. Stem end rot was the least severe in fruit treated with standard fungicides or Product a, although not significantly less than the other treatments (Table 18). *Botryosphaeria* (*Lasiodiplodia theobromae*) and *Colletotrichum gloeosporioides* were isolated from 30% and 56% of stem end rot lesions, respectively.

**Table 18 Effect of fungicide and non-traditional products as field spray treatments on severity and incidence of postharvest disease in 'Hass' fruit (Childers, harvested June 2010)**

| Treatment | Anthracnose severity (%) | Total stem severity (%) | Anthracnose incidence (%) | Total stem incidence (%) | Fruit marketability % |
|---|---|---|---|---|---|
| Untreated control | 71.6 bc | 8.07 | 92.8 a | 39.5 | 7.1 b |
| naturalGreen | 63.8 cd | 7.20 | 95.0 a | 39.0 | 11.0 b |
| EcoCarb | 78.7 ab | 7.92 | 99.0 a | 37.0 | 4.0 b |
| Aminogro | 73.5 ab | 11.3 | 97.0 a | 48.0 | 8.0 b |
| Product a | 60.4 d | 6.57 | 91.0 a | 28.0 | 12.0 b |
| Kasil | 81.5 a | 11.2 | 99.0 a | 37.0 | 3.0 b |
| Serenade Max | 78.2 ab | 8.96 | 99.0 a | 35.0 | 2.0 b |
| Rainshield | 59.2 d | 7.71 | 90.0 a | 32.0 | 13.0 b |
| Industry Standard | 38.9 e | 3.77 | 78.7 b | 23.2 | 30.3 a |

means followed by the same letter are not significantly (P<0.05) different

Samples of peel from untreated and natural green treated fruit were taken for analyses of major cations. Data were analysed by Kerri Dawson (DEEDI) using REML in Genstat, with location and treatment as fixed effects, and replicate as a random effect to account for unbalanced design. There was no significant interaction between treatment and location. Levels of N, Ca and Mg were significantly higher in fruit from Glass House Mountains compared to Childers. Ca, Mg, K and Ca:N were higher in fruit from the natural green treatment, however the difference was significant only for Mg (Table 19).

**Table 19 Effect of natural green treatments on levels of N, Ca, Mg and K in fruit peel at harvest**

| Treatment | N (%) | Ca (mg/kg) | Mg (mg/kg) | K (%) | Ca:N |
|---|---|---|---|---|---|
| Untreated control | 1.41 | 368 | 825 b | 1.82 | 263 |
| naturalGreen | 1.39 | 404 | 871 a | 1.96 | 294 |
| Location | | | | | |
| Glass House Mtns | 1.47 a | 431 a | 919 a | 2.02 | 296 |
| Childers | 1.33 b | 314 b | 778 b | 1.77 | 261 |

means followed by the same letter are not significantly (P<0.05) different

## Scoping study on brown root rot caused by *Phellinus noxius*

A detailed report on the scoping study has been published in 'Talking Avocados' (Dann, Smith *et al.* 2009). Briefly, the study identified that brown root rot is a significant constraint to production on some orchards in some avocado growing regions. The areas of greatest concern are the Atherton Tablelands and Bundaberg/Childers, where many orchards have the disease with incidence ranging from 1 tree affected (dead) to >50% of trees in a block affected. The disease has also been confirmed on properties near Kyogle NSW, and Maleny and Glass House Mountains, QLD.

It is likely than an initial infection may be the result of a basidiospore (airborne spore arising from bracket-like fruiting bodies) contacting a wounded (eg. by pruning) surface and establishing. Fruiting bodies have been seen on hoop pine, *Ficus* spp. and other rainforest species, but are not common on avocado. The disease is spread along rows by root-to-root contact. There is no recovery for a tree if it has been infected with Phellinus. Leaves wilt, turn brown and die within a very short time (weeks), and an infection 'stocking' is often (but not always) visible at the base of the trunk (Figure 6). Most attempts to replant into sites where dead trees had been removed failed. The mycelium of the fungus can survive in woody debris buried in soil for many years, so when roots from a replanted tree come into contact with the woody debris, they become infected killing the young tree.

Current control measures for avocado depend on routine inspection, removal of diseased trees and as much infested wood from the soil as possible, and quarantining of the affected area, ie. removal of one tree either side of dead or dying trees. Glasshouse and field experiments are planned for the new avocado disease project, AV10001, to assess management options. Fungicides will be evaluated for their efficacy *in vitro* and in the field; alternate host plants, eg. citrus, mango will be assessed for their susceptibility, and cultural options, eg. cover crops, high N, biofumigation will be investigated. It is hoped that feasible options for short and long term management of this disease can be recommended to Industry to minimise the negative economic impact of this insidious disease.

