USE OF FOLIAR APPLICATIONS OF PHOSPHONATE FUNGICIDE TO CONTROL PHYTOPHTHORA ROOT ROT IN AVOCADOS

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Introduction

Phytophthora root rot (*Phytophthora cinnamomi* Rands) is a significant root disease of avocados growing in all states of Australia. In 1987, a 20% formulation of phosphonate (active ingredient: mono- dipotassium phosphonate) was registered as a fungicide for trunk injection or as a 0.1% foliar spray to control Phytophthora root rot of avocados (Pegg *et al*. 1987; Guest *et al*. 1995; Whiley *et al*. 1995). Trunk-injected phosphonate fungicide applied twice per growing season has proved to be very effective in the control of Phytophthora root rot in avocados (Pegg *et al*. 1985; Pegg *et al*. 1987). However, the registered 0.1% phosphonate foliar treatment has not been as successful in controlling the disease when used on mature, fruiting trees.

Increases in the cost of production along with near static returns resulted in the Australian avocado industry commissioning research to investigate alternative methods to apply phosphonate fungicides. Methods investigated included soil drenching through fertigation systems and the development of new formulations of mono- dipotassium phosphonate that can be foliar-applied at higher concentrations than the registered 0.1% phosphonate spray. Application of phosphonate through soil drenching was found uneconomical (Kaiser and Whiley, 1998) and it is believed that such drenches may increase the risk for pathogen resistance to develop (Weinert *et al*., 1997). Foliar sprays of phosphonate fungicides have previously been found to cause leaf burn and excessive leaf drop in avocado trees. This paper details results following foliar application of new formulations of mono- dipotassium phosphonate to avocado trees for the control of Phytophthora root rot.

Materials and Methods

Efficacy of foliar phosphonate formulations

The field research in this project was carried out using ‘Hass’ trees on several commercial avocado properties located in New South Wales, Queensland, and Western Australia.

Duranbah

Three-year-old ‘Hass’ trees with no previous history of phosphonate treatment growing in a commercial orchard at Duranbah, NSW were chosen for phosphonate studies during 1998/99. The trees were growing on a replant site that was infested with *Phytophthora cinnamomi* and had been treated in previous years with Ridomil®. At the time of the first phosphonate treatment the trees were approximately 1.2 m tall and had set a light crop of fruit and were in good health (rating between 0-2 on the health scale of 0-10 where 0 = healthy and 10 = dead). Trees were treated with seven foliar sprays of either 0.1, 0.5 or 1.0% phosphonate from the 12th Nov 98 to the 3rd Jun 99. The trunk-injection treatment was given on the 12th Nov 98 and the 12th Feb 99. Phosphonate sprays were applied to trees as a tank mix combined with standard industry pesticides. These included copper hydroxide (Blueshield® DF) at 2 $g.L^{-1}$, copper oxychloride (Barmac® Copper Oxychloride) at 4 $g.L^{-1}$ and endosulfan (Endosulfan® 350 EC) at 1.5 $mL.L^{-1}$. No surfactants were used with these treatments and trees were sprayed to the point of run-off (1.5 $L.tree^{-1}$). Worm casts were also applied in another treatment to assess their ability to control Phytophthora root rot. The experimental design was six treatments using single tree plots that were replicated five times in a randomised layout. Data were analysed by ANOVA.

The study was repeated during the 1999/00 season using the same trees. However, the worm cast treatment was discontinued and Bion (a plant defence-enhancing agent) combined with phosphonate was added to the treatments. Foliar treatments were applied three times over the summer months: on the 14th Dec 99, the 15th Feb 00 and the 29th Mar 00. Trunk injections were given to the trees on the 14th Dec 99 and the 15th Feb 00. No other chemicals were combined with the treatments and no surfactants were used. Trees were sprayed to the point of run-off (about 2 $L.tree^{-1}$). The experimental design was six treatments using single tree plots that were replicated five times in a randomised layout. Data were analysed by ANOVA.

