“The Benefits of Monitoring Phosphorous Acid in the Roots of Avocados"

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Abstract

The Australian avocado industry has undergone many changes in the last twenty years. None more significant than the management of *Phytophthora* root rot. Initially limited control was obtained using cultural techniques. The development of fungicide programs and in particular phosphorous acid has seen it move through a number of phases. Firstly through the foliar application of Aliette® to the trunk injection of Potassium Phosphonate and now back to the foliar application of a high concentration and neutralised Potassium Phosphonate.

With a better understanding of the mode of action of phosphorous acid, the relevance of tree phenology has to be thoroughly understood to maintain efficient control. The use of spray application has introduced more variables to complicate the situation.

Research has been able to establish phosphorous acid levels required in the roots to stimulate protection against *Phytophthora* root rot. A commercial service has now been established to monitor these levels. The results from this service have highlighted the large number of variables that contribute to the sustainable management of root rot.

Background

Root rot caused by *Phytophthora cinnamomi* Rands is the most serious disease of avocados (*Persea Americana* Mill) (Zentmeyer, 1984). Pegg (1983) reported that it is a severe problem in all major producing countries except Israel. The disease has since reached Israel where it is causing similar problems to those seen in other countries. Without access to effective control measures, Phytophthora root rot has the potential to devastate the Australian industry.

The seriousness of Phytophthora root rot was seen in the mid-1970s when the size of the Australian avocado industry was significantly reduced. Record heavy rains that fell in the major producing areas of southern Queensland and northern New South Wales in 1974 provided conditions the disease required to debilitate or kill over half the mature tree population. The effects on yield over the whole industry were felt for several years (Fig. 1).

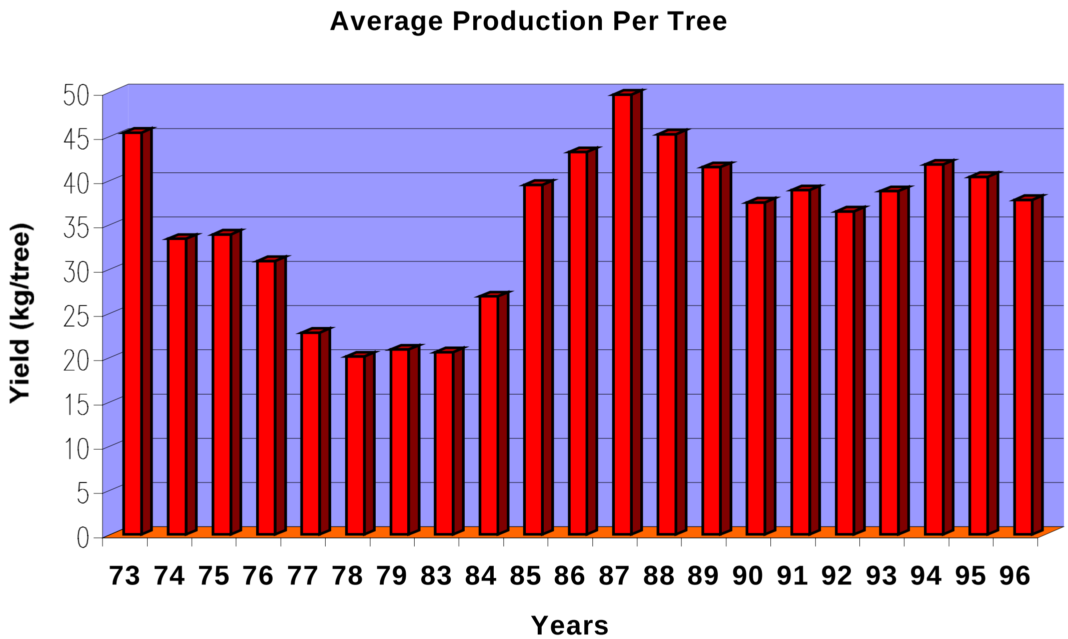

Fig. 1 Yield reduction suffered by the Australian avocado industry following the high rainfall in 1974 that led to subsequent devastation of trees by *Phytophthora cinnamomi*.

The Fungus

Phytophthora cinnamomi belongs to the group of fungi called *Phycomycetes.* It is a water mould and has a mechanism to survive for long periods of dry conditions. Growth of the fungus and infection of trees is greatest in wet soils at temperatures between 21-30°C, whereas little or no infection occurs above 33°C or below 13°C. Thus, the main infection period for trees is during the summer months, particularly when free-moisture is available in soils such as occurs during moderate to high rainfall, or under poor irrigation management. *Phytophthora cinnamomi* attacks the soft, white roots of the avocado tree, which are the most active part of the root system absorbing nutrients and water. Occasionally, the disease will move into the hardened, brown roots and it may also attack the trunks of trees at soil level causing a canker. Infection that takes place during the late summer generally has impact on tree health during flowering in spring shown by excessive leaf drop.

Managing Root Rot in Avocado Trees

Prior to the early 1970's, cultural activities were the only means of minimising the effects of this Phytophthora root rot. These included the development of Phytophthora-suppressive soils that were identified and described by Broadbent and Baker (1974). These soils had large populations of microorganisms antagonistic to *Phytophthora cinnamomi* wherein inoculum density of the pathogen was decreased through sporangia abortion, thus leading to reduced spore survival and transmission. Suppressive soils have high organic matter content that supports a thriving microflora population and in practice this can be achieved through the addition of animal manures and organic mulches. In 1977, the Australian industry developed the Avocado Nursery Voluntary Accreditation Scheme (ANVAS) to produce container-grown trees in a pathogen free environment. This is an effective means of delaying disease development and reduces the risk of introducing *Phytophthora cinnamomi* into new orchards. ANVAS was immediately effective reducing the spread of root rot and ensuring that newly planted trees survived and reached their cropping potential (Pegg, 1992). A common practise during the 1970's to minimise the effect of root rot-induced tree decline was to attempt to keep the canopy size in balance with the root system. This involved periodic scaffolding of trees, which mostly resulted in improved tree health although the treatment had a severe and detrimental impact on cropping for the first season following the treatment.