**Figure 6 *Phellinus noxius* 'stocking' advancing up the trunk of an avocado tree**

# Discussion

Rootstock selections with increased establishment and survival capability under high Phytophthora root rot (PRR) disease pressure have been identified in this project. Selections 'SHSR-02', 'SHSR-04', ungrafted 'Hass' (rooted cuttings from clonal propagation), and the commercial rootstock 'Dusa™' were significantly healthier over time than other rootstocks, including many commercially grown such as 'Reed', 'Velvick' and 'Duke 7'. There is very little evidence for the source and/or mechanisms of the observed tolerance, and further research on the G x E (genotype x environment) interactions, root regeneration capacity, biochemical and/or genetic markers (as discussed in (Smith, Dann *et al.* 2011) is necessary. Also of interest in the current study was the superior performance of ungrafted 'Hass' in one trial, and raises the question about whether grafting in some situations may exacerbate either root or canopy/fruit diseases, due to potential physiological stress imposed. This issue is planned for investigation in Phase 2 of this project (AV10001), if contracted. Discussions have occurred with industry on the potential for release of this rootstock material. The commercialisation pathway for this selected material rests within another project, AV08000, and is thus not within the scope of AV07000.

Potassium phosphonate is a very effective tool in the management of PRR if applied at the correct times and at the correct rates. Results obtained in AV07000 have contributed to more efficient and cost effective application of phosphonate. Field experiments have shown that foliar spray applications at the registered label rate of 0.1% a.i. phosphonate were ineffective, and that 0.5% a.i. was more effective, applied multiple times, at increasing phosphonate concentration in roots to levels adequate for suppression of infection by Pc. Data generated in this project on root and fruit residues after 4 sprays of 0.5% a.i. supported an application by Agrichem P/L to the Australian Pesticides and Veterinary Medicines Authority (APVMA) for an emergency use permit (and subsequent extension to the permit) for the increased rate. Results obtained in this study show that in later-maturing 'Reed' fruit, trunk injections should be delayed until fruit are not a priority 'sink' for photosynthates (and thus, injected phosphonates) otherwise the compound will accumulate in the canopy and fruit, and not in the roots where it is required. This will also reduce the risk of unacceptably high fruit residues. Presentations by project team members at field days and conferences highlighted the need for an integrated approach to Phytophthora root rot management, particularly good drainage, mulching, optimal nutrition for good summer growth flush rather than relying solely on phosphonate. The arbitrary concentration of phosphonate in feeder roots for suppression of *Phytophthora cinnamomi* infection will be addressed in future trials.

Some new products and other known fungicides were identified in this project which may have potential in management strategies for the most important diseases of harvested fruit, anthracnose and stem end rot. The addition of hydrochloric acid to the standard rate, or reduced rate of prochloraz fungicide did not reduce the incidence or severity of anthracnose in fruit, compared to prochloraz without acidification. Field applications of the Rainshield® formulation of the protectant fungicide mancozeb, and postharvest dipping in fludioxonil (Scholar®) reduced disease. Non-fungicidal products also reduced disease in some cases. For example NaturalGreen (primarily composed of calcium carbonate) reduced fruit disease and caused higher Ca accumulation in fruit peel. The beneficial effect of higher peel Ca and reduced anthracnose has been well established (Willingham, Pegg *et al.* 2001) in previous studies and also concurrently in the fruit assessment component of AV08000. Bion®, a known resistance activator in many plant species, including mango, exacerbated disease. Exposure of harvested fruit to UV-C also increased anthracnose disease. This may be due to a physical damage (not visible to the naked eye), which facilitated development of *Colletotrichum gloeosporioides*. Further trials are proposed which will re-test some of the promising products alone and in combination with strategic (rather than calendar) fungicide applications.

The current state of brown root rot in Australian avocado has been reported to Industry. It is now considered to be a disease impacting production in some orchards in key areas of Atherton Tablelands and Bundaberg/Childers, and has been since positively identified on several other properties, indicating spread but also a heightened awareness by growers who are reporting dead trees if Phellinus is suspected. Further research on this disease, including management options, will be explored in Phase 2 of this project, expected to commence January 2011.

# Technology Transfer

Project team members have disseminated information gained through the project activities via participation in regional field days (as part of Simon Newett's project AV 06003 "Study groups to achieve globally competitive avocados"), Avocados Australia 'Roadshows' (2007), Australian and New Zealand Avocado Growers Conferences (2009), World Avocado Congress, Chile, (2008), and publications in 'Talking Avocados'. Project members also attended and presented research at plant pathology conferences within Australia. See Appendix 1 for the full list of publications and events and meetings attended.

