Using phosphonate foliar sprays for managing Phytophthora root rot in avocado

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ABSTRACT

Phosphonate foliar sprays are used for managing Phytophthora root rot (PRR) on avocado caused by *Phytophthora cinnamomi* (Pc). In South Africa, the only phosphonate products registered for PRR control include potassium phosphonate trunk injections and alkyl phosphonate foliar sprays (Aliette®). The latter is not economically feasible due to the high production cost. Although trunk injections are effective against PRR, application cost has steadily increased due to increasing labour costs, especially for high density orchards. Trunk injections, furthermore, when applied according to registration labels, can result in exceedances of the maximum residue level (MRL) of fosetyl-Al in fruit set by the European Union (EU). Potassium- and ammonium phosphonate foliar sprays were therefore evaluated in two seasons in South Africa as an alternative to trunk injections. Root phosphite concentrations (breakdown product of phosphonates in plants) achieved in orchard trials with foliar sprays were comparable to those obtained with trunk injections. However, towards the end of the season, foliar sprays can sometimes yield root phosphite concentrations that are lower than those from trunk injections. This observation was further investigated in the 2017/18 trials by quantifying Pc in tree roots, which showed that foliar sprays were comparable in efficacy to trunk injections towards the end of the season. Application of foliar sprays (ammonium and potassium) only in autumn consistently resulted in fruit residues that were below the EU MRL in research trials, whereas registered trunk injection applications did not. Foliar sprays should only be applied after harvest, and not during the fruiting period, in order to avoid exceeding the EU MRL. Two phosphonate products that have been evaluated for registration as foliar sprays include Fighter 350® (potassium phosphonate) and Brilliant® (ammonium phosphonate). Orchard trials in the 2017/18 trials showed that for both formulations four and five 0.5% a.i. (phosphorous acid) sprays were comparable. Foliar spray volumes required per hectare should be calculated using the Unrath tree row formula. The pH of sprays must be adjusted to 7.2 using potassium hydroxide in order to avoid phytotoxicity.

INTRODUCTION

Phosphonate fungicides are very effective against Phytophthora root rot (PRR), caused by *Phytophthora cinnamomi* (Pc) in avocado. Different phosphonate formulations are available, including ammonium-, potassium-, alkyl- and calcium phosphonates. Of these formulations, an alkyl phosphonate (Aliette®) was the first registered product on the market for managing PRR on avocado (Darvas *et al.*, 1984; Pegg *et al.*, 1987). Subsequently, due to cost implications, potassium phosphonate has become the most widely used phosphonate formulation for managing PRR in South Africa, which is used as trunk injections (McLeod *et al.*, 2018). In addition to potassium phosphonate products (Avoguard®, Fighter® and Rootmaster 98®) being registered as trunk injections in South Africa on bearing avocado trees, Aliette® is also registered as a foliar spray. Potassium- and ammonium phosphonates are not registered as foliar sprays in South Africa on avocado.

In Australia, potassium phosphonate foliar sprays, rather than trunk injections, are most widely used for the preventative management of PRR. The curative use of foliar sprays is not advised for orchards that are in an advanced stage of PRR decline since sparse canopies cannot take up foliar sprays effectively. Foliar sprays were initially registered as 0.1% a.i. (phosphorous acid) sprays in Australia, but these were ineffective when used commercially (Whiley *et al.*, 2001). Therefore, an emergency use permit was obtained for 0.5% a.i. sprays. Subsequently, Agriphos 600® has been registered on mature bearing trees in Australia as 0.5% a.i. sprays applied at 2000 to 3000 L/ha. Not more than five applications may be made annually (https://portal.apvma.gov.au).

In avocado, the time of year during which phosphonates are applied is based on periods when roots act as a sink since phosphonates are translocated in a source-sink manner. Applications are made twice annually, following the hardening off of the summer foliar flush (fall application) and spring foliar flush (summer application), since in avocado a root flush follows a foliar flush (Whiley *et al.,* 1995). The presence of small fruits during summer applications is most likely the cause of high fruit residues that can result in an exceedance of the European Union (EU) MRL for fosetyl-Al (50 mg/kg) (McLeod *et al.*, 2018).

Stellenbosch University and ZZ2 have been conducting orchard trials for assessing the effect of foliar sprays on root phosphite concentrations and fruit residues over two seasons (2016/17 and 2017/18). Trials were also conducted in the 2018/19 season, but the data is still pending. The overall aim of the trials were to obtain data for registering foliar sprays on bearing avocado trees for the preventative management of PRR in South Africa.