In the early 1980's it was shown by Trochoulias *et al*. (1986) in Phytophthora root rot studies at Alstonville, NSW that health declined in all trees except those receiving heavy dressings of gypsum or dolomite. Snyman and Darvas (1982) also found in South Africa that calcium applications to avocado trees reduced the severity of root rot but not to the extent of the fungicide metalaxyl. This gave supporting evidence for the use of calcium in fertiliser programs as a means of reducing the severity of root rot.

A genetic solution for root rot control was sought in California during the 1950's where the search for rootstock resistance to the disease began. Little progress was made during the following 30 years as confirmed by Coffey and Guillemet (1987) who wrote "*Phytophthora is ultimately the major limiting factor in avocado production. The need to deal effectively with the problem therefore becomes paramount. In our estimation, the most important answer to the problem surely lies in discovering a rootstock with high and durable resistance to root rot*". The use of Phytophthora-resistant rootstock will always be the ultimate means to control this disease and the search for suitable material continues.

The use of fungicides to control Phytophthora root rot was delayed until the late 1970's when metalaxyl (Ridomil®) became available. This fungicide has highly protective and curative properties, and is applied in relatively low dose rates. However, in South Africa, after three continuous years of use, McKenzie and Margot (1982) found that soil bacteria were metabolising the fungicide that resulted in a loss of root rot control. Subsequently, this was confirmed by studies in Australia following continued use of metalaxyl over several years (Pegg *et al*., 1987). However, if used strategically, metalaxyl is still an effective fungicide and can be successfully applied to control root rot during field establishment of new trees.

Phosphorous acid was first available to the Australian avocado industry as Aliette®. It is a highly systemic fungicide capable of translocation from leaves to roots and roots to leaves. It is mildly fungi toxic, but more importantly capable of stimulating a defence response from the tree to block infection of avocado roots by *Phytophthora cinnamomi*. Phosphorous acid, now commonly applied to avocados as a formulation of mono- dipotassium phosphonate, remains the single most effective treatment available to protect trees from Phytophthora root rot. As with consistent use of all fungicides, concerns for its long-term effectiveness in controlling root rot have been expressed as constant exposure to the fungus may lead to the evolution of phosphonate-resistant strains of *P. cinnamomi*.

In South Africa, following long-term treatment (12 successive years) of avocado trees with phosphonate fungicides, Duvenhage (1994) found that the sensitivity of *P. cinnamomi* isolates grown *in vitro* to phosphorous acid had decreased. In more recent studies in Australia, Weinert *et al*. (1997) also showed that the sensitivity of *P. cinnamomi* is reduced following long-term exposure to phosphorous acid (Table 1).

Table 1 Phosphorous acid concentration at which the growth of *Phytophthora cinnamomi* isolates collected from roots of avocado trees was stopped (µg/mL). Values in columns are the percentage of isolates in each category. From Weinert *et al*. (1997).

H_3PO_3 Concentration	Treated [1]	Treated [2]
50	16	74
100	19	26
500	34	0
1000	29	0
>1000	2	0

[1]Isolates recovered from the roots of avocado trees that had been treated with phosphonate fungicides applied as either a foliar spray or a soil drench for 10 years.
[2]Isolates recovered from the roots of avocado trees that had never been treated with phosphonate fungicides.

Despite the change in sensitivity of *P. cinnamomi* to phosphorous acid, acceptable commercial control of root rot is still being achieved which is likely due to the defence system response within the tree. However, the results present a timely warning that this fungicide should be managed with care so as not to overly expose the pathogen directly to the chemical. With current knowledge, management strategies for sustainable control of Phytophthora root rot can be summarised as follows:

- Select a site with free draining soil.
- Obtain disease-free trees from an ANVAS accredited nursery.
- Plant on broad-based mounds to divert excess water in periods of heavy rain.
- Maintain a pH in the range most favoured by avocados – 5.0 to 5.5
- Maintain a mulch cover of fibrous materials in the canopy zone.
- Maintain an even moisture level rather than allowing extremes in wetting and drying.
- Maintain a high but balanced level of soil calcium.
- Use a strategically applied fungicide program.

If we are to maintain sustainable control of *Phytophthora* we need to utilise all of the above. If we are over dependent on our current fungicide program alone, we may find the long-term effectiveness of managing the disease is reduced.

Root Monitoring

The effective management of phosphonate fungicide to control Phytophthora root rot requires different strategies than those used for other pesticides due to its unique mode of action. Most pesticides act through direct contact or as a protective barrier however, phosphonate is taken in and dispersed throughout the plant. The accumulation of phosphorous acid in the various parts of the tree is strongly related to the relative metabolic sink strength of the various tissues at the time of application (Whiley *et al.*, 1995). A basic understanding of tree phenology is sufficient to identify the application time that will result in the most effective translocation of the fungicide to roots however, there are several other factors that influence the final concentration of phosphorous acid that accumulates in the target tissues. Hence, there is a need for an effective root phosphorous acid monitoring system that can account for treatment variation at the farm level just as leaf nutrient analysis assists with the management of tree fertilisation. Whiley *et al*. (1995) concluded that a concentration between 20-40 mg/kg of phosphorous acid in the roots would give commercial control of Phytophthora root rot. The challenge we face is to maintain this level for the period when roots are vulnerable to attack.

Hargreaves and Ruddle (1990) developed a technique to successfully measure phosphorous acid in avocado roots. This technique presented problems for widespread monitoring as sampling methods and the ability to process large numbers economically inhibited its commercial use. Agrifood Technology Pty Ltd in Toowoomba, Qld has since developed an in-house technique, which was standardised against the Hargreaves and Ruddle method. In addition, a more robust sample handling method was developed to reduce variation due to root moisture content differences.