Childers
In Dec 99 a field experiment was started in a commercial orchard at Childers, QLD using 17-year-old 'Hass' trees with varying levels of decline due to Phytophthora root rot. The health of trees was rated on a 0-10 scale (where 0 = healthy and 10 = dead) immediately before treatments were imposed. Tree health was rated again on the 5th Aug 00. The foliar treatments of either 0.1, 0.25, 0.5 or 1.0% phosphonate were applied three times over the growing season: on the 30th Nov 99, the 28th Jan 00 and the 31 Mar 00. Bion was added to the 0.25 and 0.5% phosphonate treatments. Applications were made using a Stihl backpack, mist blower unit to the point of run-off (about 9 $L.tree^{-1}$). Trunk injections were given to trees using Chemjet® syringes on the 30th Nov 99 and the 28th Jan 00. The experiment had seven treatments that were replicated five times in a randomised block layout. Data were analysed by ANOVA

Pemberton
In March 1998 a field experiment was begun in a commercial orchard at Pemberton, WA using 'Hass' trees that had reached an advanced state of decline due to Phytophthora root rot. The experiment had four treatments that were replicated six times with 15 tree plots in a randomised block design. Data was analysed by ANOVA. The treatments were:

1. Trunk injection twice per season at the standard industry rate using 20% phosphonate.
2. Trunk injection twice per season at the standard industry rate using 40% phosphonate with the pH adjusted to 7.2.
3. Trees foliar sprayed (high volume) with a 1% phosphonate formulation adjusted to pH 7.2. The sprays were applied 3-4 weeks apart during the spring and summer.
4. Trees stag-horned back to about 1 m above the ground and the regrowth sprayed as above.

The health of trees was rated on a 0-10 scale (where 0 = healthy and 10 = dead) immediately before treatments were imposed (4th Mar 98). Some trees rated as high as 9 and 65% of the trees were rated ≥ 5. Tree health was rated again on the 23rd Mar 99 (27% of trees rated ≥ 5), the 15th Nov 99 (8% of trees rated ≥ 5), the 12th May 00 and the 25th Oct 00. Individual tree yields were not collected in 1998 but were recorded in 1999 from the first complete crop cycle following the start of treatments in 1999 and again in 2000. In the first year of the experiment the 1.0% foliar sprays were applied six times from the 27th Dec to the 24th May. In the second year of the experiment the foliar spray concentration was reduced to 0.5% a.i. phosphonate and was applied three times during the summer.

Phytotoxicity of foliar-applied phosphonate fungicides
The registration for foliar-applied, mono- dipotassium phosphonate currently used by the avocado industry is a 0.1% formulation that is applied at a pH of 5.8-6.0. The two new formulations tested in this program were 0.5% and 1.0% mono- dipotassium phosphonate. Phytotoxicity studies were conducted in a commercial orchard at Childers with branches of non-fruiting 'Hass' trees sprayed with the 1% formulation adjusted to the pHs of 6.8, 7.0, 7.2, 7.4 and 7.6. In addition, the formulation was tested as a tank spray with pesticides commonly used by industry (copper hydroxide, copper oxychloride and endosulphan). Sprays were applied to trees in the morning and evening and the leaves rated for burn within seven days of application. In addition, foliar phosphonate was applied at 0.5% and 1.0% buffered to a pH of 7.2, with or without the surfactants Agral® (at 0.1 and 0.2%) and Nufilm® (at 0.05 and 0.2%) and in combination with copper hydroxide or copper oxychloride. Leaves on treated branches were evaluated for burn within seven days of treatment.

Phytotoxicity was also noted where it occurred in the efficacy and fruit residue experiments at Maleny (QLD) and Duranbah (NSW).

Application technology
This experiment was designed to evaluate the effectiveness of low and high volume foliar applications of 0.5% phosphonate on small and large trees. The experiment was carried out on 7 and 11-year-old 'Hass' trees planted at 9 x 9 m in a commercial orchard at Hampton, QLD. Low volume applications were applied with a CDA applicator using 'micromaster' heads. This gave an application rate of 3 $L.tree^{-1}$ (15 $g.tree^{-1}$ of phosphonic acid) on small trees and 5 $L.tree^{-1}$ (25 $g.tree^{-1}$ of phosphonic acid) on large trees. The high volume sprays were applied with a Stihl backpack misting unit and trees sprayed to run-off. This equated to an application rate of 6 $L.tree^{-1}$ (30 $g.tree^{-1}$ of phosphonic acid) on small trees and 12 $L.tree^{-1}$ (60 $g.tree^{-1}$ of phosphonic acid) on large trees. An additional treatment of two low volume foliar applications seven days apart was given to the large trees.