MATERIALS AND METHODS

Orchard trials

Ammonium- and potassium foliar sprays were evaluated for two seasons (2016/17 and 2017/18) in two production regions (Mooketsi and Letaba). One trial was conducted in each region for each season, totaling four trials. In each season, various foliar spray treatments were evaluated as previously described (Masikane *et al.*, 2018; McLeod *et al.*, 2018). All foliar sprays were applied as 0.5% a.i. (phosphorous acid) sprays, of which the pH was adjusted to 7.2 using potassium hydroxide. For Fighter 350® a 0.5% a.i. spray consisted of 1.4 L product/100 L and for Brilliant® it was 1.7 L product/100 L. The number of foliar sprays that were evaluated consisted of four or five weekly sprays in fall after harvest and summer (2016/17 trials) or only after harvest (2017/18 season); not more than five sprays per season. Spray volumes required per hectare were determined using the tree-row-volume (TRV) Unrath formula (Unrath, 1986):

$$\text{Spray volume} = \frac{\text{tree height} \times \text{tree canopy diameter} \times 900}{\text{row width}}$$

Depending on the season, sprays were applied in fall and summer (2016/17 season), or only in fall after harvest (2017/18 season).

Root phosphite concentrations

Root samples were taken at each of the four orchard trials at several time points post application. Root phosphite was extracted and quantified as previously described (McLeod *et al.*, 2018).

Quantification of Pc from roots

Pc was quantified from roots at 4- and 46-weeks post fall applications, only for the two trials conducted in the 2017/18 season. Quantifications were conducted using a leaf baiting technique as previously described (Masikane *et al.*, 2018).

Fruit residues

Fosetyl-Al residues in fruit from the four orchard trials were analyzed by an accredited laboratory (Hearshaw and Kinnes analytical laboratory (Pty) Ltd, Tokai, South Africa).

RESULTS

Root phosphite concentrations

In all four trials conducted in both seasons (2016/17 and 2017/18), the general trend was that root phosphite concentrations declined following the application of foliar sprays and trunk injections (data not shown). Treatments that were applied in summer, but not for those applied only in fall, resulted in a slight increase in root phosphite following the summer applications. A representative graph of the temporal nature of phosphite concentrations in tree roots for the four trials is shown in Figure 1.

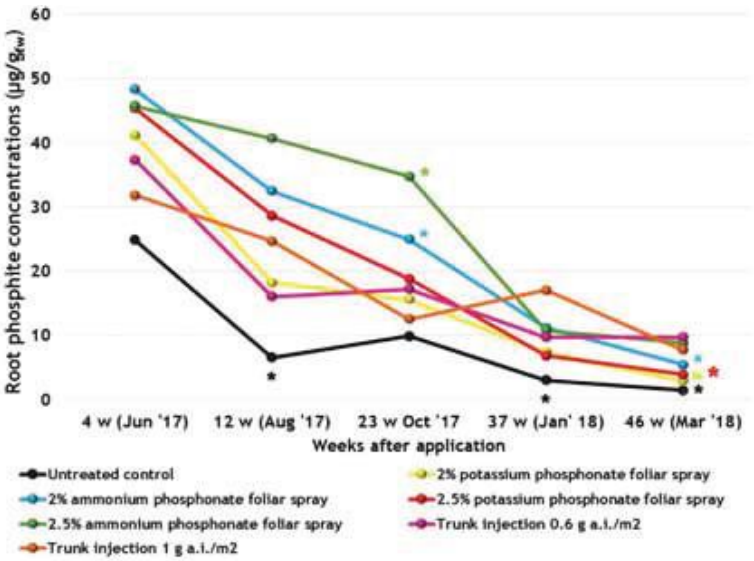


Figure 1. Root phosphite concentrations in avocado orchard trees, which received different phosphonate treatments. The 2% ammonium- (Brilliant®) and 2% potassium- (Fighter 350®) phosphonate foliar spray treatments each consisted of four 0.5% a.i. sprays, whereas the 2.5% treatments consisted of five 0.5% a.i. sprays applied only in fall. The 1 g a.i./m^2 and 0.6 g a.i./m^2 trunk injection treatments consisted of trunk injections made at the curative- (0.5 g a.i./m^2) or preventative (0.3 g a.i./m^2) dosages respectively in fall and summer. Line points followed by " * " differed significantly (P > 0.05) from the curative trunk injection treatment.

