Optimizing phosphonate use for Phytophthora root rot management in Shepard avocados in North Queensland

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HAL FINAL REPORT

Optimising Phosphonate Use for Phytophthora Root Rot Management in Shepard Avocados in North Queensland

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Purpose:
The purpose of this report is to describe the activities and outcomes associated with the project 'Optimising phosphonate use in Shepard avocados in north Queensland'.

Funding:
This project has been funded by Horticulture Australia Ltd (HAL) using voluntary contributions from the Atherton Tableland Avocado Grower's Association (ATAGA) and matched funds from the Australian Government. The Queensland Government has also co-funded the project through the Queensland Department of Agriculture Fisheries and Forestry.

30 September 2013

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MEDIA SUMMARY

Phytophthora root rot (PRR) is the most significant threat to Shepard avocado orchards in north Queensland and needs to be managed carefully via cultural and chemical management techniques to prevent widespread tree decline or deaths. It is important to note that the disease can not be controlled, but must be actively managed.

The chemical potassium phosphonate, commonly called phosphorous acid or just phosphonate, is recommended to manage PRR. Phosphonate moves inside the tree and after application, travels to the most actively growing part of the tree. To effectively manage PRR phosphonate must reach the roots. Timing applications to when roots are actively growing is of utmost importance. Monitoring phosphonate in roots to ensure adequate levels are maintained is an important part of any program

The current application method, using tree injections is seen as a costly and labour intensive practice. Due to the complexity and cost of injecting, some growers have moved to applying potassium phosphonate treatments only once during the year, either through injections or foliar applications.

Maintaining root phosphonate levels through foliar sprays is more difficult to achieve than with injections. Preliminary root monitoring data obtained from growers using foliar sprays prior to the project showed that during the critical summer period root phosphonate levels were below that required to manage the PRR.

Root monitoring for phosphonate levels was conducted on five Shepard avocado orchards in north Queensland in 2012/13. In all five orchards trees continued to receive the farmer's standard phosphonate trunk injection program (either 1 or 2 injections per annum) over the duration of the trial period. Three orchards were selected to receive the additional foliar phosphonate treatments.

Monthly root samples confirmed that foliar phosphonate applications were a highly effective way of increasing avocado root phosphonate levels in healthy trees, when applied at/or shortly before the periods of peak root flushing. As timing of application is influenced by tree growth cycles; root, flower and shoot flushes were also monitored to determine their effects on phosphonate movement to and accumulation in the roots

Two key time periods to apply phosphonate, based on shoot and root phenology and measured root phosphonate levels, were identified. These periods were from March to June and mid November to early December. Treatment by either application method (injections or foliar sprays) once a year however, may not provide adequate phosphonate levels in the roots to provide protection for a full 12 months.

The key components to maintaining root phosphonate above recommended levels in Shepard avocados within an integrated PRR program are: timing of phosphonate application based on root growth flushes, monitoring root levels during critical times and applying the correct amount and concentration, either as a high volume spray or through injections. Managing PRR using cultural, including mulching and optimising nutrition and irrigation will also help optimise phosphonate applications.

This project has been funded by Horticulture Australia Ltd (HAL) using voluntary contributions from the Atherton Tableland Avocado Grower's Association (ATAGA) and matched funds from the Australian Government. DAFF Queensland provided in-kind support.

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TECHNICAL SUMMARY

Phytophthora root rot (PRR) of avocado (*Persea americana*), caused by the pathogen *Phytophthora cinnamomi* remains the major threat to avocado production in Australia. This is despite 30 years of research, development and extension into control and management. The pathogen attacks the fine feeder roots of avocado trees and impacts on productivity by lowering yields, reducing fruit size, quality and shelf life. Severe infection can kill trees. PRR is a significant problem in the seasonally wet monsoonal climate of north Queensland, where many orchards are also grown on poor soils, low in organic matter, with poor or impeded drainage.

Chemical control of PRR of avocados is achieved through a combination of cultural methods and the use of the chemical potassium phosphonate which is applied to the tree as a trunk injection or foliar sprays. Due to the perceived complexity and cost of injecting, some growers have moved to applying potassium phosphonate treatments only once during the year either through injections or foliar applications. Maintaining optimum phosphonate levels in avocado roots via foliar application can be difficult to achieve as phosphonate is highly mobile and moves to the most actively growing plant parts.

This study was conducted from May 2012 to May 2013, across five Shepard avocado orchards in far north Queensland, on sites representing the range of local growing environments. In all five orchards trees continued to receive the farmer's standard phosphonate trunk injection program (either 1 or 2 injections per annum) over the duration of the trial period. Three orchards were selected to receive the additional foliar phosphonate treatments. Monthly tree phenology measurements were conducted and root samples collected from treatments in each of the 5 orchards to determine seasonal variation in root phosphonate levels over the growing season and its relationship to tree phenology.

Two key time periods to apply phosphonate, based on both shoot and root phenology and measured root phosphonate levels, were identified. These periods were from March to June and mid November to early December.

Root phosphonate levels can be easily increased in healthy trees with phosphonate spray or injection applications, when roots are actively flushing. This suggests that there is potential for management of orchard root phosphonate levels via an integrated injection/foliar spray system or potentially via foliar phosphonate applications alone. Treatment by either application method (injections or foliar sprays) once a year however, may not provide adequate phosphonate levels in the roots to provide protection for a full 12 months.

Study outcomes have improved understanding of Shepard tree phenology on the Atherton Tablelands and the relationship to the uptake and movement of applied phosphonate (after injection or spray application) in a range of management systems. A new 'Crop Calender' guide for Shepard avocados on the Atherton Tablelands, accessible through the Avocados Australia Best Practice Resource website, has been produced which will be a useful tool to guide farmers management practices.

