Optimizing phosphonate uptake in shepard avocado

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SUMMARY

Phytophthora root rot (PRR), caused by the pathogen Phytophora *cinnamomi*, is a significant disease of avocados worldwide and requires cultural and chemical management to prevent widespread tree decline or death. PRR cannot be controlled, but must be actively managed. Potassium phosphonate, the recommended chemical, is systemic and after application travels to the most actively growing part of the tree. To effectively manage PRR, phosphonate must reach the roots, therefore timing applications to when roots are actively growing is essential.

Phosphonate root levels were monitored monthly in five cv. Shepard avocado orchards in north Queensland, Australia, in 2012/13. Trees in five orchards trees received the farmer's standard phosphonate trunk injection program of one or two injections annually. Three orchards received additional monthly foliar phosphonate treatments. Tree phenology (root, leaf, flower and fruit growth) and root phosphonate levels were monitored to determine the effects on phosphonate movement to and accumulation in the roots.

The samples confirmed that foliar phosphonate applied at, or shortly before, periods of peak root flushing is highly effective in increasing avocado root phosphonate levels in healthy trees. In these orchards, the key periods were March to June and mid-November to early December. Results also indicated that more than one phosphonate treatment (either by injections or foliar sprays) is required to maintain adequate phosphonate levels in the roots all year round. The study also reinforced the importance of root phosphonate monitoring to achieve successful PRR management.
Keywords: *Phytophthora* root rot, *Phytophthora cinnamomi*, Phenology based management.

INTRODUCTION

Phytophthora root rot (PRR) of avocados (*Phytophthora cinnamomi*) is the most destructive and important disease of avocados (*Persea americana*) worldwide and the major limiting factor for avocado production in Australia. PRR destroys the fine feeder roots, leading to water stress, nutrient deficiencies and increased salt burn as roots are unable to control salt uptake. This reduces yields, fruit size, quality and shelf life and increases sunburn and the percentage of reject fruit at packing. Severe infection can kill trees of all ages (Pegg *et al.* 2002). The heavy monsoonal rains, warm soil conditions and in the main, poor soils low in organic matter, make conditions in the north Queensland (NQ), Australia, production areas on Atherton Tablelands and around Mareeba-Dimbulah particularly favourable for PRR.

PRR cannot be controlled, but must be actively managed. An integrated program is currently recommended for *Phytophthora* root rot management in Australian avocados using a combination of cultural methods and chemical management strategies. Potassium phosphonate (phosphonate) is the principal chemical component of this strategy. Reduced phosphonate sensitivity has been reported from *Phytophthora* isolates from phosphonate treated avocado orchards in Australia and South Africa (Dobrowolski *et al.* 2008; Duvenhage 1994). Optimizing phosphonate application is important to ensure its future use.

Phosphonate is systemic and moves up in the phloem and down in the xylem to the most actively growing part of the tree. It is applied as trunk injections or foliar sprays. Optimum application timing requires an understanding of tree phenology, which varies between avocado varieties and is influenced by local environmental conditions. A root phosphonate level of 25µg/g has been accepted as the minimum level to manage PRR, however Dann (2011) proposed a root level of 40µg/g. Monitoring levels of phosphonate in roots to ensure optimum levels are maintained is an important part of any program.

Root monitoring data from Australian production areas have suggested twice yearly applications could be replaced with a single injection once a year, after summer flush maturity (Graeme Thomas pers. comm. 2011). Applying phosphonate at a single time, either as injections or a foliar spray has become common practice in the NQ growing region. The complexity and cost of injecting has lead some growers to trial foliar phosphonate application. Maintaining root phosphonate levels through foliar sprays however is difficult to achieve.

Data, primarily from Shepard orchards, from the north Queensland production areas showed foliar applications after harvest, before pruning, can achieve root levels greater than 150µg/g. Analyses prior to application the following year however found levels below the required 25-40µg/g. (Graeme Thomas pers. comm. 2011), leaving roots susceptible to PRR attack. This is critical time both physiologically and environmentally, when trees are stressed following fruiting and roots should be flushing. It coincides with the warmest, wettest time of the year, when the PRR pathogen is most active.