The Monitoring Service

The root phosphorous acid monitoring service has only been commercially available since October 2000. Information collected from the participating orchards has been entered into a database and over time will develop very specific behavioural details of phosphorous acid down to a block basis. The long-term aim of this service is to optimise the use of phosphorous acid, maximise application efficiency, reduce costs through omission of unnecessary applications and prolong its use in the avocado industry.

To this point in time there are results that are easily explained by tree phenology, whereas in other cases root phosphorous acid concentrations have been modified by additional factors. These are covered by the following categories:

- Crop Load
- Application method
- Application volume
- Season

- Rootstock
- Location

Crop Load

Previous work by J. Leonardi and A.W. Whiley (unpublished results, 1999) clearly demonstrated a relationship between the amount of phosphorous acid accumulated in roots and the crop load on the trees at the time of application (Fig. 2). This result is a function of the relative sink strengths between each part of the tree and will be accentuated by the stage of fruit development at the time of application. When fruit set has just occurred, the sink strength of the fruit is at its greatest but this diminishes as it matures. Application just after fruit set has been shown to significantly increase phosphorous acid residues deposited in the fruit. These residues can persist at high levels until the time of harvest and can endanger the acceptability of fruit on markets. However, the application of phosphonate fungicide close to harvest has been shown to have a minimal effect on fruit residues (Whiley *et al*., 1995, 2001).

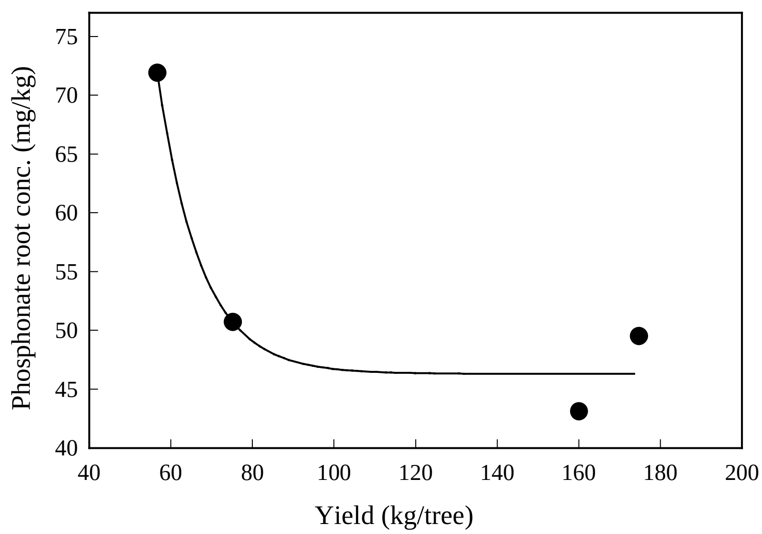

Fig. 2 Relationship between crop load (yield) and phosphonate levels in roots following a program of foliar sprays with 0.5% phosphonate. From Whiley *et al*., 2001.

The above relationship has since been confirmed from commercial root monitoring (Fig. 3). The data was generated from separate properties but the method and volume of phosphonate fungicide application was similar. With a number of other tests under varying circumstances, similar trends have been established. Hence, the combination of crop load and sink strength at the time of application can have a significant effect on root phosphorous acid concentration following the treatment of trees with phosphonate fungicide.

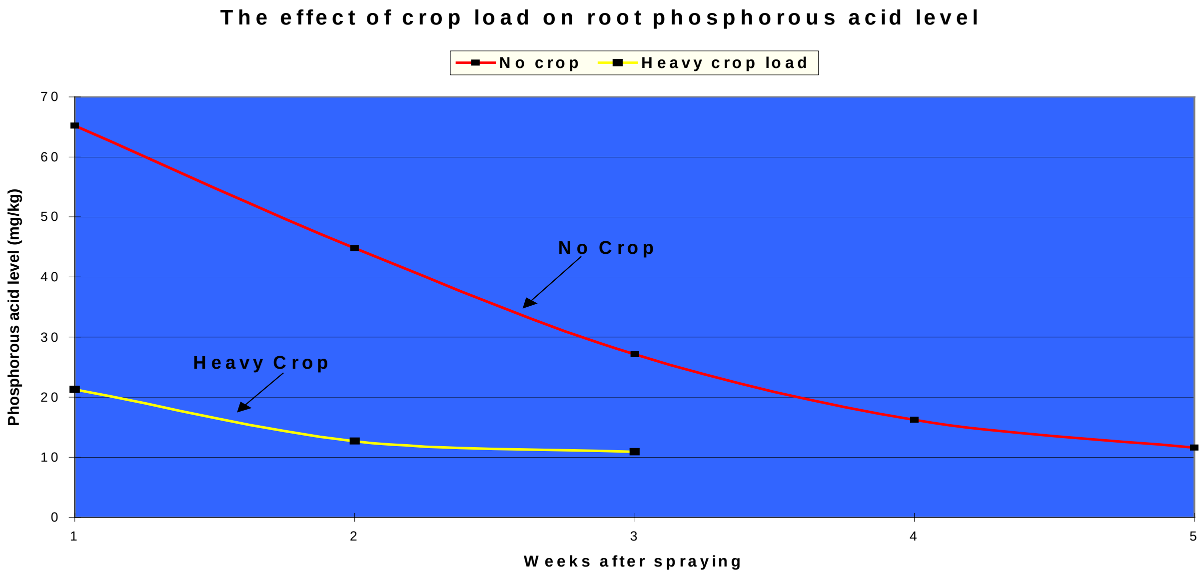

Fig. 3 The effect of crop load on the level of phosphorous acid in the roots of avocados following a single foliar application of phosphonate fungicide. Application was by high volume (approximately 1500 L/ha).