The 'Roadshows' and field days were always very well attended by growers, who had the opportunity to learn of the latest research (eg. disease management options) within an informal setting. The information is reinforced by printed material, eg. minutes containing slide presentations and articles in 'Talking Avocados'.

# Recommendations

Current climatic conditions of higher than average rainfall will favour infection by *Phytophthora cinnamomi*, and effective root rot management will be essential in all production areas. Failure for growers and Industry as a whole to be on top of this disease will lead to declining trees and fruit yields, poor quality fruit, thus impacting on the productivity of orchards.

- Serious consideration should be given to commercialising rootstocks with enhanced capacity to establish as young trees and survive under high Phytophthora root rot pressure. The commercialisation plan for this material is covered under project AV08000. It is imperative that new material continue to be identified, cloned where possible, and planted in disease nurseries for assessment under high Phytophthora conditions.
- Potassium phosphonate should be applied at the correct time and rate for maximum efficacy against Phytophthora. Multiple foliar sprays at 0.5% a.i. are required during periods of active root growth. Trunk sprays can be effective in young trees, however, trunk injections are still an effective method of targeted application without spray entering the environment. Application during flowering, fruit set or extended fruit development such as in later maturing varieties, should be avoided. Regular testing of young white feeder roots for accumulation of phosphonate is recommended.

Diseases of fruit impact yield, quality, shelf life and losses through the supply chain, consumer acceptability and repeat purchase behaviour and trade of fruit interstate or internationally. The most serious diseases are anthracnose and stem end rot, which are not visible on harvested fruit leaving the farm, although the fungi have already infected the fruit. As fruit ripen, the dormant phase of the fungi is broken and symptoms develop.

- The evaluation of new approaches or products in reducing fruit diseases must continue. Treatments which reduce inoculum of these pathogens within the canopy are just as important as those which are applied close to harvest, or after harvest to limit symptom development.
- While some products were identified which reduced disease symptoms in this project, they will require re-testing before any strong recommendations can be made to Industry. Combinations with 'soft' fungicides should be evaluated. This approach serves to reduce the usage of protectant fungicides like formulations of copper, while extending the life of valuable fungicides such as the strobilurins as overuse of these can lead to resistance developing in the target fungi such that the chemistry is no longer effective.
- New products or technologies should continue to be sought from a variety of sources including the published literature, other industries, agrichemical companies, and tested for their efficacy in avocado.

Brown root rot has been increasing in importance in Australian avocados over the last decade. It causes tree death and is insidious in its slow-but-sure spread and long term survival in infected root debris in soil.

- The current recommendation for growers with confirmed *Phellinus noxius* is to remove infected/dead trees, and isolate the infected site, via removal of apparently healthy trees either side of the dead tree, and install root barriers or dig appropriate trenches so that roots from healthy trees do not come into contact with diseased debris remaining in the soil.
- Options for cultural and chemical management of this disease should be explored, and is intended in Phase 2 of this project, expected to commence January 2011.

The recommendations for further research will largely be addressed within Phase 2 of this project AV10001: Improving yield and quality in avocado through disease management. Industry awareness and adoption of practical outcomes will be enhanced via presentations and hands-on demonstrations to grower groups at field days throughout Australia, presentations at industry Conferences and contributions to fact sheets or growers' manuals and publications in 'Talking Avocados'.

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Smith LA, Dann EK, Pegg KG, Whiley AW, Giblin FR, Doogan V, Kopittke R (2011) Field assessment of avocado rootstock selections for resistance to Phytophthora root rot. Australasian Plant Pathology 40, 39-47.

Whan JA (2009) Silicon and acibenzolar-S-methyl induced defence responses in cotton (Gossypium hirsutum L.) infected with Fusarium oxysporum f. sp. vasinfectum The University of Queensland.

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# Appendix

1. List of publications and events/meetings/field days attended by project members

'Roadshows' 2007

A field day was held in every major production area throughout Australia, ie. Atherton Tablelands, Central Queensland, Southeast Queensland and Northern New South Wales, Tri-state (Victoria, South Australia and southern NSW) and south west Western Australia. At least two project members attended each day. Presentation titles were:

Postharvest disease management
Recent advances in the avocado disease battle front
Rootstocks and the war against Phytophthora
Brown root rot: *Phellinus noxius*

Simon Newett's project AV 06003 "Study groups to achieve globally competitive avocados"

Topics covered include management of Phytophthora root rot and fruit diseases and information on brown root rot.

