Evaluating foliar phosphonate sprays as an alternative to trunk injections for controlling avocado root rot preventatively

Preliminary report

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ABSTRACT
In South Africa, phosphonates are used in a preventative strategy for controlling *Phytophthora cinnamomi* root rot on avocado. Phosphonates, in plants, are metabolised to phosphite that is active against *P. cinnamomi.* The main aim of the study was to evaluate whether ammonium- and potassium foliar phosphonate sprays have potential for replacing the currently used trunk injections for the preventative control of root rot. The efficacy of phosphonate treatments were evaluated based on the quantification of phosphite in the roots of treated trees, which were quantified at several time points after treatment applications. The potassium foliar sprays were evaluated at two different spray volumes to determine if spray volume affects efficacy. The required foliar spray volume was calculated based on the tree row volume concept, using the Unrath high spray volume formula at the full rate or three quarter rate. All applications were made during the summer application window with commercial sprayers, and for foliar sprays consisted of three weekly applied 0.6% sprays. Two trials were conducted. The ammonium phosphonate foliar spray applied at the full rate Unrath volume, yielded the highest root phosphite concentration of all of the treatments at 2, 6 and 12 weeks after application in both trials. The root phosphite concentrations were comparable for the trunk injection and the potassium phosphonate foliar spray treatments applied at the full rate and at the three quarter rate spray volumes. Root phosphite concentrations were substantially higher in the one trial site, for unknown reasons. Except for the ammonium phosphonate foliar spray treatment in the one trial, root phosphite concentrations of all the phosphonate treatments approached that of the control 28 weeks after application.

INTRODUCTION

In South Africa, Phytophthora root rot in avocado is controlled using a preventative strategy that consists of two annually applied phosphonate trunk injections. The two trunk injections are applied as one injection during the summer application window (usually February/March) and another injection in the spring application window (usually October/November). Trunk injections are labour intensive, and are therefore becoming increasingly costly due to increasing labour costs. Therefore, alternative application methods must be investigated.

Phosphonates and their breakdown product in plants (phosphite, also referred to as phosphonic acid) are highly mobile in plants, which allow for various application methods (Cohen & Coffey, 1986; Guest & Grant, 1991; Whiley *et al.*, 1995). In Australia, 0.5% foliar sprays are used in a preventative control strategy on mature avocado trees (personal communication, W.A. Whiley, Sunshine Horticultural Services Pty Ltd). Although the label instructions of all registered potassium phosphonate products in Australia indicate that sprays must be applied at 0.1% sprays, Emergency Use Permits have been acquired for application of sprays at 0.5%, which allows for the legal application of 0.5% sprays in Australia (personal communication, Elizabeth Dann, University of Queensland, Brisbane, Australia). A key technique that has been used in Australian studies for evaluating the efficacy of foliar phosphonate sprays, is the measurement of root phosphite concentrations (Whiley *et al.*, 2001; Giblin *et al.*, 2005).

In South Africa, the only phosphonate that is registered as a foliar spray on avocado is Aliette (fosetyl-AL). The label recommends that, for a preventative strategy, applications should start after the spring flush is fully developed (usually September) and to repeat sprays every six weeks, through the summer with the final spray being applied in April, resulting in a total of five to six sprays. However, due to the number of sprays required and product cost, Aliette is not used by growers as a foliar spray on avocado in South Africa.

Only two research studies have been published in non-peer reviewed journals in South Africa on the potential of foliar phosphonates sprays for use in a preventative control strategy. Duvenhage (2001) found, based on root phosphite concentrations, that two 0.75% phosphonate leaf sprays (one after summer flush completion and the other after spring flush completion) applied at 943 L/ha provided root phosphite levels (22.6 ppm), 28 days after the second application, which was equivalent to trunk injections. Consequently, Duvenhage (2001) recommended that registration trials should be done using the 0.75% foliar potassium phosphonate applications. However, no further work was conducted. In 2013/14 we evaluated the efficacy (based on root phosphite concentrations) of three to four foliar sprays applied in the summer application window at different concentrations (0.5%, 0.75% and 1% a.i.), relative to one trunk injection, in two trials. Applications were made using a knapsack sprayer. All concentrations of the foliar sprays resulted in very low root phosphite concentrations (< $3ppm_{dw}$) below that of the trunk injection, in both trials (McLeod *et al*., 2015). The poor performance of the foliar sprays is most likely due to the spray volumes that were used being too low. Spray volume is known to be important in foliar spray applications, but the adjustment of spray volumes according to the different tree sizes in South African orchards will be subjective and difficult. In Australia, the emergency use label for potassium phosphonates states "Apply spray volume of 2,000-3,000 L/ha for mature trees (depending on tree size)", which may result in variable results if growers select the incorrect volume for a specific tree size.