Quantification of Pc from roots

Quantification of Pc from roots in the 2017/18 trials showed that all phosphonate treatments (trunk injection and foliar sprays) had a lower percentage of leaf disks colonized by Pc than the untreated control at 4-weeks post application. At 46-weeks post application, the untreated control had the highest percentage of Pc infected leaf disks, followed by the five Brilliant® foliar spray treatment. The percentage of leaf disks colonized by the remaining phosphonate treatments were lower than the untreated control and comparable for the different treatments at 46-weeks post application (Fig. 2). There were, in general, no significant differences in root phosphite concentrations obtained with four versus five foliar sprays (data not shown).

Fruit residues

In both seasons, fruit residues resulting from trunk injections sometimes exceeded the MRL (Fig. 3). Both formulations of the foliar sprays (four or five 0.5% a.i. sprays) did not result in exceedances of the MRL in the four trials (Fig. 4). However, application of Brilliant® in the 2016/17 trials as a split application in fall (three sprays) and summer (1 spray) resulted in a near exceedance of the MRL for one of the 12 replicates in the trials. In the 2017/18 season when all sprays were applied only after harvest in fall, no near exceedances of the MRL occurred. Brilliant®, in general, resulted in higher fruit residues than Fighter 350® foliar sprays.

DISCUSSION

The current study, similar to a previous study (McLeod *et al.*, 2018), found that trunk injections applied according to registration labels in South Africa can result in exceedances of the EU MRL for fosetyl-Al in avocado fruit. In contrast, ammonium- (Brilliant®) and potassium- (Fighter 350®) phosphonate foliar sprays did not result in exceedances of the EU MRL. A split application of foliar sprays (3 sprays in fall + 1 spray in summer), as used in the 2016/17 season, tended to yield higher fruit residues than only fall applications. This is likely due to the fact that small fruits are present on trees during summer, which serve as a strong sink for phosphite in addition to roots being a sink in summer. Therefore, foliar sprays should only be applied in fall after harvest to reduce the risk of exceeding the EU MRL. The ammonium phosphonate formulation (Brilliant®) in general resulted in higher fruit residues than the potassium phosphonate formulation (Fighter 350®). This is in agreement with a previous study (McLeod *et al.*, 2018) where

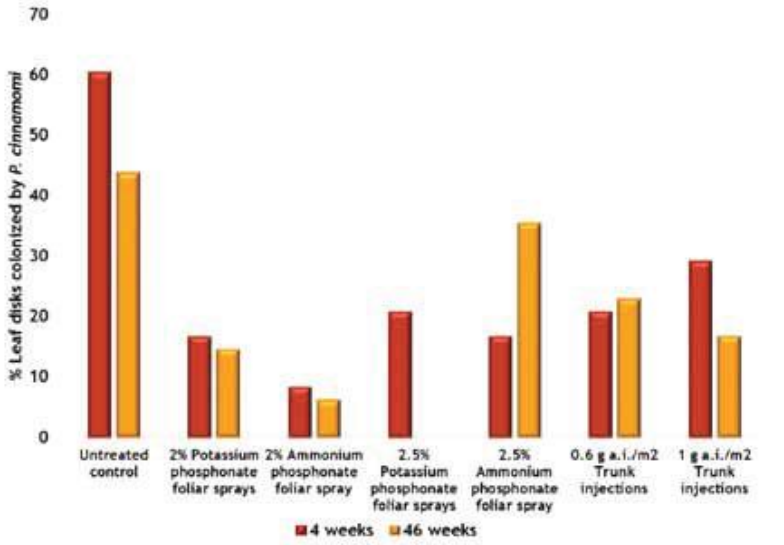


Figure 2. *Phytophthora cinnamomi* (Pc) quantities in avocado tree roots 4- (June 2017) and 46-weeks (March 2018) after application of different phosphonate treatments in fall (foliar sprays) or fall and summer (trunk injection). Pc quantities were determined using a root baiting technique, where Pc is quantified based on the percentage of lemon leaf disks infected by Pc. Results are the average of two trials that were conducted in the 2017/18 season. Treatments were as described in Figure 1.