In each case roots samples were collected for phosphonic acid analysis 14 days after the last application. The first foliar spray was applied to trees at spring flush maturity (1st Dec 99) and the treatments repeated beginning on the 23rd Mar 00 (summer flush maturity).
Fruit phosphonic acid residues

The experimental site to collect withholding data was a commercial orchard at Maleny, south east Queensland. Thirteen-year-old 'Hass' trees with no previous history of phosphonate treatment were chosen for the study. Trees were stumped in 1996 and were carrying their first commercial crop following regrowth (50 to 160 kg of fruit per tree). At the time of treatment the experimental trees were approximately 4.5 m in diameter and 4.2 m tall. The experimental design was a 3 (spray concentrations) x 5 (sample times) factorial replicated twice in a complete randomised block layout. Data was analysed as a two-way randomised block using ANOVA (Genstat 5) and judged for significance at $P < 0.05$.

When fruit reached commercial maturity (about 25% dry matter) trees were sprayed with mono- dipotassium phosphonate at either 0.5 or 1.0% using 4-5 litres of formulation per tree. Approximately 2 kg of fruit (8) were collected from each tree to determine phosphonate residue levels 2 h and 1, 3, 7 and 14 days after spraying. Each sample was placed in a polythene bag that was identified with a unique sample description number. Samples were placed in a freezer at approximately -20°C prior to analysis.

Results and Discussion

Development of foliar phosphonate formulations to control Phytophthora root rot

Duranbah

At Duranbah the health of trees in the first year of the experiment was evaluated in Mar 99 (Table 1) and Jul 99 (Table 2) while in the second year health was rated in Dec 99, May 00, Sep 00 and Nov 00 (Table 3).

Four months after beginning the experiment all phosphonate treatments had significantly ($P < 0.05$) improved root health when compared to untreated trees and those trees where worm casts were used (Table 16).

Table 1 Effect of worm casts and foliar-applied and trunk-injected phosphonate on root health of 'Hass' avocado trees at Duranbah. Root health data were collected on the 10th Mar 99 by estimating the percentage of root tips that were free of disease. Data are mean values of five trees. Values in columns followed by different superscript letters are significantly different ($P < 0.05$) as tested by ANOVA.

Treatments*	% healthy roots
Untreated	59.5^{b}
Worm castings	41.0^{b}
Foliar PO_3 @ 0.1% + Cu hydroxide + endosulphan	89.4^{a}
Foliar PO_3 @ 0.5% + Cu oxychloride + endosulphan	79.0^{a}
Foliar PO_3 @ 1.0% Cu oxychloride + endosulphan	85.0^{a}
Trunk-injected PO_3	88.0^{a}

*Worm casts were applied at the rate of 5 $L.m^2$ under the tree canopy on the 12th Nov 1998. Foliar sprays of phosphonate were applied on the 12th Nov 98, 10th Dec 98, 7th Jan 99 and 12th Feb 99. Trunk injections of phosphonate were given on the 12th Nov 98 and the 12th Feb 99 at the rate of 15 $mL.m^{-1}$ diameter of tree canopy.

A further health rating eight months following the commencement of spraying phosphonate showed that the treatments continued to provide control of Phytophthora root rot (Table 2). Root mass was significantly ($P < 0.05$) greater for phosphonate treated trees when compared to those that had worm castings while the percentage of healthy roots was significantly greater for trees sprayed with 0.5 or 1.0% phosphonate or trunk-injected with phosphonate when compared to untreated trees. While there was no significant difference in the rating of tree health as judged by the canopy, there was a general trend for trees to be healthier when sprayed with 0.5 or 1.0% phosphonate or trunk-injected with phosphonate (Table 2). Canopy ratings for tree health are best made at the completion of flowering (October) when maximum stress has been applied to the trees as this is when differences between root systems are maximised.

Table 2 Effect of worm casts and foliar-applied and trunk-injected phosphonate on root mass, root health and tree health of 'Hass' avocado trees at Duranbah. Root mass, root health and tree health data were collected on the 27th Jul 99. Root mass was estimated using a 0-3 rating system where 0 = low and 3 = high; root health was estimated as the percentage of root tips that were free of disease; tree health was estimated on a 0-10 scale where 0 = healthy and 10 = dead. Data are mean values of five trees. Values in columns followed by different superscript letters are significantly different ($P < 0.05$) as tested by ANOVA.