INTRODUCTION

Phytophthora root rot (PRR) of avocados (*Phytophthora cinnamomi*) is the most destructive and important disease of avocados (*Persea americana*) worldwide and is the major limiting factor to avocado production in Australia. The pathogen destroys the fine feeder roots of the avocado tree, leading to water stress, nutrient deficiencies and increased salt burn as roots are unable to control salt uptake. This in turn lowers yields, reduces fruit size, quality and shelf life, increases sunburn and the number 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 soil types low in organic matter, make conditions in the north Queensland (NQ) production areas on Atherton Tablelands and around Mareeba-Dimbulah particularly favourable for PRR.

It is important to note that the disease can not be controlled, but must be actively managed. An integrated program is currently recommended for Phytophthora root rot management in avocados using a combination of cultural methods and chemical management strategies. This program is known as the 'Pegg Wheel' (Figure 1). Potassium phosphonate, commonly called phosphorous acid or just phosphonate, is the principal chemical component used in this management strategy.

Figure1. The Pegg Wheel.

Phosphonate is a systemic fungicide that moves in both the phloem and xylem of the tree (up and down). Phosphonate can be applied as either trunk injections or foliar sprays. Following trunk injections, phosphonate moves first to the leaves in the transpiration stream of the xylem and then via the phloem to the site of the most actively growing part of the tree. Following foliar applications phosphonate moves from the leaves via the phloem to the most actively growing part of the tree.

A root phosphonate level of 25 µg/g has been accepted as the minimum required level to manage PRR, however recently a minimum root level of 40 µg/g has been proposed (Dann, 2011). Industry recommendations for Hass variety trees are to conduct phosphonate injections to at-risk or infected trees twice a year, to coincide with spring and autumn root flushes (usually March-May and November). Optimum application timing requires an understanding of tree phenology, which varies between avocado varieties and is influenced by local environmental conditions. Monitoring levels of phosphonate in roots to ensure optimum levels are maintained is an important part of any program.

With reduced sensitivity reported from Phytophthora isolates from avocado orchards treated with phosphonate in Australia and South Africa (Dobrowolski *et al.* 2008; Duvenhage 1994), it is important that phosphonate application is optimized to ensure the continued future of this important chemical in Australian avocado production systems.

Growers conducting avocado root analysis sampling in north Queensland have increased seven fold following two workshops on Phytophthora management in north Queensland in 2009/10 as part of the HAL funded '*AV06003 – Study groups to Grow Globally Competitive Avocados*' project. Root monitoring data in other Australian production areas have suggested the original twice/year application recommendation could be replaced with an injection treatment once a year, after the summer flush maturity (Graeme Thomas *pers. comm.* 2011). This practice of applying phosphonate at a single time, either as injections or a foliar spray is also starting to become common practice in the NQ growing region. Due to the complexity and cost of injecting, some growers have also expressed interest to switch from injections to the practice of foliar application of phosphonate. Maintaining root phosphonate levels through foliar sprays however is more difficult to achieve.

Preliminary root level data, primarily from Shepard orchards, from the north Queensland production areas showed that with foliar applications post harvest, but before pruning, root levels greater than 150µg/g can be achieved. Follow up analyses prior to application the following year however found levels well below the required 25-40 µg/g. (Graeme Thomas *pers. comm.* 2011). This leaves the roots susceptible to attack from PRR at a critical time both physiologically and environmentally, when trees are stressed following flowering and roots should be flushing and during the wettest time of the year, when the Phytophthora pathogen is most active.

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

Shepard avocados account for approximately 18% of the total Australian avocado crop with 45% of Shepard avocados produced in the Atherton Tablelands and Mareeba/Dimbulah production areas. Discussions from the 'study groups' workshops suggest that Shepard phenology is not fully understood in north Queensland. It is expected that the results from this work will be applicable to Shepard avocados grown elsewhere in Australia and reinforces the importance of monitoring root phosphonate levels across all Australian avocado production areas.

To achieve the required phosphonate concentration in avocado roots for good PRR management requires an understanding of tree phenology and monitoring and trial work to determine when a 'top up' treatment of phosphonate can be applied to maintain the 25-40 µg/g concentration in the roots.

This study was conducted across five Shepard avocado orchards in far north Queensland, on sites representing the range of local growing environments, from May 2012 to May 2013. In all five orchards trees continued to receive the farmer's standard phosphonate trunk injection program (either 1 or 2 injections per annum) over the duration of the trial period. Three orchards were selected to receive the additional foliar phosphonate treatments (monthly applications vs. non-sprayed controls). Monthly tree phenology measurements were conducted and root samples collected from treatments in each of the 5 orchards to determine seasonal variation in root phosphonate levels over the growing season and its relationship to tree phenology.

MATERIALS AND METHODS

Study design

Five Shepard avocado orchards were selected, representing the full range of growing environments in the NQ production region (Table 1). Avocado trees in these orchards had healthy, vigorous canopies, with no obvious symptoms of PRR. The design of the study was determined in conjunction with the HAL Minor Use Permit Coordinator, Peter Dal Santo. Trees in all five orchards continued to receive the grower's standard phosphonate injection program (annual or bi-annual phosphonate injection, see Table 1). Three orchards (Numbers 1 – 3) also received the + or – monthly phosphonate spray treatment. In each of these three orchards, two rows were selected, one for the phosphonate spray treatment and one as the unsprayed control. Rows on each property were separated by 1 – 2 buffer rows, to minimise edge effects.

The study was conducted from May 2012 – May 2013. Monthly root samples and phenology measurements were conducted at the start of each month, on three trees in each treatment in each orchard. Phosphonate spray treatments (Agriphos 600 supplied by Agrichem) were applied in the middle of each month for the period of the study, using the grower's mister sprayer, at a rate of 8.3mL of 60% phosphonate per litre of water, sprayed at a rate of 2000L/ha.