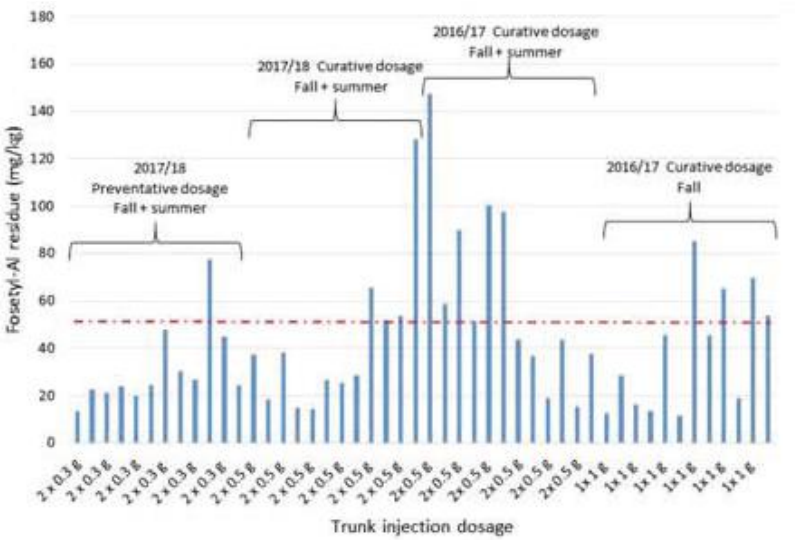
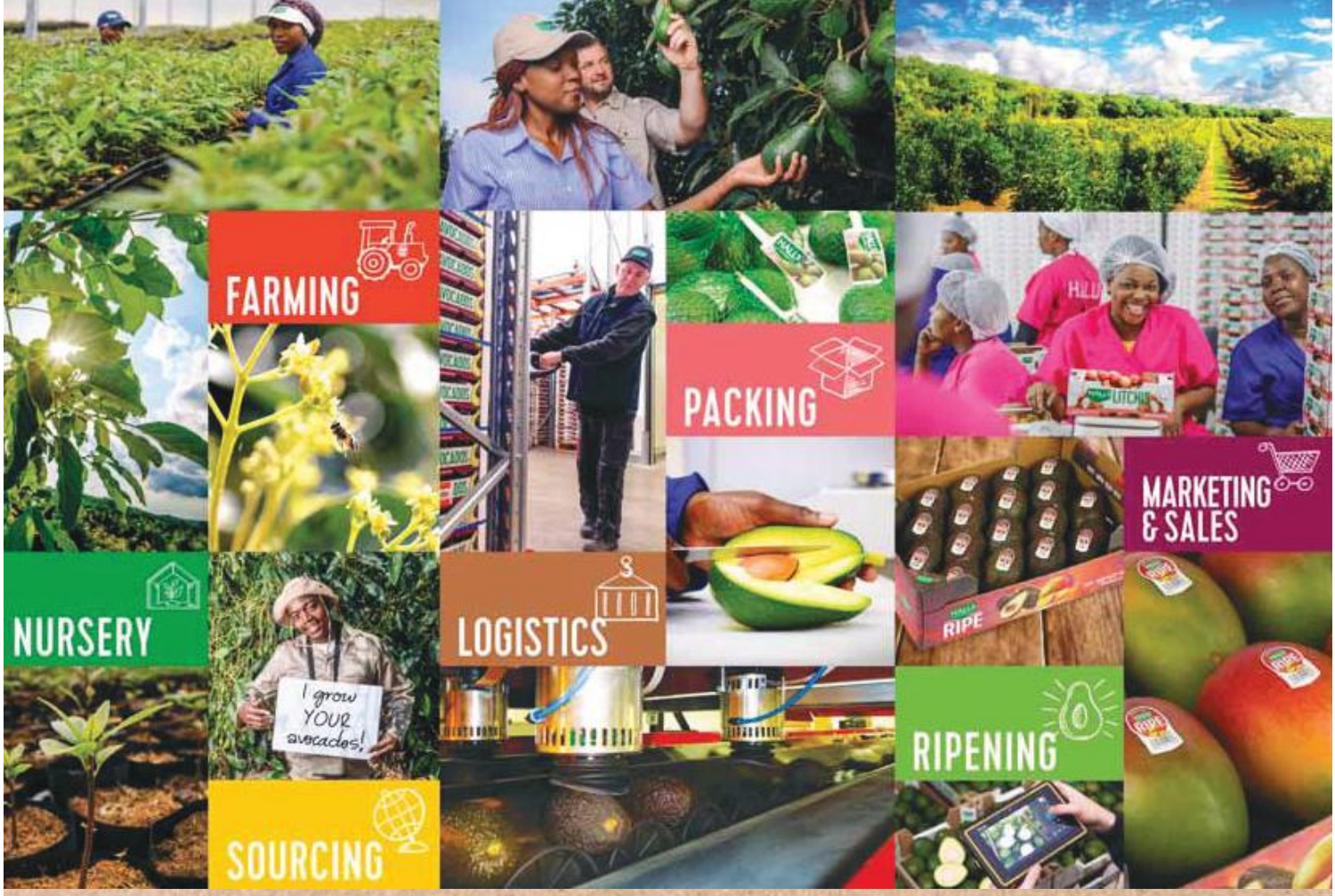