Application method

A trial was established at Hampton, Qld to compare the effects of injecting versus foliar spraying phosphonate fungicide. The results established the relationship between the two techniques. A block of 'Hass' on Mexican seedling rootstock was divided in half for the purpose of the experiment. Twenty-two trees were injected with phosphonate fungicide (200g/L a.i.) at the rate of 15mL/metre of canopy diameter once on the 2nd August 2000. This timing is similar to when applications are made in New Zealand as some preliminary results from monitoring roots from this country indicated that the levels in the June following an August application were sufficient to protect trees year-round. Foliar applications were made using 12.5 mL/L of phosphonate fungicide (400 g/L a.i.) buffered to a pH of 7.2 and applied at the rate of 370 L/ha on the 2nd August, 2000. Repeat applications were made on the 12th December 2000 and the 23rd February 2001 at 1,100 L/ha. This was a result of the information generated, that low volume applications were not effective in significantly increasing root phosphorous acid levels.

Note: *preliminary results indicate that high phosphorous acid concentrations in flowers have a detrimental effect on pollen viability and under some circumstances may reduce fruit set (P. Nartvaranant and A.W. Whiley, unpublished results, 2001). Hence, care should be taken if treating trees with phosphonate fungicide close to flowering.*

The results showed that injection with phosphonate fungicide gave a higher level of phosphorous acid in roots which persisted for longer than the sprayed treatment when applied at that time of year (Fig. 4).

The spray application made at that time was low volume and followed a severe frost. The frost may have had a detrimental effect in the uptake of the phosphorous acid. With the 2nd August application, a spray volume of 370 L/ha, delivered 15g of phosphorous acid to each tree. Subsequent applications of 1,100 L/ha increased the quantity to 45g. This compared to the delivery of 20g when each tree was injected on 2nd August.

It can be seen in Figure 4 that the efficiency of spray application is considerably less than via trunk injection. Other work has supported this data.

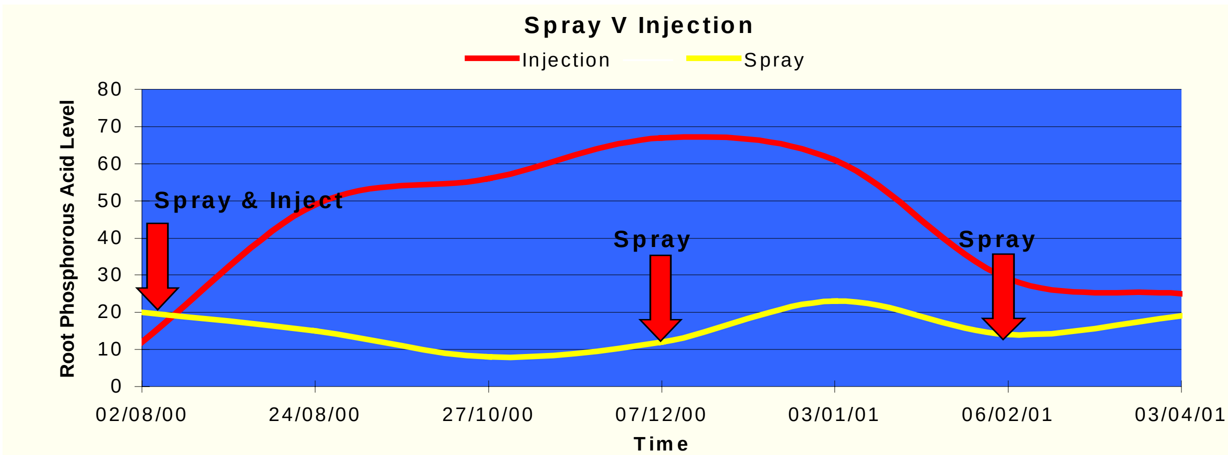

Fig. 4 The effects of different methods of phosphonate fungicide application on root phosphorous acid concentrations.

Application volume

Probably the most conclusive result that has arisen from the monitoring program is the poor results from low volume foliar applications of phosphonate fungicide. Whilst it is difficult to define an exact volume, applications in mature orchards under 1000 L/ha do not appear to be significantly increasing the phosphorous acid root concentration.

As the dilution rate to be submitted for registration cannot be varied with the volume applied, it is essential that the trees be sprayed to the point of runoff to maximise the phosphonate dosage. If the dilution rate is increased the risk of phytotoxicity under some conditions will dramatically increase. Hence the logistics of foliar-sprayed phosphonate fungicide is centred on applying a sufficient quantity of active material to trees that will result in sufficient uptake and translocation to give root protection. Thus trees receiving high volume applications will have greater root concentrations of phosphorous acid than those sprayed with low volume applications. (Fig. 5)

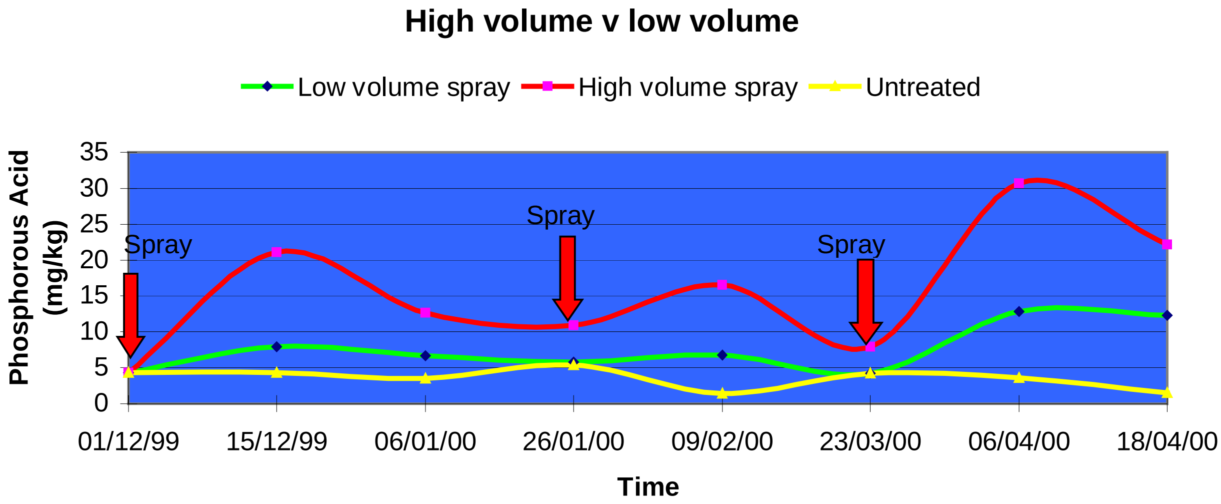

Fig. 5 The effect of spray volume on the phosphorous acid levels in the roots of avocados conducted over a growing season.