Orchard No.	Location	Annual rainfall (mm)	Main rainfall distribution	Mean max. temp. (°C)	Mean min. temp. (°C)	Soil type	Phosphonate injection dates (Jan 2011 – April 2013)
Phosphonate injection + or – Monthly phosphonate spray treatments							
1	Dimbulah	783	Nov-Apr	35	10	Shallow poor soils of granitic origin	April 11, Nov 11, April 12, Nov 12, April 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, Nov 12, May 13
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	April 11, April 12.

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

Measurements

Tree root samples and phenology measurements were conducted at the beginning of each month for the period of the study, although the April 2013 samples were not collected due to logistical issues.

Root samples from each sample tree consisted of 30 – 40 white rootlets approximately 10cm long. In the foliar sprayed treatments, the timing of sampling (end of the month) was to allow time for phosphonate which had been applied in the middle of the month, 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.

Tree phenology assessments from mature (>5 years old) trees 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), % of shoots flushing and % of shoots flowering, which were collected from each orchard at the time of monthly root sampling.

RESULTS

Data from this study is presented as trends, rather than as a statistical analysis, as the scope and budget for the project meant treatment design was simplified to achieve project objectives. Results are presented as an average of the phosphonate root levels or tree phenology measurement from the three trees in each treatment, at each orchard. Minimum residue level data was not collected as part of this project.

Phosphonate levels

Phosphonate injection + foliar spray treatments

The application of phosphonate foliar spray treatments in orchards 1 – 3, increased phosphonate levels in the roots of all treated trees above those of the untreated trees, within 3 – 6 months of foliar treatment initiation (see Figures 1-3). Red arrows on the graphs indicate the approximate date of injections in these orchards.

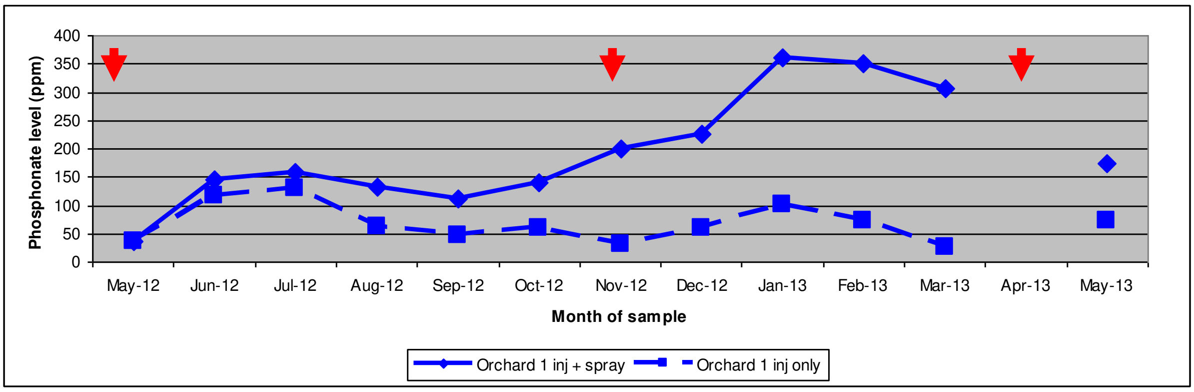

Figure 1. A comparison of phosphonate root levels in trees treated with injections only and trees treated with injections plus monthly foliar treatments in orchard 1.

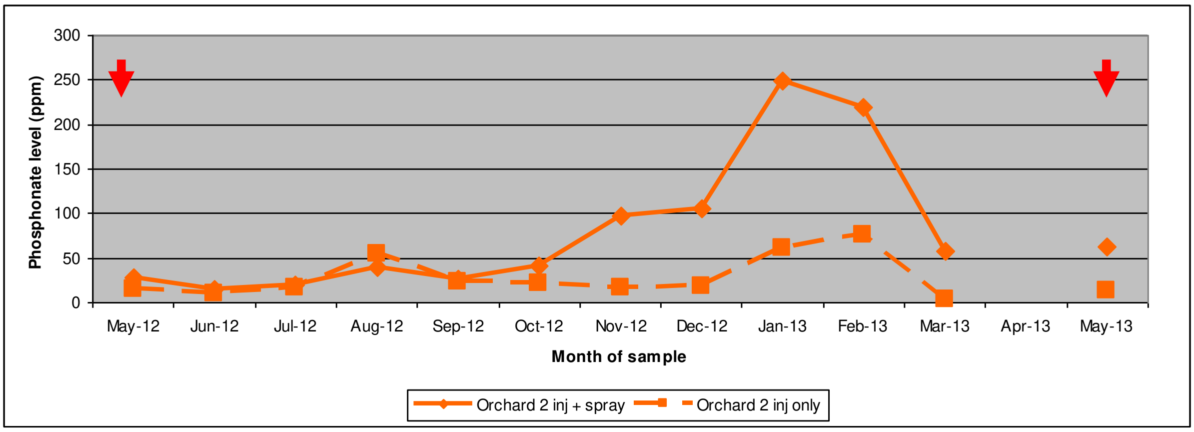

Figure 2. A comparison of phosphonate root levels in trees treated with injections only and trees treated with injections plus monthly foliar treatments in orchard 2.