Figure 3. Fosetyl-Al residues (mg/kg) in avocado fruit harvested from orchard trials receiving trunk injections that were applied at the curative dosage (0.5 g a.i./m^2) or the preventative dosage (0.3 g a.i./m^2) in fall and summer in the 2016/17 and 2017/18 production seasons. In die 2016/17 season, trunk injections were also applied only in fall after harvest at 1 g a.i./m^2. Fruit residues enclosed by one bracket are from six replicates from each of two trials (Mooketsi and Tzaneen) of the same treatment. The red line indicates the European Union 50 mg/kg MRL.



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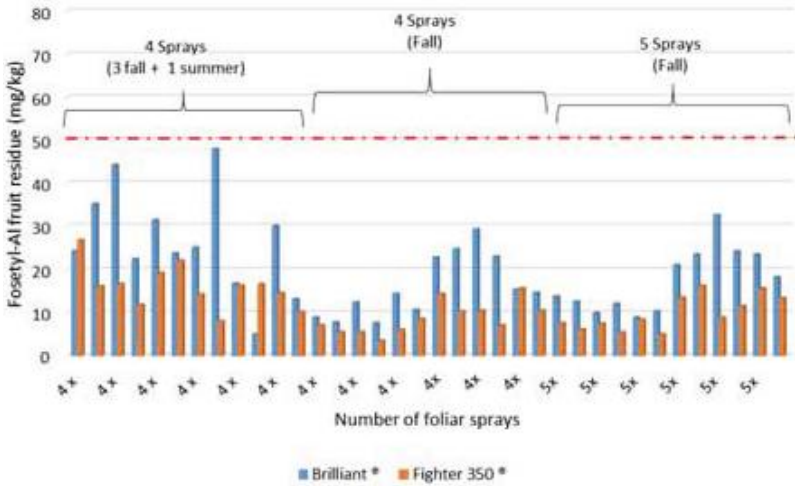

Figure 4. Fosetyl-Al residues (mg/kg) in avocado fruit harvested from orchard trials where Brilliant® (ammonium phosphonate) or Fighter 350® (potassium phosphonate) foliar sprays were applied. Fruit residues enclosed by one bracket are from six replicates of the same treatment from each of two trials (Tzaneen and Mooketsi). The red line indicates the European Union 50 mg/kg MRL.

phosphite concentrations in roots and fruit were higher for ammonium- than for potassium phosphonate sprays.

Phosphonate foliar sprays (both formulations) were shown to be as effective as trunk injections in two seasons. This was evident from measuring root phosphite concentrations and Pc root quantities. Root phosphite is considered as a reliable method for assessing phosphonate treatment performance (Thomas, 2001, 2008). Although root phosphite concentrations from foliar sprays declined toward the end of the season and were sometimes lower than that of trunk injections, Pc root quantifications showed that this did not result in a reduction in pathogen suppression by foliar sprays. It is likely that since phosphonates are increasingly being reported to function as resistance inducers (Jackson *et al.,* 2000; Massoud *et al.*, 2012), that root phosphite concentrations at the start of the season were sufficient for inducing long lasting resistance in tree roots. The root baiting method was useful for quantifying Pc and showed that quantifications conducted in June at 4-weeks post application in the untreated control trees yielded higher Pc quantities than quantifications made in March at 46-weeks post application. This is because Pc root quantities have been found to be peak in May, with quantities being the lowest in March (Jolliffe, 2019). Since Pc root infections seem to only peak after harvest, management practices should be optimal during this period in order to suppress PRR.

Future research will focus on further improving Pc quantification methods from avocado roots. Improved Pc quantification methods can assist with the evaluation of phosphonate treatment effects, which is important in addition to assessing root phosphite concentrations. The effect of time of phosphonate application after harvest on fruit residues and root phosphite concentrations will also be investigated. In the current study, foliar sprays were applied directly after harvest, however, this may not always be practical for growers. Therefore the effect of applications starting 2, 4 and 6 weeks after harvest will also be investigated.

ACKNOWLEDGEMENT

We would like to thank the South African Avocado Growers' Association and Bertie van Zyl (Edms) Bpk. for financial support of the project.

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