In the deciduous tree fruit industry, the Unrath tree-row-volume (TRV) model is used to calculate a high spray volume requirement, which assists growers in determining the spray volume required for different sized trees in orchards. The model is based on the assumption that each row of orchard trees consists of a wall of foliage and that the amount of pesticide that is required is related to the volume of the foliage within the wall. The pesticide rate per hectare is then calculated from the labelled rate of the chemical/100 L and the volume of foliage per hectare (Unrath *et al.*, 1986). The Unrath formula for determining a high volume spray is: (Tree height x Tree diameter x 937)/ Row width. The constant in the formula (937) can vary according to tree crop type. The tree-row-volume model of Unrath thus takes into account that canopy volume may vary from year to year and between orchards, and provides a good guideline for deciduous fruit growers for determining the spray volume required for different sized trees. The TRV model could be very useful in developing recommendations for foliar applications of phosphonates in the avocado industry where spray volume is important.

The aim of the current study, funded by SAAGA and ZZ2, was to evaluate the efficacy of foliar phosphonate sprays, based on root phosphite concentrations, for use in a preventative control strategy. With the foliar sprays, the efficacy of an ammonium phosphonate versus a potassium phosphonate was also investigated. The influence of spray volume was investigated by comparing results from foliar applications at the full rate Unrath spray volume versus a three quarter rate.

MATERIALS AND METHODS

Avocado orchard trials were conducted at two sites. Both orchards sites contain 'Hass' on Dusa trees, with 6 m canopy dia. and a 3 m height. The tree row width is 10 m. Commercial sprayers were calibrated to deliver a high spray volume, using the formula: (Tree height x Tree canopy diameter x 937)/Row width. This resulted in insufficient coverage of foliage and branches. Therefore, the full rate Unrath spray volume used in the trials was calculated, using a constant of 1200 [(tree height x tree canopy diameter x 1200)/ row width], which provided adequate coverage of the foliage and branches, without run-off occuring.

The trial design in both orchards consisted of each treatment being replicated three times, in a completely randomised block design. Each replicate consisted of three full length orchard rows, of which the middle row was used for root phosphite quantification.

Root phosphite concentrations were determined by taking two root samples within a replicate, which were located distantly from each other within the row. This resulted in a total of six root samples per treatment being sampled for root phosphite quantification. Root samples were taken 2, 6, 12 and 28 weeks after the last foliar applications were made. The root phosphite concentrations in samples were determined using a LC/MS-MS method (Ma, 2016).

The treatments, which were all applied in summer (May 2015), in both trials were:

1) Untreated control
2) 3 foliar potassium phosphonate sprays (0.6%) applied at one week intervals at the full rate Unrath spray volume (2160 L/ha)
3) 3 foliar potassium phosphonate sprays (0.6%) applied at one week intervals at the ¾ rate Unrath spray volume (1628 L/ha)
4) One potassium phosphonate trunk injection at 0.5 g a.i./m^2 (registered rate for curative treatment)
5) 3 foliar ammonium phosphonate sprays (0.6%) applied at one week intervals at the 3/4 rate Unrath spray volume (2160 L/ha).

All foliar spray solutions were adjusted to pH 7.2 using potassium hydroxide to prevent foliar burn.