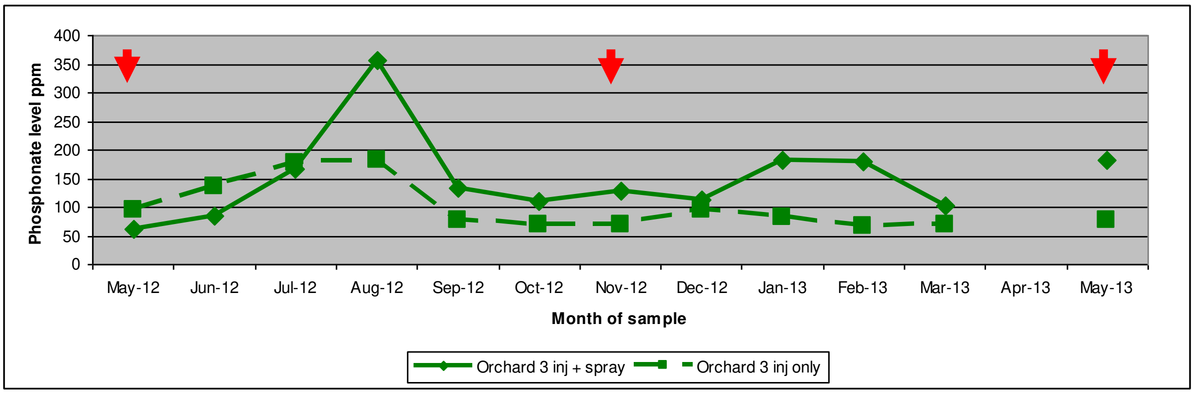

Figure 3. A comparison of phosphonate root levels in trees treated with injections only and trees treated with injections plus monthly foliar treatments in orchard 3.

In Orchard 1 (Figure 1.), at the commencement of the study, root phosphonate levels for both treatments were similar (~ 40 µg/g), with levels then quickly rising in both treatments after the April injection. Root phosphonate levels were greater in trees which had also received the monthly foliar spray treatment by June, a trend which continued and became more pronounced over the duration of the trial. Root phosphonate levels in both treatments then dropped from August to October before increasing in conjunction with the post-spring root flush (October – January). The second injection in November 2012 was followed by a second peak in root phosphonate levels for both treatments in January 2013. Foliar sprayed treatments in January 2013 had an extremely high mean root phosphonate level of 350 µg/g. Root phosphonate levels in both treatments then dropped steadily from February to May 2013, although levels remained substantially greater in trees which received the monthly foliar spray treatment. A final injection in April 2013 was applied in the weeks prior to the May 2013 measurement. Root phosphonate levels in unsprayed trees showed an increased phosphonate concentration at the final measure, although root levels in sprayed trees continued to decline. Phosphonate takes 16 – 35 days after injection to translocate to the roots (Whiley *et al.*, 1995) and it likely the full response to this last injection was not captured at the time of this final measure.

In Orchard 2 (Figure 2), root phosphonate levels for both the unsprayed and foliar sprayed treatments remained similarly low (< 50 µg/g) for the first 6 months of the study. It is thought that this was due to either a mister calibration/operator error that substantially reduced the amount of phosphonate applied, which was rectified in September 2012, or a dilution of phosphonate in the roots due to a root flush. A combination of both these reasons is the most likely cause. Root phosphonate levels for the foliar sprayed trees rose quickly after this adjustment and then remained substantially greater than the unsprayed trees for the duration of the trial. A phosphonate injection was conducted in May/June 2012, which was followed by a small increase in root phosphonate levels by August 2012. Root phosphonate levels in both treatments increased in January/February at the same time as a root flush. Increased root levels in the injection only treatment suggests translocation of stored phosphonate from other parts of the plant to the root flush, as the major contributor to the increased root phosphonate levels. In a similar response to Orchard 1, root phosphonate levels in the foliar sprayed treatments in Orchard 2 rose rapidly in January, with a high level of 250 µg/g measured. Root phosphonate levels then dropped rapidly from February – May for both treatments, although the foliar spray treatments remained above 50 µg/g.

Orchard 3 (Figure 3) had the highest root phosphonate levels (50 – 98 µg/g) of all three orchards at the commencement of the study in May 2012. Root phosphonate levels of the foliar sprayed trees were initially lower than foliar sprayed trees for the first few months, however by August 2012 these had surpassed the unsprayed trees. Root phosphonate levels in the foliar sprayed trees then remained higher than the unsprayed trees for the remainder of the study period. Phosphonate injections were carried out on all trees in Orchard 3 in May/June 2012. The foliar spray treated trees recorded a high spike in phosphonate levels (350 µg/g) after this operation, which is likely due to the already high phosphonate levels present prior to injection. Foliar sprayed trees recorded additional spikes in phosphonate levels to 190 µg/g, in January/February 2013 at a time of high root flushing levels.

To illustrate the trends for trees in all three orchards treated with injection and foliar sprays root phosphonate levels are shown in Figure 4. Levels in orchards 1 and 3 increased with treatments in May and June with levels in orchard 2 not increasing for reasons previously described. Levels in all orchards increased significantly with foliar applications in mid November or December.