Most phosphonate research has been done on 'Hass' in south-east Queensland and northern New South Wales. Limited research on other cultivars has demonstrated different application and different timings are required to ensure translocation to the roots (Dann, 2011). No specific phosphonate research has been conducted on Shepard.

Shepard avocados account for approximately 18% of the total Australian avocado crop with 45% of Shepard avocados produced in NQ production areas and discussions with growers suggest that Shepard phenology is not fully understood.

MATERIALS AND METHODS

The study was conducted from May 2012 – May 2013. Five Shepard avocado orchards with healthy vigorous canopies and no obvious PRR symptoms, representing the full range of growing environments in the NQ production region, were selected (Table 1). Trees in all orchards received the grower's standard phosphonate injection program, detailed in Table 1. In orchards 1-3, two rows separated by two buffer rows, were selected. One received the phosphonate spray treatment and one as the unsprayed control. Phosphonate spray treatments were applied in the middle of each month using the grower's mister sprayer, at a rate of 8.3mL of 60% phosphonate per litre of water, sprayed at 2000L/ha.

Table 1. Climate and soil information for the avocado orchards used in this study

Orchard No.	Location	Annual rainfall (mm)	Main rainfall distribution	Mean max. temp. (°C)	Mean min. temp. (°C)	Soil type	Phosphonate injection dates (Jan 2011 – Apr 2013)
Phosphonate injection + or – Monthly phosphonate spray treatments							
1	Dimbulah	783	Nov-Apr	35	10	Shallow poor soils of granitic origin	Apr 11, Nov 11, Apr 12, Nov 12, Apr 13
2	Tolga	1400	Oct-Jul	25	16	Deep rich red basaltic soils	May 11, May 12.
3	Paddy's Green	1000	Nov-Apr	30	14	Shallow sandy clay loam	May 11, Nov 11, May 12.
Phosphonate injection only							
4	Tolga	1400	Oct-Jul	25	16	Deep rich red basaltic soils	May 11, Nov 11, Nov 12.
5	Paddy's Green	1000	Nov-Apr	30	14	Shallow sandy clay loam	Apr 11, Apr 12.

Three mature (>5 years old) trees in each orchard were selected for monthly root samples and root and shoot phenology measurements, conducted at the start of each month. Root samples from each sample tree consisted of 30 – 40 white rootlets approximately 10cm long. The timing of the root sampling was to allow time for applied phosphonate to be translocated to the roots. Root samples were dried for 24 hours (70°C) and then sent to the Toowoomba laboratories of SGS Australia for analysis. The April 2013 samples were not collected due to logistical issues
Tree phenology assessments included a root flush rating (0-3, where 0=no root flush, 1= <30% root flush, 2=30-60% root flush and 3=>60% root flush) and % of shoots flushing, assessed in each orchard at the time of monthly root sampling.

RESULTS

Study data is presented as trends from an average of measurements from three trees, rather than as a statistical analysis, as the scope and budget for the project meant treatment design was simplified to achieve project objectives.

Phosphonate injections + foliar spray treatments

Phosphonate foliar spray treatments in orchards 1-3, increased phosphonate levels in the roots of all treated trees above those of the untreated trees 3-6 months after foliar treatment initiation (Figure 1). Red arrows on the figures indicate the approximate date of injections in these orchards. Orchard 2 did not receive the November 2012 injection.

In Orchard 1 (Fig 1) root phosphonate levels for both treatments were ~ 40µg/g at the start of the study then rose quickly after injection in April. Levels were greater in trees that received the monthly foliar sprays by June becoming more pronounced during the trial. Levels in both treatments dropped from August to October, then increased with the October-January root flush. The November 2012 injection, increased in levels for both treatments in January 2012. Foliar sprayed treatments in January 2012 had an extremely high mean root phosphonate level of 350µg/g. Levels in both treatments then dropped steadily from February to May 2013, with levels substantially greater in trees which received the monthly foliar spray treatment. An injection was applied in April 2013 prior to the May 2013 measurement resulting in increased levels in unsprayed however root levels in sprayed trees continued to decline.