Season

The variability of phosphonate responses that occur over a fruiting season are best explained by understanding the demands that are made by the different parts of the tree for sugars to provide growth at different times of the year. Phosphorous acid moves passively with the flow of sugars and nutrients through the tree in both an upward (xylem) and downward (phloem) direction. Even when applied as a trunk injection, phosphonate is translocated to the leaves prior to moving in the phloem to the root system. If at a particular time of the year the greatest energy requirement is parts of the tree other than the roots, phosphorous acid will concentrate in those organs. This can be seen when there is a strong vegetative flush or when fruit set first occurs (Table 2). In these circumstances, the majority of the phosphorous acid will be deposited in those organs.

Table 2 Effect of time of foliar application of 0.5% phosphonate fungicide on the phosphorous acid concentration of 'Hass' fruit. Source from A.W. Whiley, unpublished results.

Date of application	Stage of fruit development	Fruit phosphorous acid concentration (mg/kg)
3rd November	Early growth (3 – 5 mm diameter)	160.8
30th January	About 1/3 grown	21.6
16th July	Fully mature	3.7

Therefore, regardless of the method of application, if the metabolic sink strength is not centred on the root system, the efficiency of phosphonate application will be significantly reduced. This can be seen in Fig. 6 where the root phosphorous acid level peaked at different levels when all facets of the method of application were identical. The differences are solely attributed to the different relative sink strengths between the various organs of the tree at the time of application.

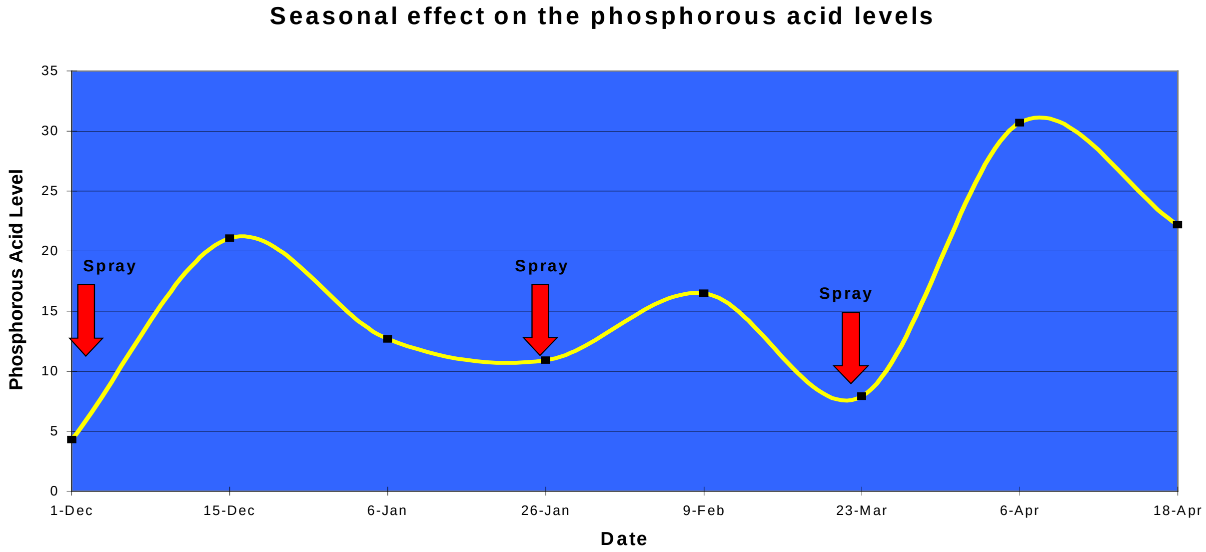

Fig. 6 The effects of seasonal variability of metabolic sink strength on the phosphorous acid level in the roots of avocados

As the roots are the target organs for phosphorous acid, it is essential that we appreciate when the roots of an avocado are in a period of strongest sink strength. From the phenology cycles developed by Whiley *et al*. (1988), it can be seen that there are two distinct periods when metabolites are directed to the roots. The generalised version can be seen in Fig. 7.

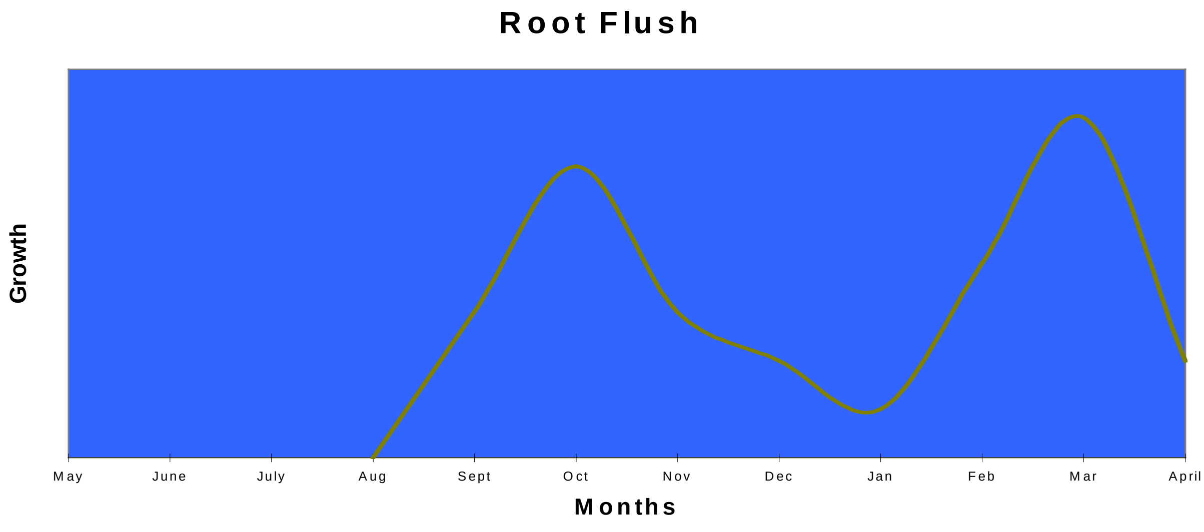

Fig. 7 The annual growth cycle of avocado roots. This is a generalised cycle as climatic conditions vary the exact timing and the magnitude of the growth. Source: Whiley *et al*. (1988).