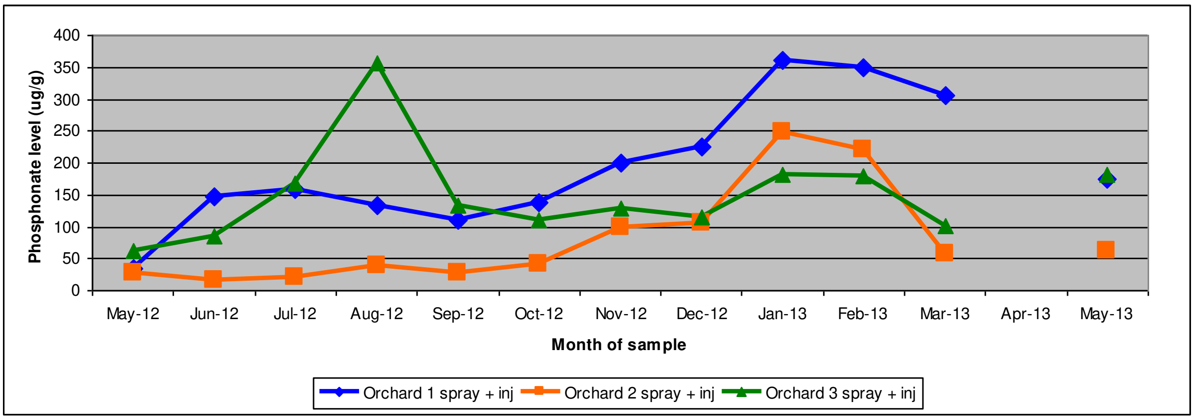

Figure 4. Combined root phosphonate levels in trees treated with injections + sprays for Orchards 1-3.

Phosphonate injection only

Phosphonate levels in trees receiving only phosphonate injections in all orchards are indicative of standard phosphonate injection practices (Figure 5).

The five orchards in this study all received phosphonate injections (either annually or biannually) over the duration of this study. Standard injection practice for Orchards 1, 3 and 4 is normally to conduct phosphonate injections after harvest in April – June then again after the hardening of the spring shoot flush in November/December. In the 2012 year however, Orchard 3 only received 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 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 November 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 40 ug/g (minimum threshold level) or greater, for the duration of the study.

Orchard 2 had a peak root phosphonate level above threshold levels in August 2012 (shortly after injection), before dropping to unsatisfactory levels between September – December. Phosphonate levels then peaked above threshold levels again in January/February which corresponded with a root flush. The January peak in phosphonate levels was 6 months after phosphonate injection, indicating phosphonate could be stored in sinks in other parts of the tree for an extended period, before being translocated to the roots in the advent of a seasonal root flush. Phosphonate levels then crashed to negligible levels throughout March – May 2013

Orchard 3 had initially high phosphonate levels in May 2012, which may have been due to an accumulation of tree phosphonate from biannual injections in May and November 2011. A large root phosphonate peak followed the May 2012 injection, with levels then declining over September – November. A smaller peak occurred in December/January shortly after a strong root flush. This was a similar response to that experienced in Orchard 2, suggesting longer term tree phosphonate storage and then translocation to the new root flush. Phosphonate levels remained above 25-40 ug/g (minimum threshold level) in Orchard 3 for the duration of the study.

Orchard 4 had initially high phosphonate levels in May 2012, which may have been due to an accumulation of tree phosphonate from biannual injections in May and November 2011. Root phosphonate levels then varied in association with small root flushes in October, December and February. The injection in November 2012 may have replenished phosphonate levels temporarily, however rates had dropped to below 40ug/g by March 2013 and it was apparent that a further phosphonate treatment was required.

Orchard 5 had very low initial phosphonate levels but these quickly rose in June/July 2012 as a response to the April injection. Phosphonate levels then dropped steadily passing the 40ug/g threshold in September and reaching almost negligible levels by January 2013. Root phosphonate levels increased to 40ug/g in response to a root flush in February 2013, but then dropped again in March. The rapid increase in the root phosphonate levels seen in Orchard 5 from April to May was due to a single foliar phosphonate application, based on results from the project, which was applied on 29 March as the orchard owner was advised the project had finished. This result shows that when foliar phosphonate applications are done 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.

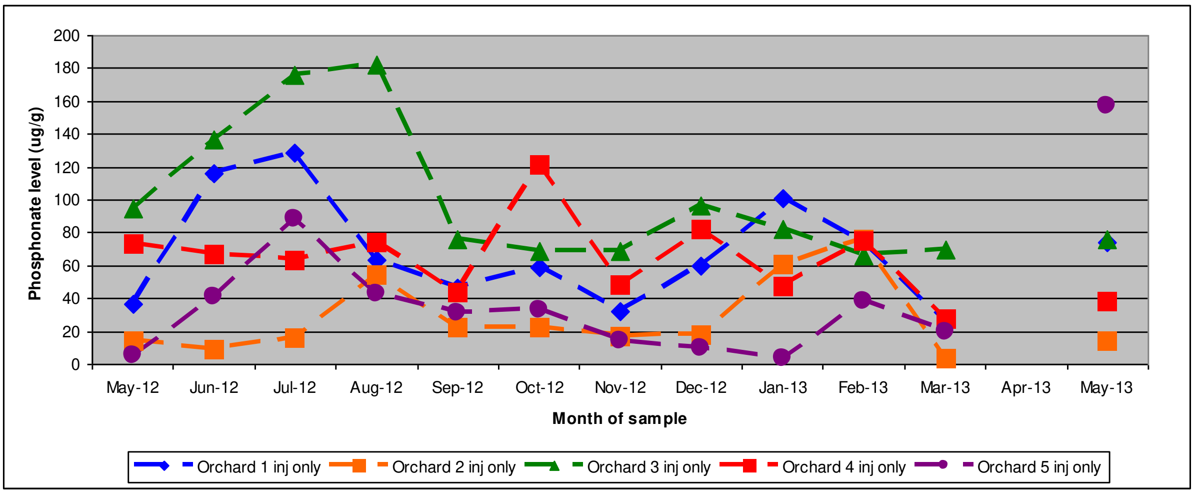

Figure 5. Phosphonate levels in trees from all orchards treated with phosphonate injections only.

Shoot phenology

Shoot flushing varied across the orchards (Figure 6), although some general trends were observed. Peak shoot flushing events were seen in all orchards in September/October and then again in December/January. Shoot flushing was least in May and November.