RESULTS

In both trials the ammonium phosphonate foliar application applied at the full rate Unrath spray volume resulted in the highest root phosphite concentrations,

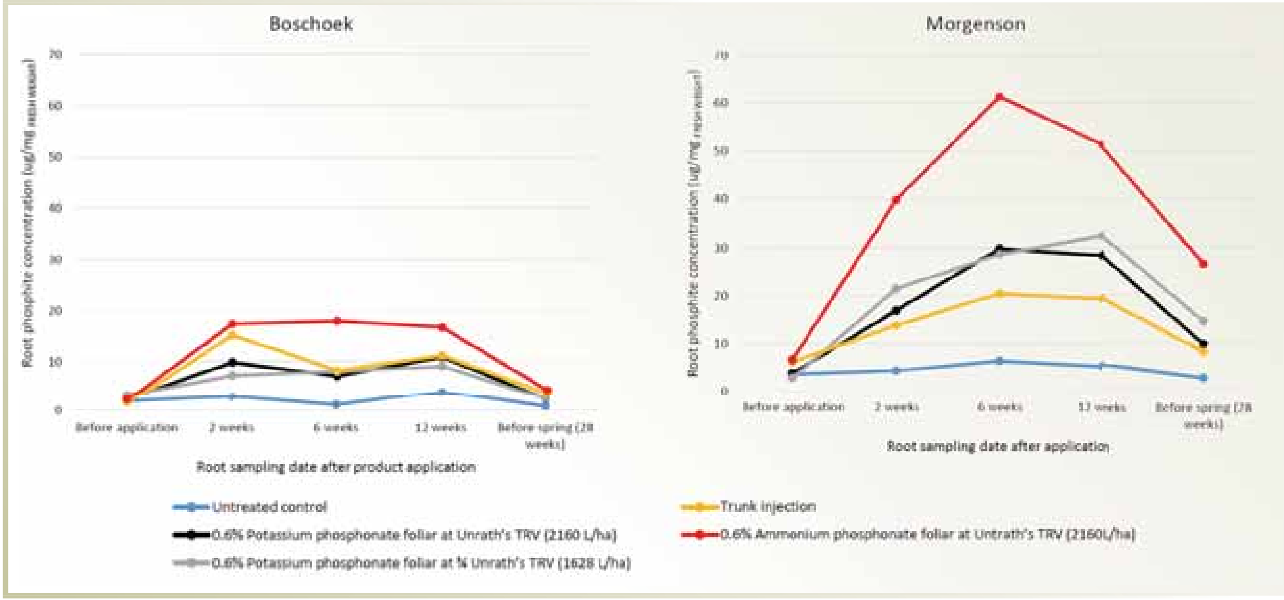

Figure 1. Root phosphite concentrations in two avocado orchard trials (Boschoek and Morgenson) treated with different phosphonate treatments. The treatments consisted of one trunk injection (0.5 g a.i.) or three foliar applications at 0.6% a.i. (potassium or ammonium phosphonate). Foliar applications were applied at a full rate Unrath's spray volume [tree height x tree dia x 1200)/row width] or ¾ Unrath volume [(tree height x tree dia. x 800) / row width]. All foliar sprays were applied with a commercial sprayer, three sprays at weekly intervals. Root phosphite concentrations were measured 2, 6, 12 and 28 weeks after the last foliar applications.

which were higher than the standard trunk injection at 6 and 12 weeks after application (Fig. 1). The potassium phosphonate foliar application applied at the full rate Unrath spray volume did not differ much in root phosphite concentration from the ¾ rate Unrath spray volume. The latter two treatments were comparable in root phosphite concentration to the standard trunk injection treatment at 6, 12 and 28 weeks after application (Fig. 1).

The Morgenson trial in general had higher root phosphite concentrations than the Boschoek trial, especially for the foliar applications (Fig. 1). For the trunk injection the Boschoek, root phosphite reached a maximum value of 15 µg/mg$_{FW}$ at 2 weeks after application, which declined to 11 µg/mg$_{FW}$ at 12 weeks. At Morgenson for the trunk injection, the maximum root phosphite concentrations were 20 to 19 µg/mg$_{FW}$ at 6 and 12 weeks after application, respectively. The foliar potassium phoshphonate sprays at Boschoek had a more or less constant root phosphite concentration of approximately 10 µg/mg$_{FW}$ from 2 to 12 weeks after application, whereas at Morgenson these treatments had approximately 30 µg/mg$_{FW}$ at 6 and 12 weeks after application. The better performance of foliar sprays at Morgenson was even more prevalent for the ammonium phosphonate treatment that peaked at 61 µg/mg$_{FW}$, whereas at Boschoek the highest concentration was 18 µg/mg$_{FW}$.