Root phosphonate levels for both treatments in Orchard 2 (Fig 1.) remained low (< 50 µg/g) for the first 6 months of the study and increased in September 2012. Levels for the foliar treatment then rose quickly, remaining higher than the unsprayed trees for the trial duration. An injection in May/June 2012, increased levels by August 2012 then levels in both treatments increased in January/February coinciding with root flushing. Levels in the foliar sprayed treatments in rose rapidly in January to 250µg/g then levels for both treatments dropped rapidly from February-May, with the foliar spray remaining above 50µg/g.

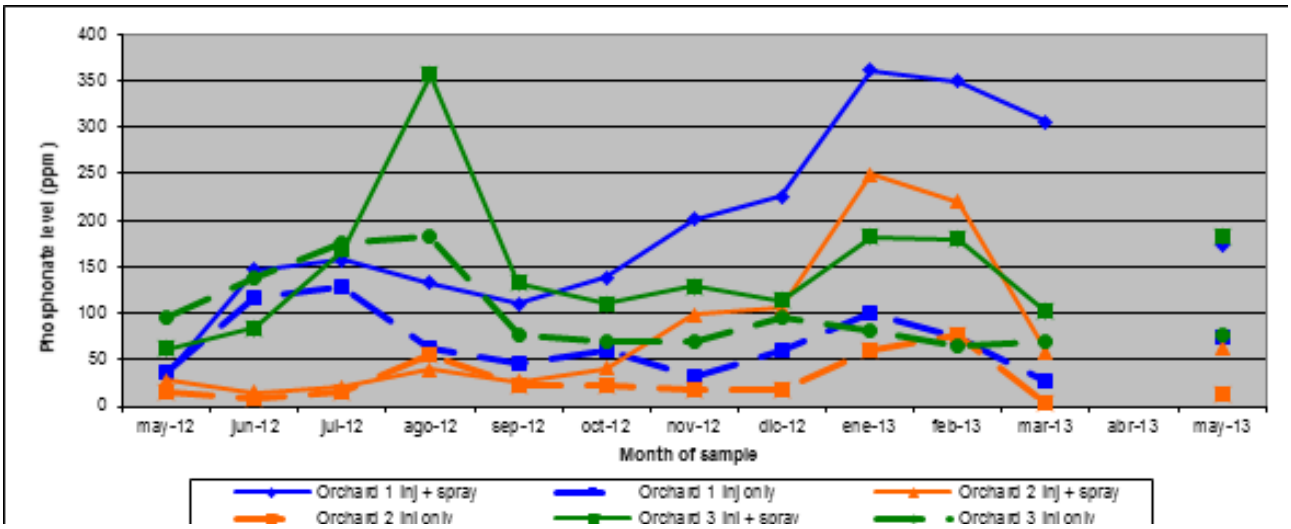

Figure 1. Comparison on root phosphonate levels in in trees treated with injections only and with injections plus monthly foliar sprays in orchards 1-3

Orchard 3 (Fig 1) had the highest root phosphonate levels (50-98µg/g) of all three orchards at the start of the study. Levels in the foliar treatment were initially lower than the injected trees, however by August 2012 were higher than the unsprayed trees. Root phosphonate levels in the foliar treatment then remained higher than the unsprayed trees for the remainder of the study. Phosphonate injections were carried out on all trees in Orchard 3 in May/June 2012. The foliar spray treated trees recorded a phosphonate level of 350 µg/g after this operation, which is likely due to the high phosphonate levels prior to injection. Foliar sprayed trees recorded an additional spike in phosphonate levels to 190µg/g, in January/February 2013 at a time of high root flushing levels.

Phosphonate injections only

Phosphonate levels in trees receiving only phosphonate injections in all orchards are indicative of standard phosphonate injection practices (Figure 3). The five orchards in this study all received phosphonate injections during this study. Standard practice for Orchards 1, 3 and 4 is to inject phosphonate after harvest in April-June then again after the spring flush hardens in November/December. In 2012 however, Orchard 3 only was only injected in May and Orchard 4 only in November. The standard practice for Orchards 2 and 5 is a single injection in April/May, which was carried out as per usual practice. In orchards that received the recommended injection treatments, after the spring (November) and summer (April or May) flushes – orchards 1, 3 and 4 – root phosphonate levels remained above recommended levels (25-40 µg/g) for the period of the study.