Beerwah, September 2007
Childers, February 2008
Alstonville, June 2008
West Moreton, October 2008
Comboyne, May 2009
Walkamin October 2009
Pemberton May 2010

World Avocado Congress, Chile, 2007

A.W. Whiley, F.R. Giblin, K.G. Pegg and D.G. Whiley (2007) Preliminary results from avocado rootstock research in Australia

F.R. Giblin and L.M. Coates (2007) Avocado fruit responses to Colletotrichum gloeosporioides

F.R. Giblin, K.G. Pegg, G.L Thomas, A.W. Whiley, J.M. Anderson and L.A. Smith (2007) Phosphonate trunk injections and bark sprays

ANZAGC, July 2009

Dann, E, Smith, L, Pegg, K, Grose, M, and Pegg, G (2009) *Phellinus noxius*: Brown root in avocado, a presentation at the 4th Australian and New Zealand Avocado Growers Conference – "Avocados for Life", 21-24 July 2009, Cairns Convention Centre, Cairns, QLD.

Dann, E, Pegg, K, Smith, L, and Whiley, T (2009) Managing *Phytophthora cinnamomi,* a presentation at the 4th Australian and New Zealand Avocado Growers Conference – "Avocados for Life", 21-24 July 2009, Cairns Convention Centre, Cairns, QLD

Dann, E, Coates, L, Smith, L, Pegg, K, Dean, J and Cooke, T (2009) Impacts of fruit disease management on quality, a presentation at the 4th Australian and New Zealand Avocado Growers Conference – "Avocados for Life", 21-24 July 2009, Cairns Convention Centre, Cairns, QLD

'Talking Avocados' articles

Dann, L, Weinert, M., Grose, M. and Smith, L. (2008) Survey of Phellinus on the Atherton Tablelands, *Talking Avocados*, 19: 22.

Pegg, K., Smith, L., Dann, L., Coates, L. and Whiley, T. (2008) Phytophthora resistance in avocado rootstocks, *Talking Avocados*, 19: 23-25.

Coates, L., Dann, L., Smith, L., Pegg, K., Cooke, T., Anderson, J. and Dean, J. (2008) Evaluation of new fungicides for the control of avocado fruit diseases, *Talking Avocados*, 19 (2):26-27.

Pegg, K., Dann, L. and Coates, L. (2008) New exotic diseases of avocado, *Talking Avocados*, 19 (3); 18.

E. Dann, L. Smith, K. Pegg, M. Grose, G. Pegg (2009) Report on Phellinus noxius, the cause of brown root rot in Australian avocados, Talking Avocados, 20 (2): 28-34.

E. Dann, L. Smith, K. Pegg (2010) Phytophthora trunk canker, *Talking Avocados*, 20: 26-27.

E. Dann, L. Smith, K. Pegg (2010) Verticillium wilt more severe in 2009, *Talking Avocados*, 20: 32-33.

Scientific Conference abstracts and presentations

Dann, E. K., Hassan, M. K., Irving, D. E., Pegg, K. G., Smith, L. A., Dean, J. R. and Coates, L. M. (2008) Effect of variety or rootstock on biochemical defences and postharvest disease development in mango and avocado, presented at the International Conference on Biotic Plant Interactions, University of Queensland, 27-29 March 2008.

Dann, E. K., Smith, L. A., Grose, M. L., Pegg, G.S. and Pegg, K. G. (2009) Phellinus noxius: brown root rot is increasing in importance in the Australian avocado industry. 17th Biennial Australasian Plant Pathology Society Conference, Newcastle, Australia, 29 September – 1 October, 2009, "Plant Health Management: An integrated approach".

L. A. Smith, E. K. Dann, K. G. Pegg and A. W. Whiley (2010) Management of *Phytophthora cinnamomi* in Australian avocado orchards, abstract submitted for the 6th Australian Soilborne Diseases Symposium, 9-11 August 2010, Twin Waters, QLD

E. K. Dann, L. A. Smith and K. G. Pegg (2010) Soilborne diseases impacting avocado production in Australia, abstract submitted for the 6th Australian Soilborne Diseases Symposium, 9-11 August 2010, Twin Waters, QLD

Scientific peer-reviewed journal article

Smith LA, Dann EK, Pegg KG, Whiley AW, Giblin FR, Doogan V, Kopittke R (2011) Field assessment of avocado rootstock selections for resistance to Phytophthora root rot. *Australasian Plant Pathology* 40, 39-47.