DISCUSSION

The evaluation of ammonium versus potassium phosphonate foliar sprays showed that at both trial sites, the ammonium phosphonate sprays were more effective since the highest root phosphite concentrations were reached with this treatment. Potassium phosphonates are most commonly used for the control of *Phytophthora* in all crops, and to the best of our knowledge there is no published literature on the efficacy of ammonium- versus potassium phosphonates. The reason for the better performance of the ammonium phosphonate is thus unknown. Further studies are required to determine if all potassium phosphonate products are less effective than ammonium phosphonates, since in the current study only one product of each was used. Results may vary with different commercial potassium phosphonate products.

Spray volume is known to influence root phosphite concentrations when foliar phosphonate sprays are applied. In both trials, the full rate Unrath spray volume and the ¾ Unrath spray volume yielded comparable root phosphite concentrations. Since the ¾ Unrath spray volume will be more cost effective, this spray volume can thus be used in future trials. The ¾ Unrath spray volume for trials can be calculated using the formula: (Tree height x tree canopy diameter x 900) /row width.

The Morgenson trial yielded higher root phosphite concentrations for all treatments than the Boschoek trial. This effect was somewhat more prevalent for the foliar sprays than the trunk injections. The efficacy of foliar sprays are known to be site specific. This is due to the fact that several factors can affect root phosphite concentration, including crop load (higher yielding orchards have lower root phosphite concentrations), time of root flush when applications are made (root phoshite is higher when applications are made at the start of root flush than at the end), climate (sprays are more effective in mediterannean climates than subtropical climates) and tree health (Whiley *et al*., 1995, 2001; Thomas, 2001, 2008; Shearer *et al*., 2009; personal communication, A.W. Whiley). None of the aforementioned factors were obviously different between the two trial sites, and therefore the reason for the difference in root phosphite concentrations between the two trials is unknown.

Three foliar phosphonate sprays, either ammonium or potassium phosphonate, can be an alternative to one trunk injection for the preventative management of root rot, when applied in the summer application window. This was evident from the fact that all foliar treatments (ammonium- and potassium phosphonate) yielded root phosphite concentrations that were similar or higher than the trunk injection treatment. The root phospite concentrations in both trials declined at 28 weeks after application for all treatments. These concentrations, except for the ammonium phosphate treatment at Morgenson, declined to levels approaching that of the control. This would suggest that reapplication of sprays will be required in the spring application window in order to sustain root phosphite concentrations until the next summer application. In the current trials, one additional foliar spray was thus applied for all the foliar treatments, and a trunk injection for the trunk injection treatment in the spring application window. The data must still be analysed to assess if only one additional spray will be sufficient in spring.

It is difficult to compare the exact cost of foliar versus trunk injections, since this will vary with the product used, labour efficacy, labour- and spray cost and tree size. Considering average costs, the cost of three ammonium phosphonate foliar sprays applied at 0.5% and at the ¾ Unrath spray volume, will be comparable to that of two trunk injections for trees with a 3 to 6 meter canopy diameter. Since slight burn occurred with all the 0.6% foliar sprays, future sprays should rather be applied at 0.5%. The foliar sprays have the advantage of mechanisation, which is important considering the continued rising cost of labour. With increasing labour costs, the cost of four foliar sprays may in future be equal to that of two trunk injections. Therefore, foliar sprays may be a cost effective alternative to trunk injections. The application of foliar sprays in avocado using ammonium- and potassium phosphonates is not legal in South Africa yet, since this application method is not registered. Therefore, foliar spray registration trials will be investigated in future. The measurement of fruit residues will be important, to ensure that MRLs are not exceeded with foliar applications.

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