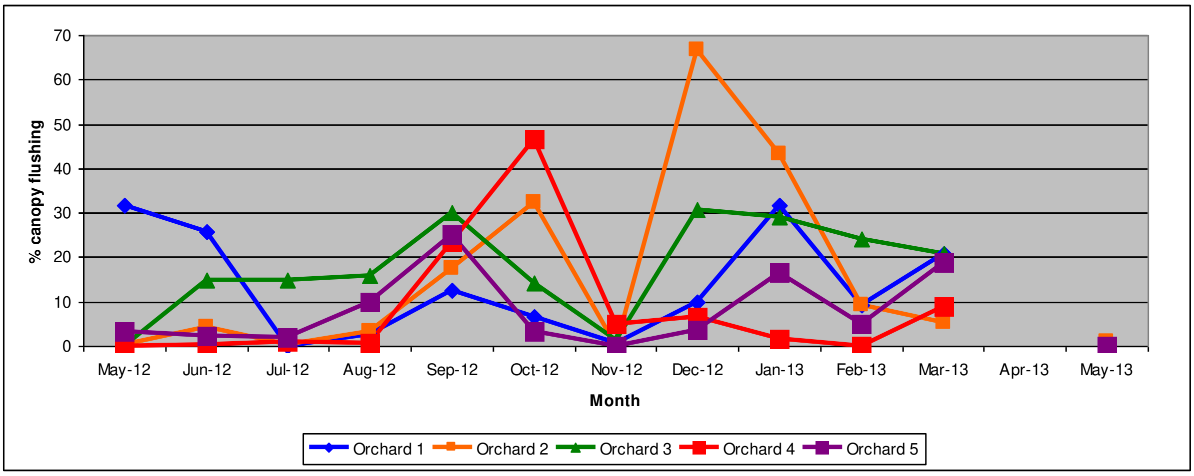

Figure 6. Percentage canopy with shoot flushing in the 5 orchards.

Flowering phenology

Flowering started with a minor flowering in all orchards in May/June 2013 (Figure 7). Orchards 2, 3 and 5 then continued to flower, while flowering slowed in Orchards 1 and 4, producing 2 flowering peaks. The major flowering event in all orchards was in August and September with all flowering completed by October 2012.

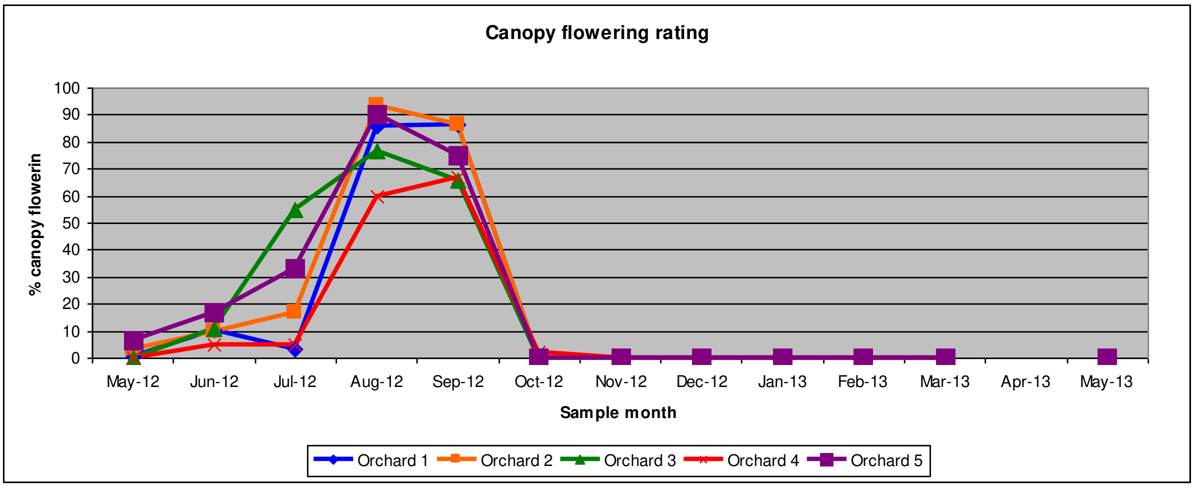

Figure 7. Percentage of canopy flowering in the 5 orchards.

Root phenology

Root phenology varied across the orchards (Figure 8). 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.

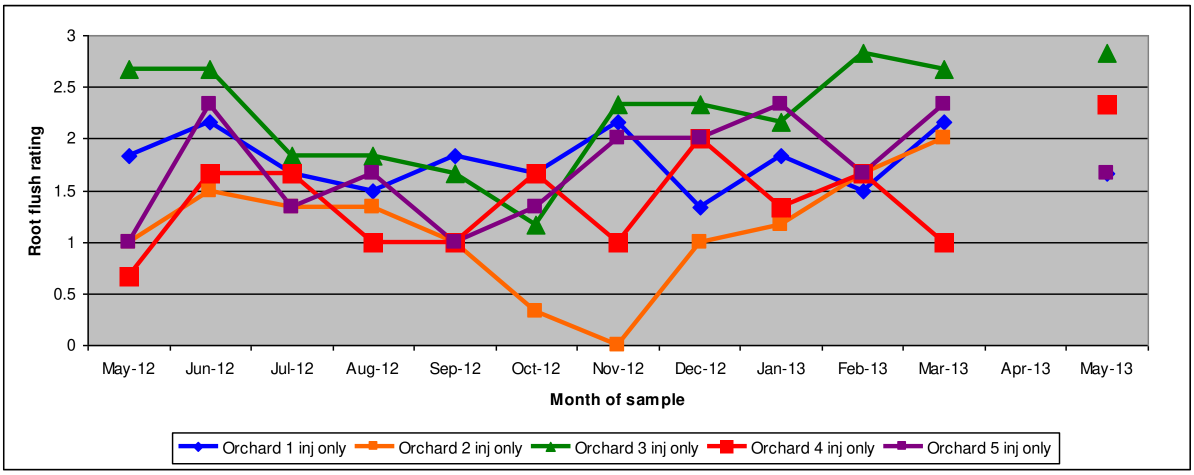

Figure 8. Root flush rating across the 5 orchards (where 0 = no flush, 1 = 1-30% roots flushing, 2 = 30-60% roots flushing and 3 = > 60% root flushing).