The characteristics of these cycles will vary between seasons and locations and as a result the behaviour of phosphorous acid will be different in each growing region. This is illustrated in Fig. 8.

In Pemberton, Western Australia the phosphorous acid levels appear to elevate much quicker and persist for longer at specific times during the year than has occurred in other regions. This may relate to the sink strength of the roots in this region when compared to elsewhere.

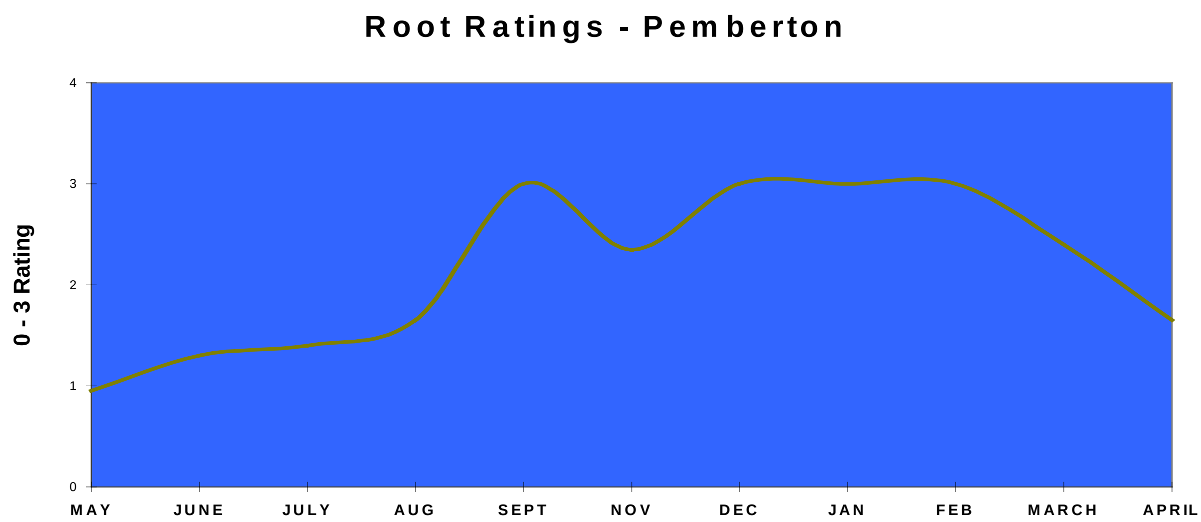

Fig. 8 Root flush ratings from Pemberton in Western Australia. The rating scale used was that developed by A.W. Whiley, QHI.

When the vegetative growth is vigorous, it will be a stronger sink than the roots. From Fig. 9 the generalised curve gives some indication of the period to avoid. If phosphonate fungicide is applied during periods of peak vegetative growth, very little phosphorous acid will be translocated to the roots.

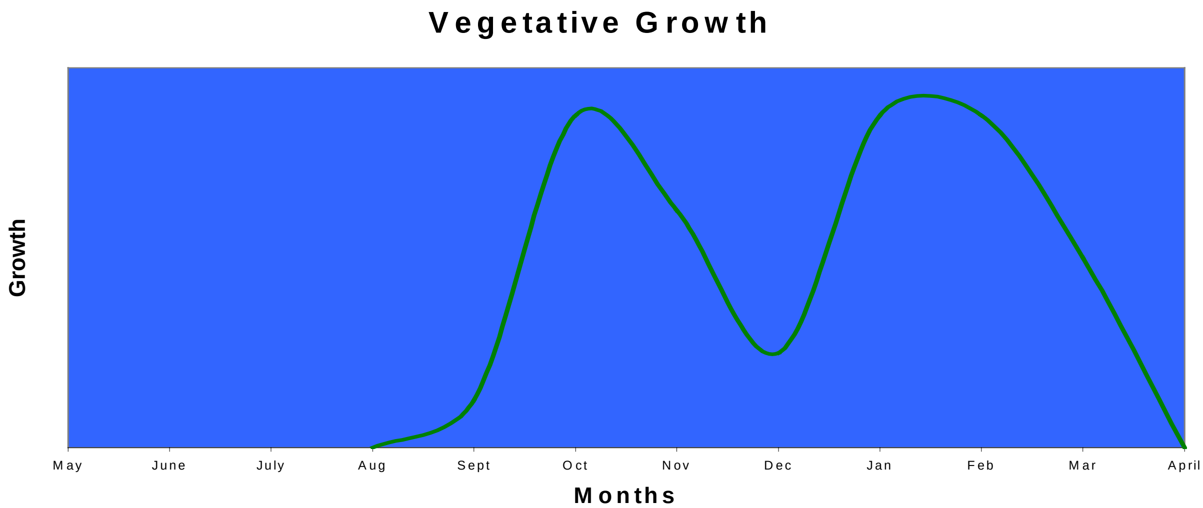

Fig. 9 The generalised vegetative growth cycle for avocado. For specific regions this will vary with time and magnitude. Source: Whiley *et al.* (1988).

As these phases are not clearly separated, there will be period when the strength of the vegetative phase is diminishing. These periods of overlap can be seen in Fig. 10.