Treatments*	Root mass (1-3)	% healthy roots**	Tree health (0-10)
Untreated	1.7 [ab]	50.0 [b]	2.8 [a]
Worm casts	1.3 [b]	74.5 [ab]	3.8 [a]
Foliar PO_3 @ 0.1%	2.3 [a]	73.0 [ab]	2.0 [a]
Foliar PO_3 @ 0.5%	2.5 [a]	91.0 [a]	1.6 [a]
Foliar PO_3 @ 1.0%	2.3 [a]	90.0 [a]	1.6 [a]
Trunk-injected PO_3	2.5 [a]	85.0 [a]	1.0 [a]

*Worm casts were applied at the rate of 5 $L.m^2$ under the tree canopy on the 12th Nov 1998. Foliar applications of phosphonate were applied on the 12th Nov 1998; 10th Dec 1998; 7th Jan 1999; 12th Feb 1999; 10th Mar 1999; 14th Apr 1999 and the 3rd Jun 1999. Trunk injections of phosphonate were given on the 12th Nov 98 and the 12th Feb 99 at the rate of 15 $mL.m^{-1}$ diameter of tree canopy. **Significant at $P < 0.09$.

The improvement in tree root health following foliar-applied 0.5 and 1.0% phosphonate as well as trunk-injected phosphonate was during a year of extreme disease pressure when in excess of 3250 mm of rain was recorded that the site. This is viewed as a good result for these new formulations which on young trees tended to be superior to the registered 0.1% phosphonate application.

When ratings were resumed in the second year of the experiment (Dec 99) there was an overall decline in tree health across all treatments when compared with the ratings in Jul 99 (Table 3). Throughout the year the health of trees in all treatments generally improved but at each time the ratings were taken there was no significant difference between treatments. This was a "normal" rainfall year at this site and it is likely that other management factors together with the deep, well-drained soil and the light crop being carried by the trees contributed to the improvement in health irrespective of whether trees had been treated with fungicide or left untreated.

Table 3 Effect of foliar and trunk-injected phosphonate (PO_3) applications on the health of 'Hass' trees at Duranbah during 1999/00. Health ratings were scored on a 0-10 scale (0 = healthy and 10 = dead). Data in columns are mean values of 5 trees and was analysed by ANOVA with differences judged at ($P \leq 0.05$). There were no significant differences between treatments at any of the times that trees were rated.

Treatments	Health ratings			
	14 Dec 99	18 May 00	27 Sep 00	16 Nov 00
Control	4.2	2.2	2.8	2.9
Foliar PO_3 @ 0.1% a.i.	4.2	1.8	2.4	2.8
Foliar PO_3 @ 0.25% a.i. + 0.05 $g.L^{-1}$ Bion	4.8	3.6	3.8	3.6
Foliar PO_3 @ 0.5% a.i.	4.0	2.6	3.6	2.6
Foliar PO_3 @ 0.5% a.i. + 0.05 $g.L^{-1}$ Bion	4.6	3.8	4.6	3.8
Foliar PO_3 @ 1.0% a.i.	3.8	1.4	2.4	1.4
Trunk-injected PO_3 at commercial rate	3.8	3.2	3.4	3.2

Childers

At the start of experiment the control trees on average rated amongst the healthiest however, without treatment the decline in health was significantly greater than all other treatments (Table 4). All foliar phosphonate treatments of 0.25% a.i. or greater concentration improved tree health over the duration of the experiment as did trunk-injected phosphonate. However, there was no significant difference between these treatments on their effect on tree health. The 0.1% foliar phosphonate treatment resulted in a decline in tree health over the duration of the study.

Table 4 Comparison between untreated, trunk-injected and foliar-sprayed phosphonate with or without Bion on the recovery in health of 'Hass' avocados at Childers, Qld. Trees were rated for health on a 0-10 scale (where 0 = healthy and 10 = dead) prior to treatments being applied (Nov 99). Values in columns are means of 5 trees and those followed by different letters are significantly different at $P < 0.05$.