In the orchards which received the foliar phosphonate spray treatments, root flushing intensity was greater in trees that received the additional spray treatments (Figure 9). 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.

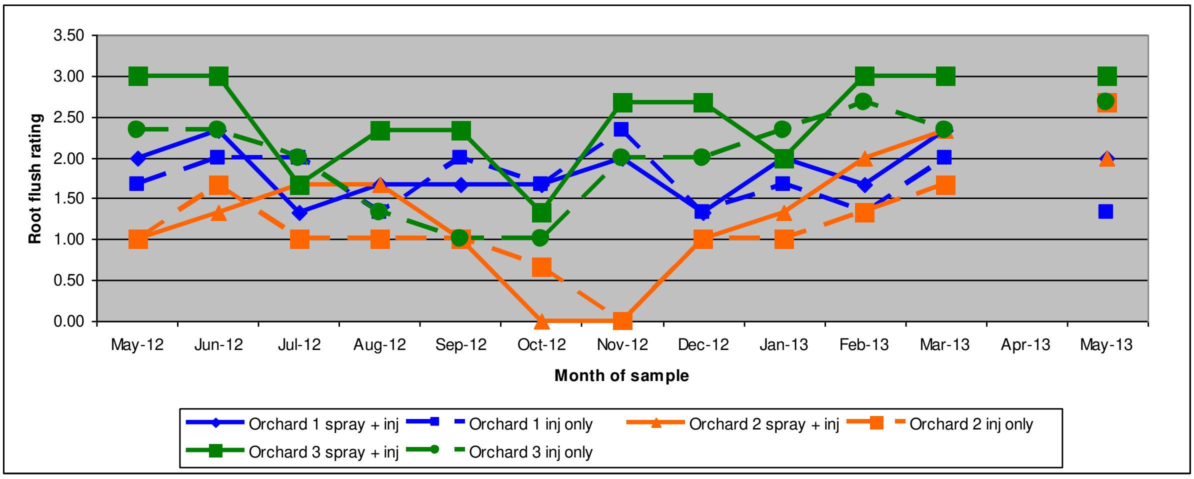

Figure 9. Comparative root flushing of trees that received spray treatments and those that did not in the 5 orchards.

DISCUSSION

Phosphonate levels

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

Phosphonate sprays

In all three orchards, root phosphonate levels were higher in the foliar spray treatments by the end of the project. For Orchard 2 it took six months to achieve these results. Initially it was unclear why this was the case, however there are 2 possible reasons for this. It was determined that the recommended volume of phosphonate was not being applied to the trees in the early part of the trial. Once this was corrected, root phosphonate levels began to rise in this orchard. The second reason is that the roots of the trees in this orchard were vigorously flushing, greater than trees in all the other orchards, at this time and the applications were simply being 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, which also coincided with the two peak periods of root flushing. 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.

Phosphonate injection

The five orchards in this study all received phosphonate injections (either annually or biannually) over the duration of this study. Standard injection practice for Orchards 1, 3 and 4 is normally to conduct phosphonate injections after harvest in April – June then again after the hardening of the spring shoot flush in November/December. In the 2012 year however, Orchard 3 only received 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.

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 the minimum threshold level (25-40 ug/g) or greater, for the duration of the study.

Orchard 2 had a peak root phosphonate level above threshold levels in August 2012 (shortly after injection), before dropping to below recommended levels between September – December. Phosphonate levels then peaked above threshold levels again in January/February which corresponded with a root flush. Phosphonate levels then decreased to negligible levels throughout March – May 2013. The January peak in phosphonate levels was 6 months after phosphonate injection, indicating phosphonate could be stored in sinks in other parts of the tree for an extended period, before being translocated to the roots in the event of a seasonal root flush.

Orchard 3 had initially high phosphonate levels in May 2012, which may have been due to an accumulation of tree phosphonate from biannual injections in May and November 2011. A large root phosphonate peak followed the May 2012 injection, with levels then declining over September – November. A smaller peak occurred in December/January shortly after a strong root flush. This was a similar response to that experienced in Orchard 2, suggesting longer term tree phosphonate storage and then translocation to the new root flush. Phosphonate levels remained above the 25-40 ug/g (minimum threshold level) in Orchard 3 for the duration of the study.

Orchard 4 had initially high phosphonate levels in May 2012, which may have been due to an accumulation of tree phosphonate from biannual injections in May and November 2011. Root phosphonate levels then varied in association with small root flushes in October, December and February. The injection in November 2012 may have replenished phosphonate levels temporarily, however rates had dropped to below 40ug/g by March 2013 and it was apparent that a further phosphonate treatment was required.

Orchard 5 had very low initial phosphonate levels but these quickly rose in June/July 2012 as a response to the April injection. Phosphonate levels then dropped steadily passing the 40ug/g threshold in September and reaching almost negligible levels by January 2013. Root phosphonate levels increased to 40ug/g in response to a root flush in February 2013, but then dropped again in March. The rapid increase in the root phosphonate levels seen in Orchard 5 from April to May was due to a single foliar phosphonate application, based on results from the project, which was applied on 29 March as the orchard owner was advised the project had finished. This result shows that when foliar phosphonate applications are done 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.