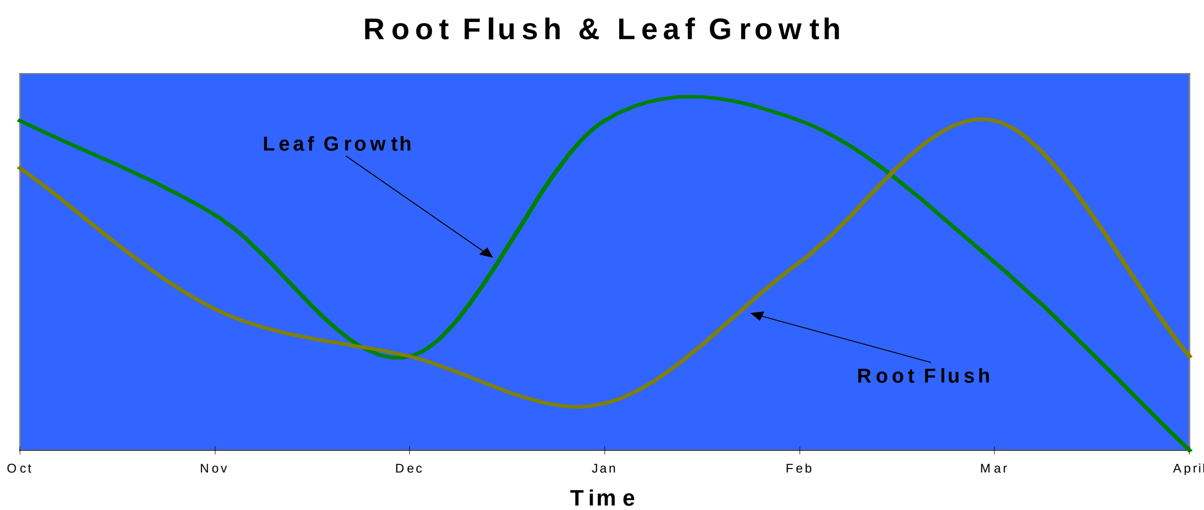

Fig. 10 The root flush and vegetative growth flush cycles as extracted from the annual cycle but the time frame is condensed to match the period of root monitoring

The above observations and principles can be seen in the results of the Hampton trial investigating foliar phosphonate applications conducted by J. Leonardi and A.W. Whiley (unpublished data, 2000). The results of this trial are overlaid on the root and vegetative growth phases (Fig. 11). It can be seen that the root phosphorous acid concentration from the 1st

December application was higher than that obtained from the late January application. However, by far the highest phosphorous acid root concentration was achieved with the mid March application, which corresponded with the peak in root growth.

Unless exact measurements are being made of all facets of the phenology cycle, the results from applications of phosphonate fungicide will be variable. This will occur without variations in spray application or crop load differences.

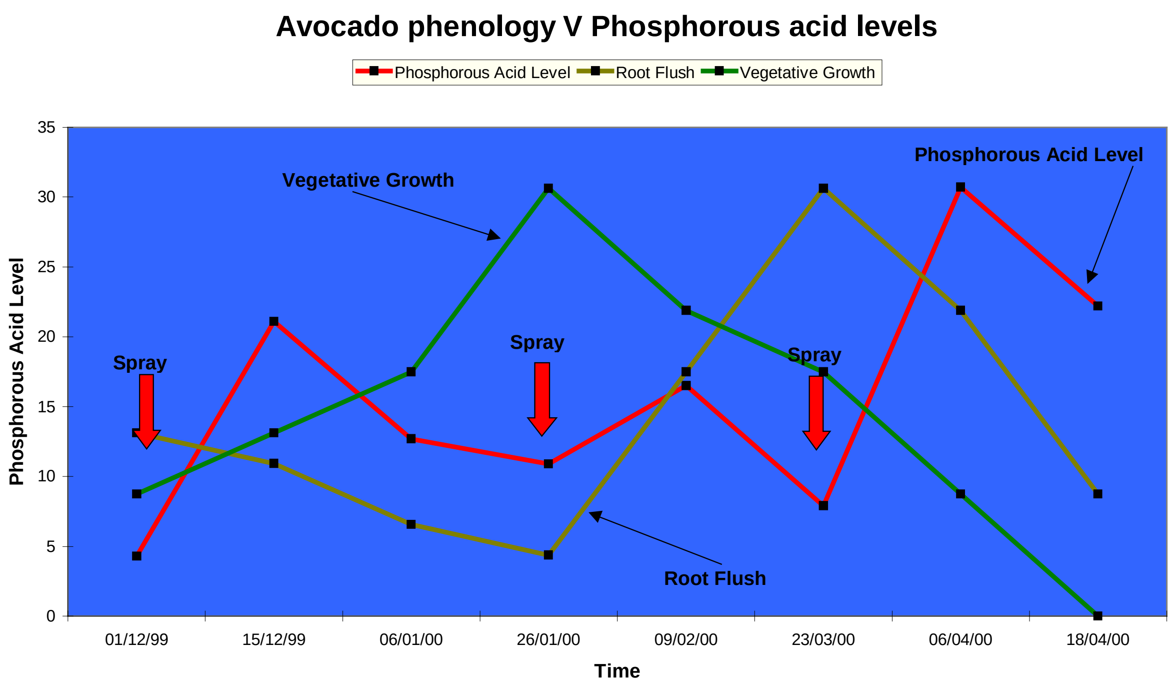

Fig. 11 Root phosphorous acid level responses when compared to the phenology cycles of root and vegetative flushes.

Rootstock

Unless carefully monitored, the potential differences in the response of different rootstocks are difficult to detect. The number of growers with known rootstocks is limited and the number of samples that are submitted with all factors similar, other than the rootstock is extremely limited. However, from a very small base, there have been some differences noted.