Treatments*	Tree health ratings (0-10)		Health improvement
	23rd Nov 99	5th Aug 00	(0-10 scale)
Control	2.8 ^{a}	5.6 ^{a}	-2.8 ^{a}
Foliar phosphonate @ 0.1% a.i.	4.0 ^{a}	4.4 ^{ab}	-0.4 ^{b}
Foliar phosphonate @ 0.25% a.i. + Bion	4.6 ^{a}	3.0 ^{bc}	1.6 ^{c}
Foliar phosphonate @ 0.5% a.i.	4.0 ^{a}	2.4 ^{c}	1.6 ^{c}
Foliar phosphonate @ 0.5% a.i. + Bion	4.0 ^{a}	3.0 ^{bc}	1.0 ^{c}
Foliar phosphonate @ 1.0% a.i.	4.2 ^{a}	2.6 ^{c}	1.6 ^{c}
Trunk injection	4.0 ^{a}	2.8 ^{c}	1.2 ^{c}

The trees at the Childers site set and carried a significant commercial crop over the duration of the study and hence are representative of mature, bearing orchards across

Australia. With trees carrying commercial crops of fruit there is a reduced availability of tree resources for root growth (Whiley, 1994) thus limiting the ability of the tree to replace roots damaged by Phytophthora root rot. Hence, damage by *Phytophthora cinnamomi* is potentially much greater than in young orchards which have not reached their cropping capacity. In this study, three sprays of 0.1% foliar-applied phosphonate at six-weekly intervals was not sufficient to control the disease with the treated trees suffering a further decline in health over the duration of the experiment. However, all foliar-applied phosphonate treatments of ≥ 0.25% phosphonate improved tree health and gave a similar result to the registered trunk injection procedure. This result supports the anecdotal observations that the foliar-applied 0.1% phosphonate treatment is insufficient to maintain or improve tree health although the registered method for the use of this formulation is for greater application frequency. The reduced application frequency of higher concentration phosphonate formulations will have significant cost savings for avocado growers while maintaining or improving tree health.

Pemberton

There was improved tree health across all treatments during the first year of the experiment with further improvements being made by Nov 99 (Table 5). The two trunk injection treatments gave a similar result despite twice the amount of active ingredient being used in the 40% formulation. The 1% foliar spray without pruning was the least effective treatment but it still gave a considerable improvement in health over the 20 month period (health rating from 5.3 to 2.5). The health of trees in this treatment further improved through to May 00 despite the phosphonate application being reduced to 0.5% a.i. and applied at six weekly intervals three times during the summer. However, by Oct 00 the health of these trees had declined. The most effective treatment on tree health was where trees were stag-horned and the regrowth sprayed with 0.5 or 1% phosphonate (Table 5).

Table 5 Comparison between trunk-injected and foliar-sprayed mono- dipotassium phosphonate on the recovery in health of 'Hass' avocados at Pemberton, WA. Trees were rated for health on a 0-10 scale (0 = healthy and 10 = dead) prior to treatments being applied (Mar 98). Values in columns are means of 75 trees and those followed by different letters are significantly different at $P < 0.05$ as tested by ANOVA.

Treatments	Mar 98	Mar 99	Nov 99	May 00*	Oct 00
Trunk-injected with 20% phosphonate at pH 5.6	5.3 [a]	3.9[a]	1.9 [b]	1.0 [b]	1.6 [b]
Trunk-injected with 40% phosphonate at pH 7.2	5.3 [a]	3.8 [a]	1.6 [b]	1.4 [ab]	1.8 [b]
Foliar-sprayed 0.5 or 1% phosphonate at pH 7.2	5.3 [a]	4.1 [a]	2.5 [a]	1.7 [a]	2.7 [a]
Pruned: regrowth foliar-sprayed with 0.5 or 1% phosphonate at pH 7.2	5.2 [a]	0.6 [b]	0.9 [c]	0.3 [c]	0.7 [c]
Means	**5.3**	**3.1**	**1.7**	**1.1**	**1.7**

With respect to tree yield there was no significant difference between either of the trunk injection treatments or the foliar spray application where trees were not pruned. Mean fruit yields on these trees ranged from 13.5-16.3 t ha^{-1} (98/99) or 27-32.5 kg $tree^{-1}$ (99/00). However, there was a significant and severe reduction in yield where trees were stag-horned prior to foliar spraying over the two years of the experiment (Table 6).

Table 6 Comparison between trunk-injected and foliar-sprayed mono- dipotassium phosphonate on the yield of 'Hass' avocados at Pemberton, WA during a health recovery phase. Values in columns are means of 75 trees and those followed by different letters are significantly different at P < 0.05 as tested by ANOVA.