Tree phenology

Root flushing

As root flushing is integral to the timing of phosphonate applications this was the key phenological stage studied. Root phenology varied across the orchards, however the 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 varies 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.

A key component facilitating vigorous root flushing events seems to be mulch. The farm with the consistently highest root flush rating (Orchard 3) also had 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 trees that had been mulched.

It has been suggested that high root phosphonate levels (>250µg/g) can inhibit root flushing. For root flushes in Shepard in north Queensland, our study data does not support this theory. The spray treated trees in Orchards 1 and 3 had consistently high root phosphonate levels, yet also had the highest root flush rating.

Shoot flushing

Shoot flushing phenology shows that under the climatic conditions on the Atherton Tablelands Shepard avocados are prone to flushing throughout the year. 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 is at its greatest.

Flowering

Flowering phenology data shows that Shepard commences flowering, albeit at low levels, starting in May and with the peak flowering period in July, August and September. These findings show it is important to have all phosphonate applications done by mid May, so flowers don't become a sink for phosphonate, as root levels start to decline in July.

Technology transfer

The project has improved understanding of Shepard tree phenology on the Atherton Tablelands and how this controls the uptake and movement of applied phosphonate (after injection or spray application) under a range of management systems. This improved knowledge will allow better targeted applications of phosphonate treatments, (both foliar and injection) to more effectively manage PRR. This work will build on the work done to optimize phosphonate application on cultivars other than Hass in '*AV07000 – Improving yield and quality in avocado through disease management*'.

Project results have been delivered through:

- A field day to launch the project was held on 03 February 2012. A presentation outlined the project and identified field trial sites. Jim Kochi, the chair of Avocados Australia Limited (AAL) also presented information on Infocado, the AAL market information system at this workshop.
- A article detailing the project was published in the February 10, 2012 edition of Guacamole, the AAL electronic newsletter (http://bit.ly/14fjLJ5)
- A second workshop detailing project progress of was held on 10 October 2012. At the workshop an update on the progress of for the development of the pheromone and trap for fruit spotting bugs, a component of the HAL funded project MT10049 A multi target approach to fruitspotting bug management, was also provided.
- A presentation of the final results of the project was delivered at the North Queensland Qualicado workshop, run by Avocados Australia and held on August 15, 2013 in Dimbulah. Over 120 growers and industry service personnel attended the workshop, a record number for an Australian avocado industry field day, see http://bit.ly/1fvQ9a0. Originally planned as a stand alone workshop for the AV11011 project, the workshop was combined with the Qualicado workshop to avoid a clash of dates or having 2 avocado workshops within a short period of time. Other topics presented on the day included an overview of the AAL Best Practice Resource (BPR) and information program (Julie Petty AAL), and Fruit Spotting Bug project particularly alternative chemistry (Ian Newton, Ruth Huwer). A copy of the AV11011 project presentation is hosted on the AAL BPR website at http://bit.ly/19e2wWA
- An article detailing the final results for the project has been submitted for publication in the spring edition of AAL magazine, Talking Avocados, due for publication in October 2013. The article was approved for publication by the HAL communications section on 30/08/13.
- Results from AV11011 were used to develop the crop management calendar for Shepard avocados in North Queensland. This is hosted on the AAL website in the BPR section see http://bit.ly/15EN9CI and is attached as an appendix.

RECOMMENDATIONS

This study has improved understanding of Shepard tree phenology on the Atherton Tablelands and how this is linked to the uptake and movement of applied phosphonate (after injection or spray application) under a range of management systems.

Improved knowledge of tree phenology and its relationship to phosphonate root levels captured in this project has been used in the development of a new 'Crop Management Calender' for Shepard avocados on the Atherton Tablelands. This calendar is a useful guide for farmers when planning a wide range of Shepard avocado management practices.

Management of root phosphonate levels above the recommended 25-40ug/g throughout the year will require more than the practice of an injection at a single time per year. Foliar phosphonate applications can help increase root phosphonate levels in healthy trees, when applied at/or shortly before periods of peak root flushing and when shoot flushes have matured. In Shepard avocados on the Atherton Tablelands the peak periods to apply phosphonate, either as foliar sprays or as injections occurred in May – July and November – January. Root accumulation of phosphonate was negligible from late August – October, despite regular monthly foliar applications. Growers are reminded that foliar phosphonate applications only work with healthy trees and that trees which already have reduced canopies from PRR must be treated with injections.

The study reinforces the importance of monitoring phosphonate levels in avocado roots, not just in north Queensland but in all avocado production regions of Australia. Monitoring of root phosphonate levels in avocado orchards is a simple and inexpensive operation that growers should undertake to assist with their Phytophthora management program.

Trees should then be treated again in April or May with either foliar sprays or injections and samples taken in May or June to ensure adequate root phosphonate levels. Samples should not be collected earlier than 3 weeks after the last phosphonate application (injection or spray) to enable sufficient time for phosphonate to move to the roots.

A second lot of samples should be collected in October, approximately 2 weeks prior to the shoot flush hardening. Due to the large dilution in root levels caused by the root flush in January through March, if root levels are below 90 ug/g trees should be treated with either a foliar spray or injection at the recommended rate.

This process 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.

The effectiveness of foliar applied phosphonate to increase root phosphonate levels, even as a single spray in healthy trees was highly encouraging. This suggests that there is potential for effective management of orchard root phosphonate levels above recommended thresholds (25-40 ug/g), via an integrated system (one injection per year + the use of foliar sprays) or via foliar phosphonate applications alone. The replacement of one or all phosphonate injection operations with a foliar phosphonate spray regime has the potential to reduce grower's 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.

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APPENDIX 1. North Queensland Shepard Crop Calendar