In orchards that only received a single injection treatment per year, after the summer flush had matured (April or May) – orchards 2 and 5 – root phosphonate levels increased slowly after the treatments but declined rapidly, so that by September levels in both orchards were below the recommended levels. Levels in both these orchards however increased in December (Orchard 2) and January (Orchard 5) suggesting stored phosphonate had been translocated from other parts of the plant to the roots.

Orchard 1 was the only orchard to receive biannual injections. The first injection conducted in April 2012 was followed by a peak in root phosphonate level in July/August, with a further injection in November 2012 followed by another phosphonate peak in January/February. This regime maintained phosphonate levels at about 40ug/g or greater, for the study duration.

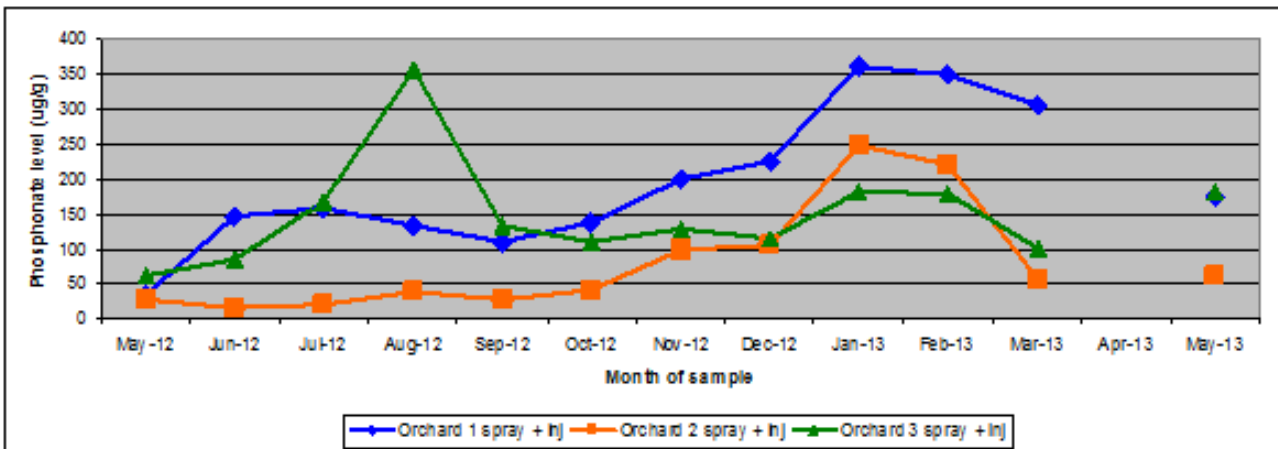

Figure 2. Combined root phosphonate levels in trees treated with injections + sprays for Orchards 1-3.

Orchard 2 had a peak root phosphonate levels above threshold in August 2012 (shortly after injection), which dropped to unsatisfactory levels from September-December. Levels then peaked above threshold in January/February corresponding with a root flush. The January peak was 6 months after phosphonate injection. Phosphonate levels then crashed to negligible levels throughout March-May 2013

Phosphonate levels were initially high in May 2012 in Orchard 3. A large root phosphonate peak followed the May 2012 injection, levels then declined during September-November. A smaller peak occurred in December/January shortly after a strong root flush, similar to in Orchard 2. Phosphonate levels remained above 25-40 ug/g (minimum threshold level) in Orchard 3 for the duration of the study.