Treatments	Yield (kg $tree^{-1}$)		
	98/99	99/00	Cumulative
Trunk-injected with 20% phosphonate at pH 5.6	32.5 [a]	77.1 [a]	109.6 [a]
Trunk-injected with 40% phosphonate at pH 7.2	29.3 [a]	86.5 [a]	115.9 [a]
Foliar-sprayed 0.5 or 1% phosphonate at pH 7.2	*27.0 [a]	**81.3 [a]	108.2 [a]
Pruned: regrowth foliar-sprayed with 0.5 or 1% phosphonate at pH 7.2	*0.1 [b]	**43.1 [b]	43.2 [b]
Means	**22.2**	**72.0**	**94.2**

*Sprayed with 1% phosphonate at pH 7.2; **Sprayed with 0.5% phosphonate at pH 7.2.

The health rating was directly correlated to crop load where the higher the yield the poorer the health rating of the tree (Fig. 1). This is expected, as fruit will compete more strongly than roots for tree resources hence roots are not repaired as quickly on trees with high crop loads.

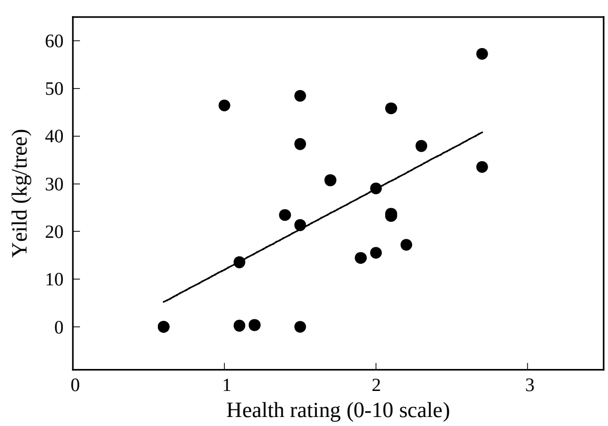

Fig. 1 Relationship between health rating and crop load on the 15 Nov 99. The regression line is represented by y = 16.96x – 4.92, r^2 = 0.35.

The use of foliar-applied phosphonate sprays of firstly 1.0% and then 0.5% at Pemberton also demonstrated the ability of higher concentration formulations to improve tree health with the treatment giving similar results to trunk injection. However, there was some indication that three sprays of 0.5% phosphonate was insufficient in a heavy cropping year (99/00) as the health of trees declined when compared to those trunk-injected with phosphonate and having a similar cropping profile. Trees that were stag-horned then treated with foliar phosphonate maintained the best health of all treatments but carried significantly less fruit for the duration of the study. This further highlights the interaction between crop load, phosphonate treatment and tree health.

Phytotoxicity of foliar-applied phosphonate fungicides

Results from the evaluation of 1% phosphonate sprays at Childers that were buffered to different pH values showed that phytotoxicity (leaf burn) was related to the pH of the formulation applied to the trees. Where phosphonate was used without any other pesticides there was significantly ($P < 0.05$) less damage when the formulation was adjusted to pH 7.2 (Table 7). When phosphonate was combined with copper hydroxide plus endosulphan the formulation with a pH of 7.6 gave significantly ($P < 0.05$) less damage than the same pesticide combination at other pHs. There was a trend for the pH 7.2 formulation to give the least damage when phosphonate was combined with copper oxychloride and endosulphan (Table 7). A rating of ≤ 1 was commercially acceptable.

Table 7 Phytotoxic effects of 1% phosphonate sprays on 'Hass' leaves at Childers. Leaf burn was rated on a 0-5 scale where 0 = no burn and 5 = extensive burn. Data are mean values of ratings from 12 trees. Values in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

pH treatments*	Pesticide combinations		
	Phosphonate	Phosphonate + copper hydroxide + endosulphan	Phosphonate + copper oxychloride + endosulphan
6.8	2.00 ^{a}	2.00 ^{a}	1.58 ^{a}
7.0	1.33 ^{bc}	1.75 ^{a}	1.42 ^{a}
7.2	0.83 ^{c}	1.75 ^{a}	1.08 ^{a}
7.4	1.42 ^{abc}	1.58 ^{ab}	1.42 ^{a}
7.6	1.67 ^{ab}	1.25 ^{b}	1.42 ^{a}

*The pH of the phosphonate solution was adjusted through the addition of potassium hydroxide.