The information presented in Fig. 12 are data collated from one orchard and is presented to give an indication of what may be happening to trees on different rootstocks. In this case Hass growing on Guatemalan rootstocks had considerably greater increase in root phosphorous acid concentrations than similar trees on Mexican rootstocks following 3 foliar sprays at 12.5 ml/L of 400g / L Potassium Phosphonate. Each block consisted of 1500 trees, were at the same growth stage and a random sample of approximately 20 trees was taken. All factors other than the rootstock were similar. Whilst this response is not conclusive, it may indicate the need to apply greater quantities of phosphonate fungicide to trees grafted to Mexican rootstocks compared with those on Guatemalan rootstocks.

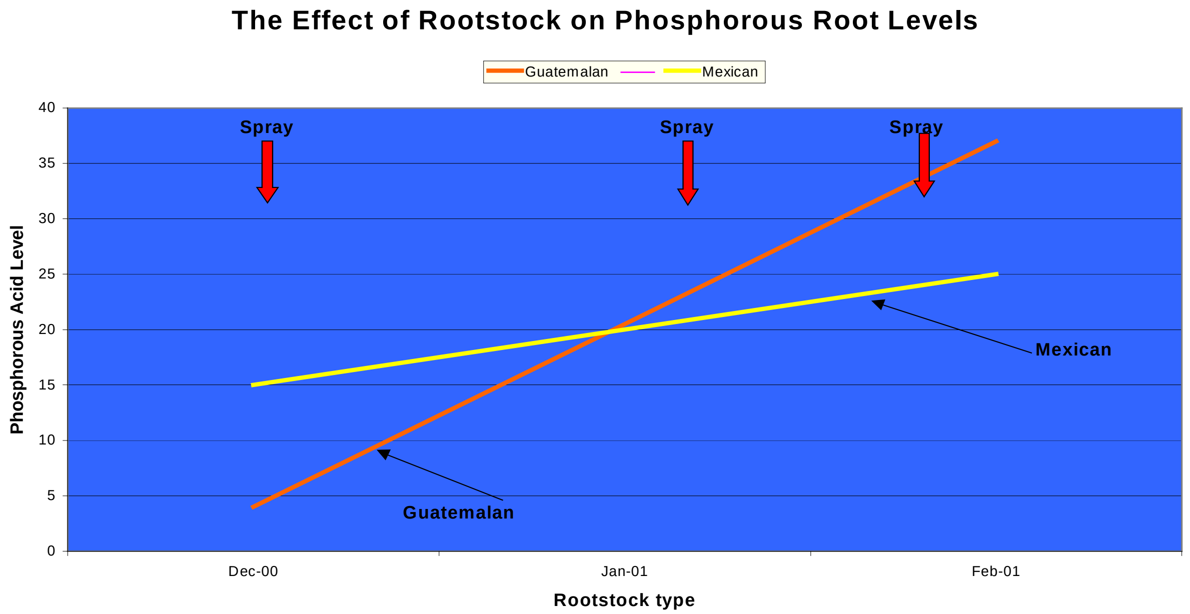

Fig. 12 The effect of different rootstocks on the uptake of phosphorous acid in the roots of Hass avocados. Phosphonate was foliar-applied to the trees on the 11th December 2000, 8th January 2001 and the 22nd January 2001.

Location

Results to date indicated large differences in the response from applications of phosphonate fungicide between the Atherton Tablelands in North Queensland and the Pemberton / Busselton region in southwest Western Australia. The magnitude of these differences is best seen in the detail of two the samples compared in Table 3.

The trend has been noted from a number of samples.

Table 3 Effect of location on the phosphorous acid concentration in roots of 'Hass' avocados following foliar applications of mono-dipotassium phosphonate.

Comparative Conditions	Location	
	North Queensland	S.W. West Aust
Rootstock	Guatemalan	Guatemalan
Crop load	Low	Low
Tree health rating	Healthy	Healthy
Tree height (m)	2.0	2.0
Tree diameter (m)	4.0	2.0
Tree volume (m^3)	25.0	6.3

Volume phosphonate applied / application (ml)	63.0	25.0
Volume phosphonate applied / m^3. (ml)	2.5	3.9
Number of applications	4.0	1.0
Date(s) applied	13/10, 4/11, 23/11, 11/12	20/12
Days from last application to sampling	43.0	41.0
Root phosphorous acid concentration (mg/kg)	**31.0**	**65.0**

The data in Table 3 shows that the root phosphonate concentration in trees growing on the Atherton Tableland was only half that from similar trees growing in south west Western Australia. It should be noted that tree size (volume) was four times greater for trees growing on the Atherton Tablelands, which resulted in a 36% reduction in the dose rate of phosphonate per cubic meter of canopy. This would have some affect on final root concentration as well as the changing phenology over the eight-week period of treatment. It would also be expected that four applications in North Queensland versus one in Western Australia would have a cumulative effect to some degree. Nevertheless, the data does highlight the potential difference in results between the two regions adding strength to the need to monitor phosphorous acid levels in the roots of trees following treatment with phosphonate fungicides.

Summary

It is very early to be certain that the individual results disclosed will be repeated in the future. Many results such as the method and time of application, volume of sprays applied and the effects of crop load, have endorsed the research that has occurred in our industry over the years. The early work carried out by Dr. Tony Whiley and Ken Pegg and their teams with respect to the importance of timing phosphonate applications for maximum affect has been vindicated by the commercial results obtained.

The data to date strongly indicates that to manage the application of phosphonates effectively, the monitoring of phosphorous acid in the roots is essential. With the change from trunk injection to foliar spray applications, the industry has introduced another range of variables that will produce some disappointing results in the control of Phytophthora root rot in this industry. If the root levels are not monitored, in time to come there will be many making overtones that phosphonate fungicides are no longer effective. It will be more likely that the wide range of variables have not been considered when root rot management programs are put in place. This is a rare opportunity that has been made available to our industry; a scientific tool that we can measure how effective a fungicide application has been in achieving protection against a crippling disease. Used together with all the other strategies to control Phytophthora root rot, we can maximise the benefits of using phosphonate fungicides and maintain healthy, productive orchards.

Acknowledgements
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