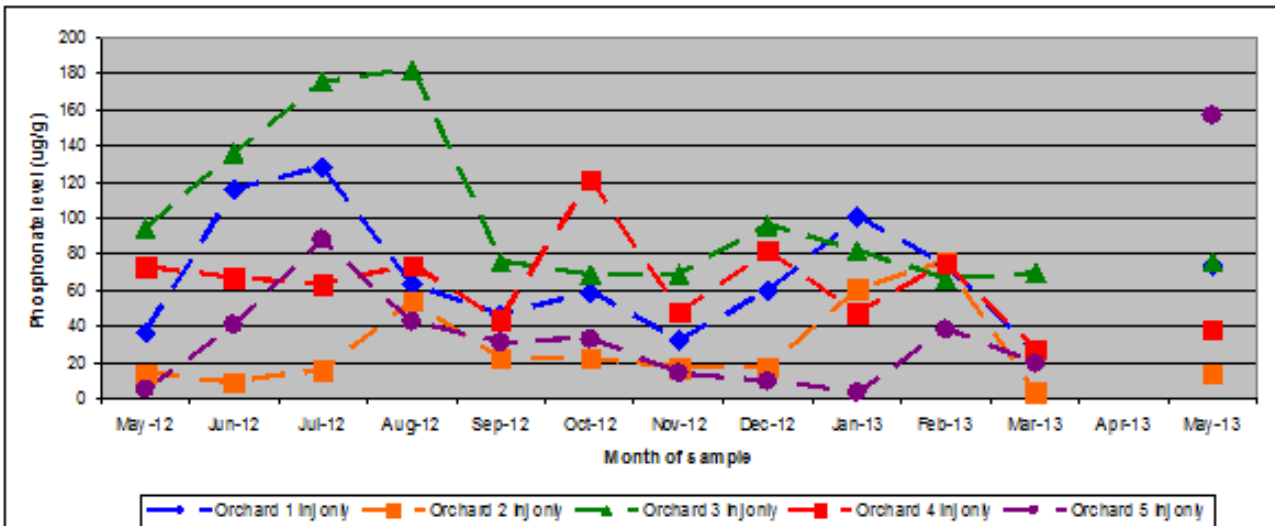

Figure 3. Phosphonate levels in trees from all orchards treated with phosphonate injections only.

Orchard 4 had initially high phosphonate levels in May 2012, also possibly due to an accumulation of tree phosphonate from biannual injections in 2011. Root phosphonate levels then varied in association with small root flushes in October, December and February. The injection in November 2012 replenished phosphonate levels temporarily, however levels dropped below 40ug/g by March 2013.

Low initial root phosphonate levels in orchard 5 rose in June/July 2012 after the April injection, dropping to under the 40ug/g in September and to almost negligible levels by January 2013. Levels increased to 40ug/g with a root flush in February 2013 dropping again in March. The rapid increase in the root phosphonate levels in Orchard 5 from April to May was due to a single foliar phosphonate application, applied on 29 March as the orchard owner was advised the project had finished.

Shoot phenology

Shoot flushing varied across the orchards (Fig 4). Peak shoot flushing events were seen in all orchards in September/October and again in December/January. Shoot flushing was least in May and November.