In other experiments at Childers it was shown that there was minimal phytotoxicity from 0.5% phosphonate sprays where the formulation was adjusted to a pH of 7.2 but the addition of Agral® or Nufilm® significantly increase the risk of phytotoxicity (either leaf burn and/or leaf drop) (data not presented). It was also found that there were less phytotoxic symptoms when trees were sprayed during the morning compared with spraying in the evening (data not presented).

At Maleny the 1% phosphonate + copper hydroxide + endosulphan formulation resulted in leaf burn following the 2nd spray. The burn was not commercially acceptable so the treatment was discontinued at this site. Phytotoxicity from the other treatments was minimal and within commercial tolerances. At Duranbah, some leaf burn occurred on most treatments following the 1st and 3rd sprays given to trees. The burn was more severe from the 1.0% sprays compared to the 0.5% sprays. The leaf burn was more severe than what was observed at Maleny and may be due to the high volume application of treatments at the Duranbah site or the higher day temperatures reached at the coastal site. It was decided to cease application of phosphonate with other pesticides until the issue of phytotoxicity was resolved and there was no further leaf burn recorded on these trees for the rest of the season with foliar phosphonate being applied alone to the trees.

Application technology

Root phosphonic acid concentrations in small trees were 4.8 and 8.3 $mg.kg_{fw}^{-1}$ for low and high volume applications, respectively (Table 8). Root concentrations in the large trees were higher at 7.9 and 21.1 $mg.kg_{fw}^{-1}$ for low and high volume applications, respectively and 11.6 $mg.kg_{fw}^{-1}$ in those trees receiving two low volume applications one week apart. However, the base level of phosphonic acid from previous treatments was higher in the large trees (1.0 vs 4.3 $mg.kg_{fw}^{-1}$). The root concentration in small trees that had received the high application rate was lower than expected and is likely due to the extremely heavy crop load that these trees were carrying at the time of treatment as young fruit are very strong sinks.

Following the summer treatment, root phosphonic acid concentration in small trees was 14.3 and 18.6 $mg.kg_{fw}^{-1}$ for low and high volume applications, respectively (Table 8). Root phosphonic acid concentrations in the large trees were 12.8 and 30.7 $mg.kg_{fw}^{-1}$ for low and high volume applications, respectively and 20.5 $mg.kg_{fw}^{-1}$ in those trees receiving two low volume applications one week apart. As root phosphonic acid concentrations were still comparatively low in small trees following the summer application it is likely that the very heavy crop retained by these trees was still limiting redistribution to the weaker sinks.

In large trees the results showed that the high volume application was effective in increasing the root phosphonic acid concentration to greater than 20 $mg.kg_{fw}^{-1}$ but a single low volume application was not sufficient (Table 8). This is not surprising since 60 g of phosphonic acid was applied to trees receiving the high volume application while only 25 g of phosphonic acid was applied to the same size trees receiving low volume application. Repeating the low volume application was effective in increasing the root phosphonic acid concentration but still had only 55-67% of the efficiency of high volume applications.

Table 8 Phosphonic acid concentration (mg.kg_{fw}^{-1}) in roots of 'Hass' avocado trees at Hampton 14 days after a foliar spray of 0.5% mono- dipotassium phosphonate (pH 7.2). The foliar sprays were applied on the 1st Dec 99 (spring) and the 23rd Mar 00 (summer). For trees receiving two low volume applications the second spray was applied 7 days after the first spray. Data in columns are mean values from five trees ± standard errors.

Treatments*	Phosphonate applied (g.$tree^{-1}$)	Spring applied	Summer applied	
			Before	After
Small trees (7-years-old)				
Untreated	-	1.0 ± 1.0	1.3 ± 1.3	NDR
Low volume (3 L.$tree^{-1}$)	15	4.8 ± 1.0	3.7 ± 0.4	14.3 ± 3.2
High volume (6 L.$tree^{-1}$)	30	8.3 ± 1.6	8.6 ± 2.1	18.6 ± 2.1
Large trees (11-years-old)				
Untreated	-	4.3 ± 1.0	4.2 ± 0.3	3.6 ± 1.7
Low volume (5 L.$tree^{-1}$)	25	7.9 ± 0.7	4.2 ± 1.2	12.8 ± 1.0
Low volume x 2 (10 L.$tree^{-1}$)	50	11.6 ± 1.5	9.4 ± 1.8	20.5 ± 5.8
High volume (12 L.$tree^{-1}$)	60	21.1 ± 3.0	7.9 ± 2.4	30.7 ± 5.1

*Low volume treatments were applied with a CDA applicator while high volume treatments were applied with a Stihl backpack mist-blower unit.