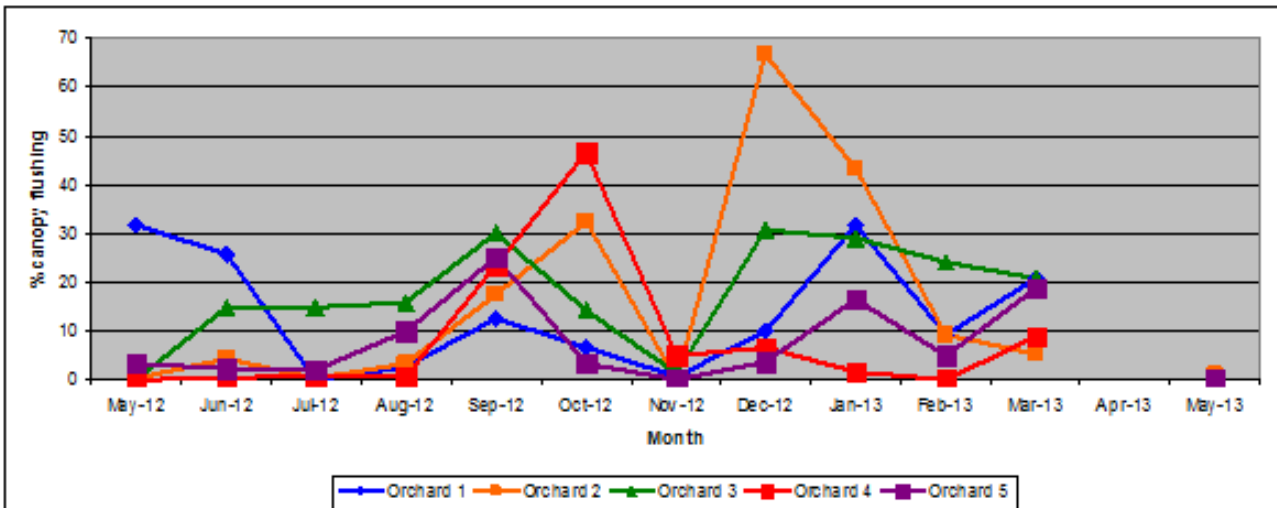

Figure 4. Percentage of canopy with shoot flushing in the 5 study orchards.

Root phenology

Root phenology varied across the orchards (Fig 5). Trees in all orchards produced a good root flush in May-June and again in February-April. Most orchards (except Orchard 2) also produced a good root flush in November/December. Orchard 3 had the consistently highest root flushes, which may be an outcome from enhanced soil health management at this orchard, including large planting mounds and the greatest levels of hay mulch along tree rows.

In the orchards which received the foliar phosphonate spray treatments, root flushing intensity was greater in trees that received the additional spray treatments (Figure 6). If the sample points for the 3 orchards are added to provide a total of 36 data points, in the trees which had received the monthly spray treatments, root flushing intensity was higher for 23 of the 36 data points.

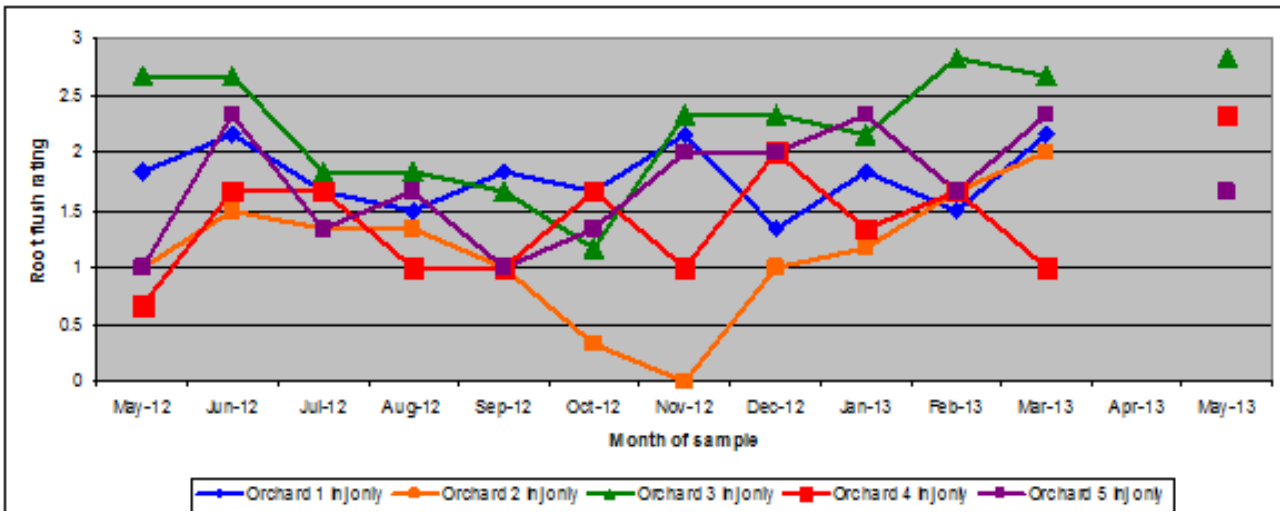

Figure 5. Root flush rating across the 5 orchards (where 0=no flush, 1=1-30% roots flushing, 2=30-60% roots flushing and 3=> 60% root flushing).

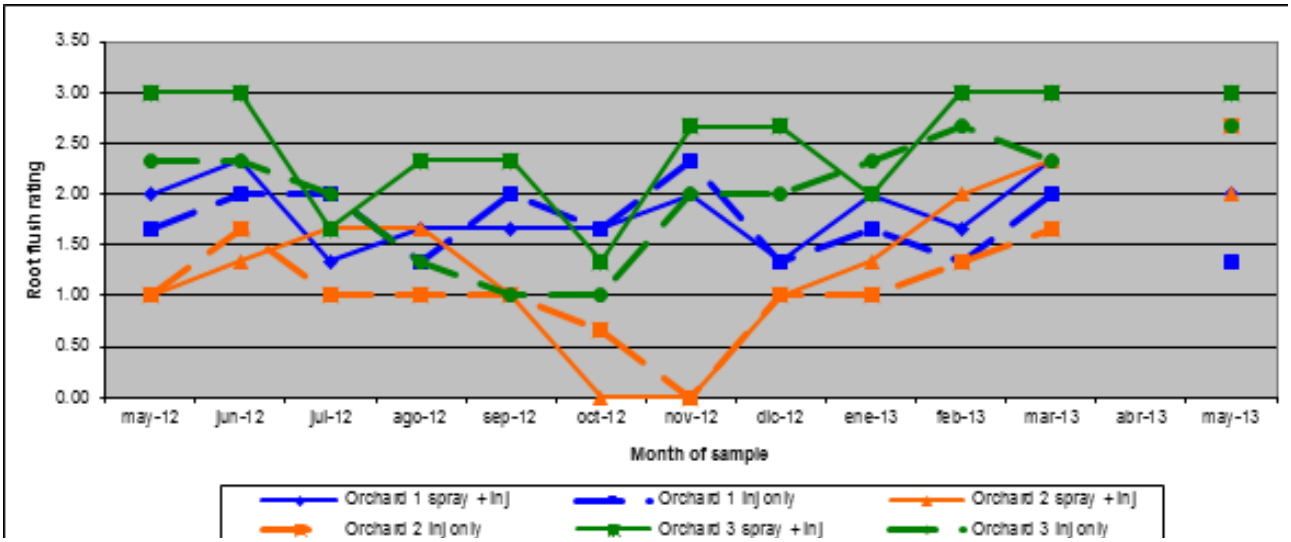

Figure 6. Comparative root flushing of trees that received spray treatments and those that did not in the orchards receiving spray treatments.

DISCUSSION

Phosphonate sprays

In all three orchards receiving foliar sprays, root phosphonate levels were higher in the foliar spray treatments by the end of the project. Orchard 2 took six months to achieve these results. The cause was initially unclear, however it was determined that the recommended volume of phosphonate was not being applied to the trees in the early part of the trial. Once corrected, root phosphonate levels began to rise in this orchard. Roots of the trees in this orchard were vigorously flushing, greater than trees in all the other orchards, at this time and the applications may also have been diluted by this vigorous root flush. A combination of both these reasons is the most likely scenario.

The overall trend for root phosphonate levels is that these can be easily increased in healthy trees with phosphonate spray applications, when roots are actively flushing. The post-study test example in Orchard 5 demonstrated that a single foliar application at peak root flushing (March) can greatly increase root phosphonate levels, with root levels rising from 20 to 160ug/g in 5 weeks.

The greatest increase in root phosphonate levels in response to foliar phosphonate application occurred between May-July and late November-January, coinciding with the peak root flushes. The least effective period for foliar application was from late August-October when roots were less active. This also coincided with significant shoot flushing in all orchards.

The rapid increase in root phosphonate levels from a single spray, evident in orchard 5, based on results from the project shows that when foliar phosphonate applications are applied correctly it only takes 4-5 weeks for significant levels to reach the roots. It also helps identify which application times resulted in the root level increases from the foliar application treatments.