Fruit phosphonic acid residues

Data on mean residue concentrations of phosphonic acid in fruit are reported in Table 9. Phosphonic acid residues were highest in fruit from trees treated with the 0.5 and 1% phosphonate formulations (3.62 and 3.85 mg.kg_{fw}^{-1}, respectively) however, there was no significant difference between treatments. Mean phosphonic acid concentrations of fruit harvested at different times after foliar treatment were not significantly different with time and ranged from 1.83 to 2.87 mg.kg_{fw}^{-1} (Table 9).

Table 9 Phosphonic acid concentrations (mg.kg_{fw}^{-1}) measured in avocado fruit following foliar applications of 0.5 and 1.0% potassium phosphonate solutions at 0.08, 1, 3, 7 and 14 days after treatment. Data in columns are mean values (n = 5 or 6). Statistical analysis were by two-way ANOVA and there were no significant ($P < 0.05$) differences in fruit phosphonate residues between the different foliar spray concentrations or the time after spraying that fruit were collected.

Concentration of Foliar Application			Time after foliar application (days)				
0	0.5%	1.0%	0.08	1	3	7	14
0.05	3.62	3.85	2.87	2.82	2.73	1.83	2.28

The range of phosphonic acid residue concentrations across treatments was 0-4.8 $mg.kg_{fw}^{-1}$ and values for each treatment combination are presented in Table 10. There were no significant interactions between treatments.

Table 10 Phosphonic acid residues ($mg.kg_{fw}^{-1}$) measured in avocado fruit following foliar applications of 0.5 and 1.0% potassium phosphonate solutions at 0.08, 1, 3, 7 and 14 days after treatment. Data in columns are mean values (n = 2). Statistical analysis was by two-way ANOVA and there were no significant ($P < 0.05$) interactions between treatments.

Foliar concentration (%)	Time after foliar application (days)				
	0.08	1	3	7	14
0	0.25	0	0	0	0
0.5	4.05	4.15	3.40	2.80	3.70
1.0	4.30	4.30	4.80	2.70	3.15

Conclusions

The results from the phosphonate fungicide research reported in this paper indicate the following:

1. Foliar application of 0.5% phosphonate applied up to eight times per growing season from spring flush maturity (November) through to summer flush maturity (May) will give commercial control of Phytophthora root rot in mature fruiting trees with minimum risk of phytotoxicity. The number of applications required will vary with location, season and crop load and may be monitored through using a commercial phosphonic acid root analysis service;
2. Apply the phosphonate fungicide without the use of a wetting agent or spreader and do not mix with other pesticides;
3. Only use copper oxychloride for anthracnose control (increased risk of phytotoxicity if copper hydroxide is present on the leaves of trees when foliar treated with phosphonate fungicide);
4. Apply the phosphonate fungicide with the pH of the tank mix adjusted to 7.2 (note: most farm water will reduce the pH of the tank mix if using a phosphonate fungicide buffered to 7.2);
5. Know the characteristics of your spray applicator as it is the grams a.i. of phosphonate that are sprayed on the canopy with each treatment that is important with respect to increasing root phosphonic acid levels;
6. Treatment of trees with phosphonic acid at spring and summer flush maturity are the two most effective times in relation to increasing root phosphonic acid concentrations. All other treatment times will give significantly lower increases in the root phosphonic acid levels;
7. Treatment of trees at fruit maturity increased fruit phosphonic acid levels by < 5 mg/kg, which is negligible in relation to allowable fruit residues.

Note: at the time of writing this paper an application was being prepared to support the registration of the foliar application of mono- dipotassium phosphonate at 0.5% a.i. for use on avocados. The only registration currently approved for foliar phosphonate application is for the application of 0.1% a.i. mono- dipotassium phosphonate.

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