Phosphonate injection

The five orchards in this study all received phosphonate injections (either annually or biannually) during of this study. Standard injection practice for Orchards 1, 3 and 4 is phosphonate injections after harvest in April-June then again after spring shoot flush hardening in November/December. In 2012 however, Orchard 3 received only one injection in May and Orchard 4 only received one injection in November. The standard injection practice for Orchards 2 and 5 is a single phosphonate injection in April/May, which was carried out as per usual practice.

In the majority of trees receiving injections alone root levels were above the threshold level for the period of the study, however orchards 2 and 5 struggled to keep levels above 40ug/g, indicating that once yearly injections are insufficient to maintain levels to manage PRR. Peaks occurred after injections in all orchards agreeing with (Whiley *et al.,* 1995) who found that phosphonate takes 16-35 days after injection to translocate to the roots. In several of the orchards levels continued to rise for several months after injections.

Increased root phosphonate levels seen in several of the orchards during root flushing several months after injections indicate phosphonate is stored in sinks within the tree for extended periods, before translocation to the flushing roots.

Foliar applied phosphonate cab effectively increase root phosphonate levels, even as a single spray in healthy trees, suggesting effective management of root levels above 25-40 ug/g, via an integrated system (one injection per year + the use of foliar sprays) or foliar applications alone. The replacement of one or all phosphonate injections with a foliar phosphonate spray regime has the potential to simplify treatment, reduce costs and improve the effectiveness of PRR management in Shepard avocados in north Queensland. A more detailed investigation of these management options, including a cost benefit analysis of foliar sprays versus injections, is required to fully capture these potential economic gains

Root phenology

Root flushing is integral to successful phosphonate applications and was the key phenological stage studied. Root phenology varied across the orchards, however common root flush events for Shepard avocados on the Atherton Tablelands were in February-April, June and November-December. The exact timing of the flushes varied upon location and it is expected that there may be seasonal variation in the root flush events as they generally follow leaf flushes, which can be mediated by local temperatures.

Mulch encourages vigorous root flushing events. Orchard 3 had the consistently highest root flush ratings during the trial period and also the thickest mulch layer applied under the trees. In Orchard 2 the treatment trees had mulch applied in July 2012, two weeks before the untreated trees and root flushing occurred earlier in the mulched trees.

High root phosphonate levels (>250µg/g) did not inhibit root flushing in our study. The spray treated trees in Orchards 1 and 3 had consistently high root phosphonate levels, yet also had the highest root flush rating.

Shoot phenology

Shoot phenology shows that on the Atherton Tablelands Shepard avocados are prone to flushing year round. Key flush periods are August to October (commonly called the spring flush) and December to January. The shoot flush observations suggest that November, is an ideal the time to apply the 'top up' phosphonate to carry root levels through the wet season; shoot flushing is at its lowest and root flushing at its greatest

RECOMMENDATIONS

Attaining root phosphonate levels above the recommended 25-40ug/g throughout the year requires more than a single injection per year. Foliar phosphonate applications can increase root phosphonate levels in healthy trees, when applied after shoot flushes have matured and at/or shortly before periods of peak root flushing. In Shepard avocados in the study area optimum phosphonate application times, occurred in May-July and November-January. Root accumulation of phosphonate was negligible from late August-October, despite regular monthly foliar applications.

Root phosphonate concentration trends were developed for each of the orchards. These trends and phenological data were used to develop recommendations to optimize phosphonate applications for the management of PRR in Shepard avocados, to ensure application times do not coincide with key fruit development times, leading to unacceptable fruit MRL levels.

The study reinforces the importance of monitoring phosphonate levels in avocado roots. Monitoring of root phosphonate levels in avocado orchards is simple and inexpensive. A recommended process for monitoring root levels is summarised below.

Commencing after harvest;

1. Monitor root flushing events and apply a single injection or 2-3 foliar sprays as per label recommendations in April or May.
2. Sample roots 4 weeks after injection or the final foliar application. If root levels are below 150ug/g apply a further phosphonate treatment.
3. Sample roots again in mid to late October, approximately 2 weeks before the spring flush hardens. If root levels are below 90ug/g apply a single injection or a foliar spray as per label recommendations, when all or the majority of the flush has hardened.

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